FACTORS REGULATING ZOOPLANKTON BIOMASS, ABUNDANCE, AND COMMUNITY STRUCTURE IN A SOUTHCENTRAL TEXAS RESERVOIR

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ABSTRACT

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This study focused on zooplankton dynamics in a shallow hard water reservoir during summer months and the influence of reservoir water residence time and off-channel areas on zooplankton dynamics. Thirteen crustacean and eight rotifer taxa were observed. Net zooplankton abundance and biomass, cladoceran abundance and biomass, copepod abundance and biomass, and rotifer abundance and biomass were all significantly related to water residence time and sampling station location (off-channel versus pelagic). I hypothesized that net zooplankton biomass and abundance would be greater in slower flow velocity off-channel areas compared to upstream pelagic sites and that rotifer biomass and abundance would dominate that of crustaceous zooplankton in upstream lotic-like areas. My results showed that net zooplankton abundance and biomass were greater in the off-channel areas and that rotifer abundance was much greater than copepod and cladoceran abundance at the upstream sites. However, rotifer biomass was much lower than that of cladocerans and copepods at these same lotic-like areas. Most of the crustacean zooplankton observed at these upstream areas were large copepods. I suggest that zooplankton abundance and biomass were directly related to water residence time, but that rotifer biomass was also influenced by competition for food with much larger crustaceans. I also suggest that the off-channel areas were used as refuge areas especially when water residence time was below 1 day. During the summer of 2004, Lake Dunlap was highly influenced by heavy rains and high releases from the upstream Canyon Reservoir.

I. INTRODUCTION

Zooplankton are an integral part of freshwater aquatic ecosystems where they function as primary and secondary links in the food chain (Hutchinson 1967; Wetzel 1983). They play a crucial role as grazers, nutrient regenerators, and as a food source for other invertebrates and fish. Factors regulating zooplankton biomass include light, nutrient concentrations, food availability, predation, competition and hydrological regime (Soballe and Kimmel 1987; Vanni 1987a; Vanni 1987b; Basu and Pick 1996). The freshwater zooplankton are largely made up of three groups that vary in size, growth characteristics, modes of reproduction, and locomotion differences (Allan 1976). The smallest of the three groups, the rotifers, have much higher potential growth rates than the copepods or cladocerans, and can therefore act more as an r-selected group where the other two are more k-selected relative to the rotifers (Allan 1976).

Numerous studies on lentic (lake and reservoir) and lotic (river) freshwater systems have described factors regulating zooplankton dynamics. While rivers and natural lakes tend to differ considerably in their physical, chemical, hydrological, and biotic properties, reservoirs have been described as intermediate between rivers and natural lakes (Baxter 1977; Benson 1982; Kimmel and Groeger 1984; Carline 1986; Soballe and Kimmel 1987). The intermediate properties of reservoirs may influence the plankton dynamics within them (Kimmel and Groeger 1984; Thornton 1984). Flow velocity and water residence time may be two such properties.

According to Baxter (1977), reservoirs may exhibit a longitudinal zonation of zooplankton with the upstream region of a reservoir having a relatively low zooplankton population in contrast to the lower, slower moving region. Soballe and Kimmel (1987) concluded that water residence time (WRT) is a useful factor in predicting the ecological structure and function of different aquatic ecosystems, although zooplankton community structure was not included in their study. Basu and Pick (1996) concluded that zooplankton biomass is strongly related to water residence time in temperate rivers. In addition, several studies have shown that water velocity (fast-moving versus slow-moving) is an important factor in determining riverine zooplankton community dynamics (Rzoska 1978; Saunders and Lewis 1988; Saunders and Lewis 1989; Basu and Pick 1997; Reckendorfer *et al.* 1999) and floodplain zooplankton dynamics (Baranyi *et al.* 2002). Obertegger *et al*. (2007) also found WRT to be a significant factor in zooplankton structure in a montane lake with highly variable WRT. Renella and Quiróz (2006) similarly determined that macrozooplankton biomass was positively related to WRT in shallow lakes in Argentina. This may also be the case for other aquatic systems, particularly for reservoirs with a short water residence time.

In systems with a short water residence time and/or highly variable flow velocities (short water residence time = high water velocity), phytoplankton (zooplankton food source) biomass and abundance tend to be much lower than for systems with longer water residence time and more static flow conditions (Soballe and Kimmel 1987). This is important because food availability has been shown to have a strong influence (bottom-up control) on zooplankton biomass, abundance, and species composition in many aquatic systems (Pace 1984; Vanni 1987a; Conde-Porcuna, *et al.* 1994; Morales-Baquero *et al.* 1994; Burns and Dodds 1999; Schultz and Sterner 1999). In a comparison study between rivers, lakes, and reservoirs, Soballe and Kimmel (1987) found that algal abundance increased with increasing water residence time. Thus, in a short water residence system with greatly variable flow velocities from upstream to downstream reaches, phytoplankton abundance may be reduced and/or vary greatly along a horizontal gradient. A food gradient can, in turn, affect the zooplankton dynamics along that gradient (Neary *et al.* 1994). Another consideration in short water residence time systems is removal of zooplankton as a result of advective downstream loss. Previous studies show that rivers exhibit a considerably lower zooplankton biomass and abundance than lakes having similar nutrient and chlorophyll concentrations (Pace *et al.* 1992; Thorp *et al.* 1994) and suggest that the shorter water residence time of rivers is the reason. Basu and Pick (1996) similarly concluded that zooplankton biomass in rivers is positively related to water residence time. They also found zooplankton that required shorter regeneration times (e.g. rotifers) made up the majority of the zooplankton communities within these rivers. Thus, zooplankton with longer generation times (e.g., copepods and cladocerans) may be more vulnerable to advective loss in systems with a short water residence time (Basu and Pick 1996). In a study on Danube River floodplain, Baranyi *et al.* (2002) found that rotifer biomass dominated during lotic-like conditions (water age <7 days) and crustacean zooplankton biomass dominated during lentic-like conditions. They defined water age was defined as "how long the water has been contained in the respective water body system, up to any position within the system and at any point in time". In their study, both rotifer and crustacean zooplankton biomass were positively correlated with water age, though rotifer biomass was surpassed by crustacean biomass at water age of 14 days, presumably because rotifers were suppressed by crustaceans. While zooplankton biomass in lakes is influenced mainly by productivity (e.g. Chl a or TP), (Pace 1981; McCauley and Kalff 1984; McQueen *et al*. 1986), water residence time may have a strongly limiting influence on zooplankton in short water residence reservoirs, though this has not been examined.

Off-channel areas may act to prevent advective loss in short water residence reservoirs. As well, there may be a marked difference in zooplankton biomass between the off-channel areas and open water and possibly between the vertical zones formed during summer stratification. Rzoska (1978) and Saunders *et al.* (1989) found that high current velocities are a limiting factor for zooplankton. Areas of lower flow velocities such as coves, sidearms, and the eplimnion of stratified water columns may serve as refuges for zooplankton from advective loss. Inshore habitats have also been shown to be important for riverine invertebrate population and community dynamics (Saunders and Lewis 1989; Hildrew 1996; Robertson *et al*. 1997; Reckendorfer *et al.* 1999). Studies performed by Reckendorfer *et al.* (1999) and Schiemer *et al.* (2001) revealed that the availability of “storage zones” (zones in river channels where flushing was much lower than in the main channel itself) with low velocity or still water was positively correlated with the zooplankton abundance in rivers. These previous results beg the question of what influence, if any, do off-channel areas serve in the zooplankton dynamics of short water residence reservoirs.

The purpose of this study was to describe the zooplankton community in Lake Dunlap, a southcentral Texas reservoir on the Guadalupe River. This study describes the longitudinal abundance, biomass, and species composition of zooplankton within the reservoir from May to August, 2004, and focuses on the influence of whole-lake water residence time on the zooplankton community. Variables measured include crustacean zooplankton biomass, abundance, and species composition, rotifer biomass, abundance and species composition, water residence time of the reservoir, and chlorophyll a. A previous study on this reservoir suggests that algal growth was limited at a relatively high flow velocity despite the fact that the site was downstream of a waste water treatment plant and nutrients were at levels that would support higher algal growth (Groeger & Martin 2002). The study also concluded that algal biomass was greater near the dam, where the water experiences more lentic conditions and there is more time for the algae to grow and accumulate. Chlorophyll a concentrations were measured to support these findings and compare with zooplankton abundance and biomass. Lake Dunlap tends to decrease substantially in water clarity from upstream to downstream reaches (Groeger & Martin 2002), so light attenuation was considered along with temperature and depth. I considered the following hypotheses: (1) total zooplankton biomass and abundance will increase in slower flow velocity storage zones compared to upstream pelagic sites; (2) the ratio of rotifer biomass and abundance of rotifers versus crustacean biomass and abundance of crustacean zooplankton will be greater in more lotic-like conditions and less in more lentic-like condition; (3) both rotifer and crustacean zooplankton biomass and abundance in the reservoir will be positively related to water residence time.

II. STUDY SITE

Lake Dunlap is a hardwater reservoir located on fifth-order stretch of the Guadalupe River in southcentral Texas (29°39’13”N, 98°04’57”W) with a surface elevation of 175.3 m amsl, a surface area of 1.5 km^2, and volume of 6.33 X 10^6 m^3 (Groeger 2002). The reservoir is relatively shallow with a mean depth of 4.4 m and has a short water residence time (mean monthly water residence time for 1933 – 1999 was 6.0 days) (Groeger 2002). Virtually all of Lake Dunlap’s drainage basin is located on the Edwards Plateau, which is made up of primarily limestone resulting in the reservoir’s hardwater properties. The reservoir often has a very distinct summer plunge point (point where the cooler inflowing water plunges below the warmer surface waters) during normal or dry flow years (Groeger 2002). High chlorophyll concentrations have been found to be characteristic of the plunge point during the summer (Groeger & Martin 2002). Also during the summer, in normal or low flow periods, the reservoir will stratify vertically in the down-lake region downstream of the plunge point. During this stratification, high algal production occurs in the warm surface waters close to the dam leading to eutrophic or hypereutrophic conditions (Groeger 2002). According to Groeger, (2002) the low summer flows result in increased water residence time and decreased dilution of nutrient input from the waste water treatment plant (WWTP) located upstream from the dam. In a study conducted during the summer of 2001, Groeger and Martin (2002) found that chlorophyll concentrations increased greatly closer to the dam in the stratified surface waters, water clarity greatly decreased closer to the dam, and phosphorus concentrations were much greater downstream of the creek used the WWTP for its discharge waters. Another characteristic of this reservoir, that has received less attention, is its relatively short water residence time. Also, the horizontal hydraulic regime throughout the reservoir is extremely variable. The upstream region of the reservoir consists of very fast-moving water because of a shallower and narrower channel and water velocity decreases further downstream as the reservoir deepens and widens. Both the short water residence time and variable hydraulic regime may have a strong influence on the abiotic and biotic properties of the reservoir. The morphometric and hydrological characteristics of Lake Dunlap are summarized in Table 1.

Table 1. Physical and chemical characteristics of Lake Dunlap, Texas and its drainage basin (summarized from Groeger (2002), Groeger and Martin (2002).

Surface area	1.5 km^2
Volume	6.33×10^6 m^3
Mean depth	4.4 m
Maximum depth	8 m
Mean annual residence time	6.0 days
Elevation	175.3 m amsl

III. MATERIALS AND METHODS

Sampling

Samples were taken at 6 fixed sites (4 pelagic, 2 off-channel) along Lake Dunlap (Figure 1). The four pelagic sites were designated D1 (located 0.06 river km upstream from the dam), D2 (located 2.62 river km upstream from the dam), D3 (located 6.3 river km upstream from the dam), and D4 (located 9.03 river km upstream from the dam). The two off-channel sites were designated D2.5 (located 4.92 river km upstream from the dam) and D3.5 (located 7.94 river km upstream from the dam). Sampling was to be conducted weekly from May 2004 until lake-turnover in the fall of 2004. However, high flows in the reservoir due to excessive rainfall and Canyon Reservoir releases during the sampling period prevented this. Inflows into the reservoir were monitored consistently throughout the study period and sampling was done on days when the reservoir was safely accessible and navigable. Unsafe conditions due to flooding led to the closure of Lake Dunlap from June 30 to July 19. Thus, there were sampling dates that occurred from within 1 week of each other to as much as 4 weeks apart. Sampling took place during the summer because preliminary sampling revealed the greatest quantitative abundance of zooplankton could be collected in the summer months. Preliminary sampling took place during a dry year, however, and the summer this study took place had high flows and a water column that was not stratified as a result of the high flows.

Zooplankton were collected by making triplicate vertical tows using a 63-µm Wisconsin plankton net from one-half meter above the substrate to the surface at each station. Discrete samples were to be taken throughout the study period in the epilimnion and the metalimnion during stratification to study vertical segregation. However this was done on only one date, June 4, because this was the only sampling date that the reservoir was stratified, though only weakly so. Samples were concentrated in the laboratory depending on sample size and preserved with a sucrose-formalin solution. Zooplankton abundance was determined by taking subsamples so that at least 200 organisms were enumerated. Copepods, cladocerans, and rotifers were counted using a compound microscope at the appropriate magnification. Cladoceran zooplankton were identified to species while rotifers were identified to genus. Copepods were categorized as adult calanoids, cyclopoids, harpacticoids, or nauplii. Keys used in identification included those of Brooks (1957), Pennak (1989), and Thorp and Covich (2001). Body lengths of no less than 25 individuals for each species of cladocerans and each body type of copepods were measured using an ocular micrometer. Biomass estimates for crustaceous zooplankton were determined from measured lengths and length-dry mass relationships as described in Bottrell *et al*. (1976). Rotifer biomass was calculated using biovolume measurements described by Ruttner-Kolisko (1977) and dry mass conversions assuming a specific density of 1.0 (Dumont *et al*. 1975) and a dry mass: wet mass ratio of 0.1 (Bottrell *et al*. 1976).

One-liter surface water samples were collected at each sampling site for determination of alkalinity, chlorophyll a analysis and turbidity measurements. A light profile was done at each station using a light meter, however, heavy cloud cover prevented this activity on four of the sampling dates. A Secchi disk was used to measure water clarity. A Hydrolab profile from the surface to the reservoir bottom was carried out at 1-m increments to collect measurements of temperature, pH, dissolved oxygen, and specific conductance. Water depth was measured using a depth finder installed on the sampling boat. Inflow into the reservoir was monitored via USGS gauge data and used to determine water residence time within the reservoir on sampling dates. Whole-lake water residence time (WRT) was calculated using the general formula for residence time:

$$WRT = V/q$$

Where V is the volume of the system and q is the inflow.

Statistical analysis

Total zooplankton, crustacean (copepod and cladoceran), and rotifer distribution and population parameters were analyzed using two-way ANOVA on the factors of reservoir station and water residence time. Multiple regression models were used to evaluate the relationship of crustacean and rotifer biomass and abundance to physical, chemical and biological parameters. Factors that were included in multiple regressions are WRT, chlorophyll a, alkalinity, pH, turbidity, temperature, dissolved oxygen, specific conductance, and reservoir location.

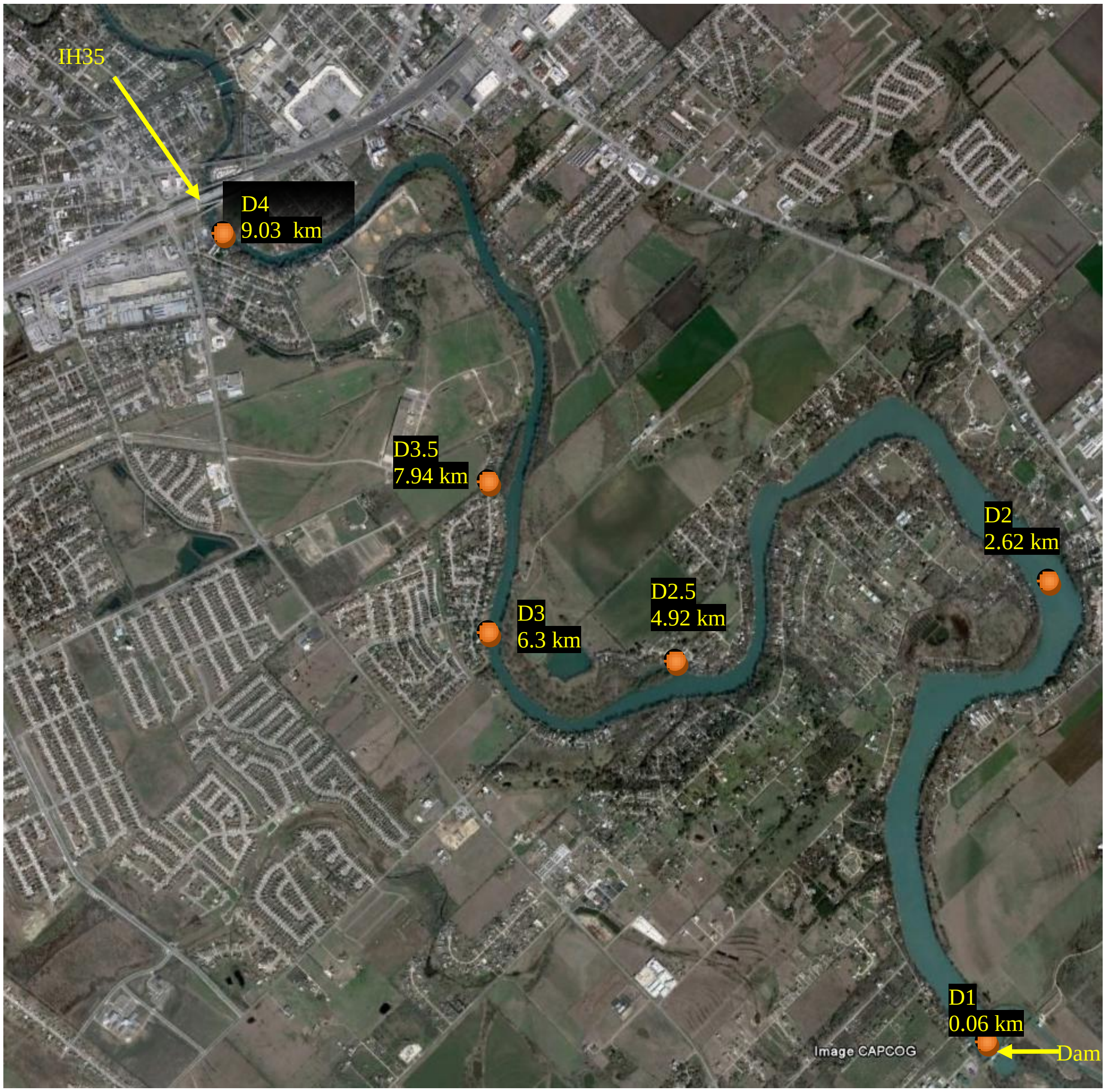

Figure 1. Map of Lake Dunlap.

IV. RESULTS

Water residence time

The mean monthly water residence time for May 2004- August 2004 was 1.5 days (Table 2), much shorter than the 6.0 day long-term median (Groeger 2002). Daily water residence times for May through August 2004 are included in Appendix III. For this study, the mean whole-lake water residence time for one week (7 days) prior to each sampling date and the sampling date was used (a total of 8 days) to reflect recent hydrologic history. Mean WRT for different time periods (from 0 to 10 days before the sampling date and the sampling date) were explored statistically and the mean WRT for a time period of 8 days showed a significantly better predictive relationship than others. This was a period of high rain and flooding activity which led to higher flows and shorter water retention in Lake Dunlap, placing 2004 in the upper 10% of wettest summers within the 70 year record. Water releases from upstream Canyon Reservoir contributed strongly to this wet summer. It appears that the total zooplankton abundance increases with a longer WRT and decreases with shorter WRT (Figure 2). The same positive relationship between total zooplankton biomass and WRT is suggested as well (Figure 3).

Zooplankton community characteristics

Zooplankton were seldom observed in samples collected at D4, the most upstream station. This sampling site was also either inaccessible for sampling or had flows too high for zooplankton collection for sampling that occurred June 18 through August 4, 2004,

Table 2. Mean water residence time (WRT) for the study months of May through August 2004 and long term median WRT (USGS 1933-2008).

Month	Mean WRT (days) 2004	Long term median WRT
May	1.7	3.6
June	0.9	3.7
July	1.0	4.6
August	2.3	5.6

excluding this station from sampling for three of the eight sampling dates. Because of these exclusions, this station was not included in statistical analyses. To meet the assumptions of normality and homogeneity of variances for statistical analysis, plankton data were log (x + 1) transformed. The assumption of independence of samples is believed to have been met due to the facts that (1) there was great enough distance between sampling stations that migration of animals between the sampling stations was assumed minor and (2) the life cycles of most animals are much shorter than the one to four week interval between sampling periods. However, it is possible that some overlap may have occurred during this study due to transport of organisms downstream by flood waters. Differences in total net zooplankton abundance and biomass, total cladoceran abundance and biomass, total rotifer abundance and biomass and total copepod biomass were significant spatially and temporally with significant interaction effects ($p < 0.0001$, Table 3) in all, suggesting that these variables are related to WRT and reservoir site location independently as well as interactively. Total copepod abundance was significantly different spatially ($p=0.0015$) and temporally ($p=0.0222$) but had no significant interaction effects ($p=1.000$).

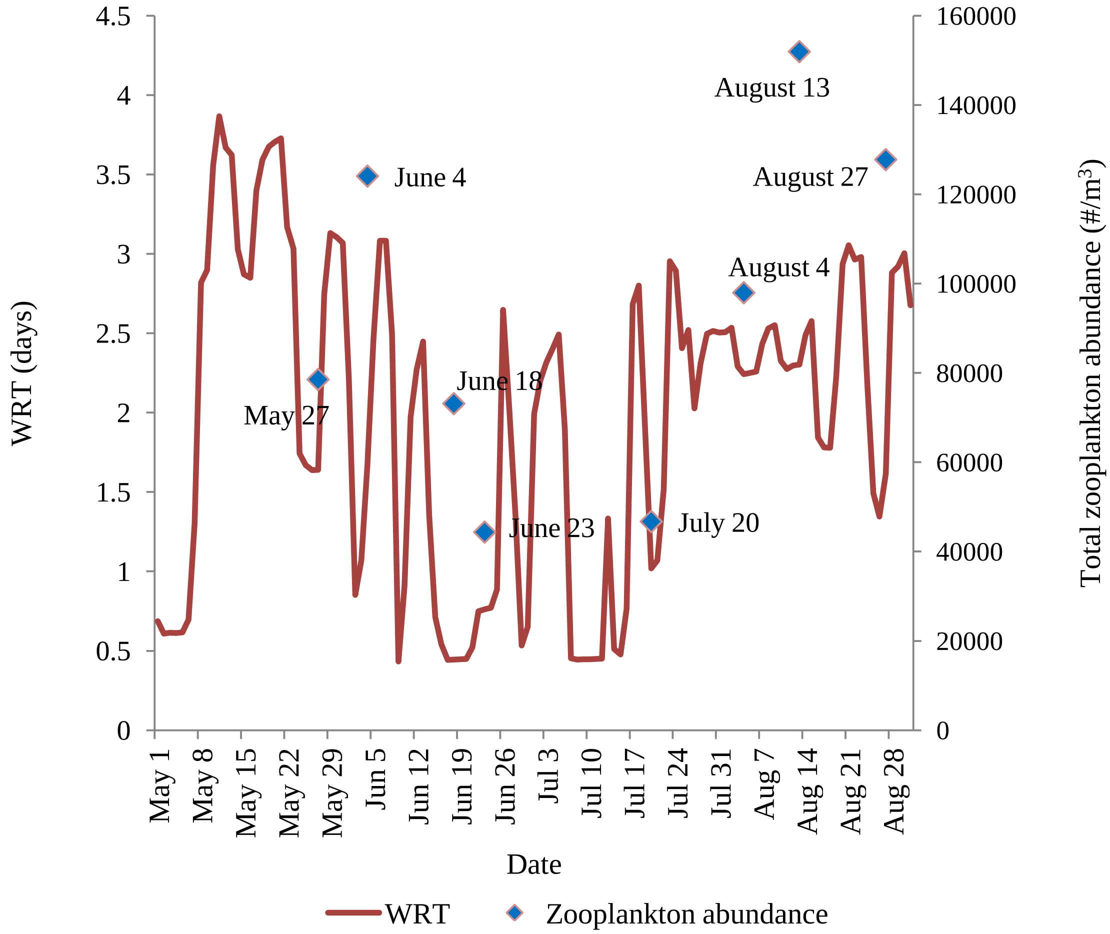

Figure 2. Total whole-reservoir zooplankton abundance and calculated daily water residence time (WRT). WRT for the months of May through August and the total abundance of net zooplankton observed for each sampling date of the study period are shown in reference to the sampling date collected.

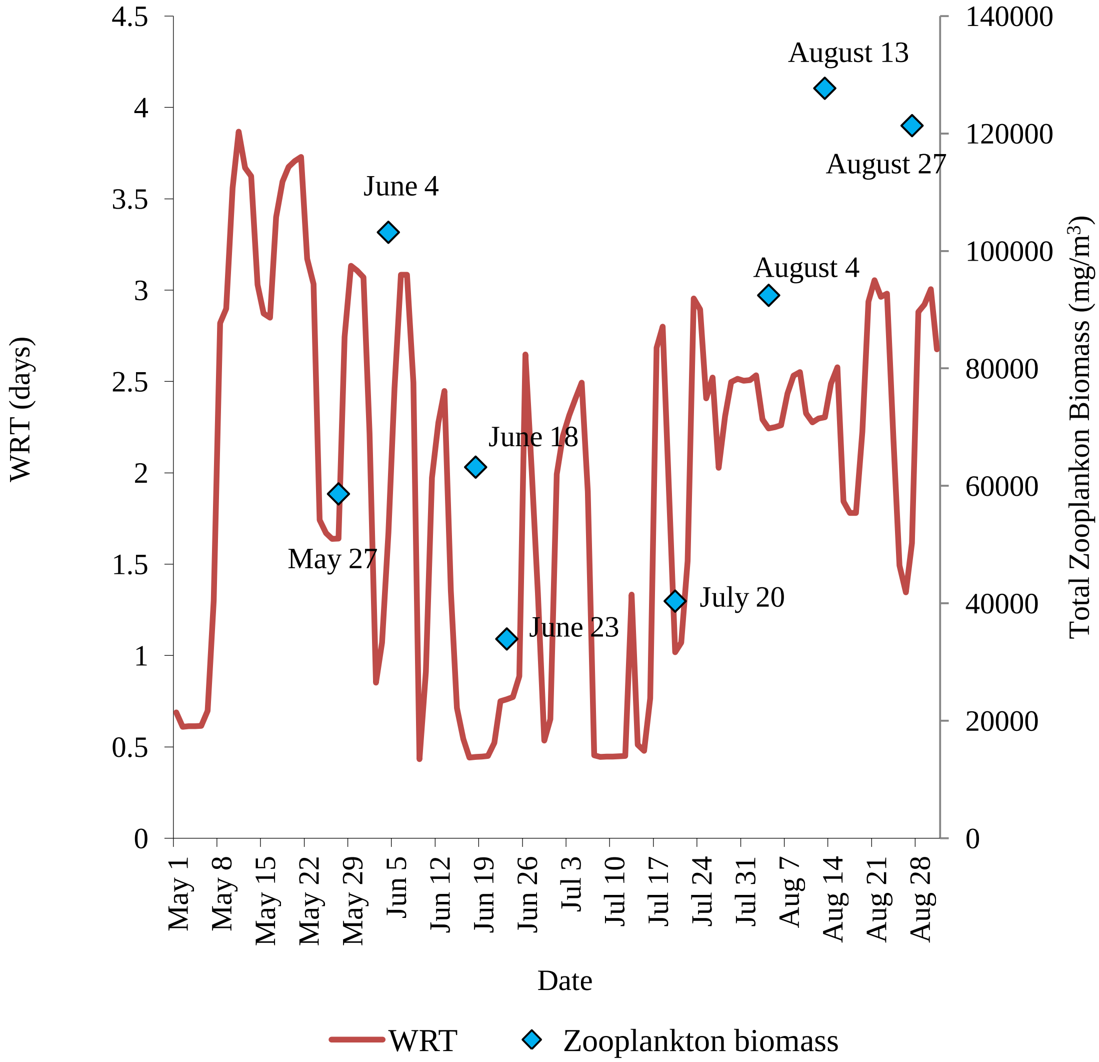

Figure 3. Total whole-reservoir zooplankton biomass and water residence time (WRT) by date. WRT for the months of May through August and the total number of net zooplankton observed for each sampling date of the study period are shown.

Table 3. Two-way ANOVA summary on net zooplankton taxonomic categories on factors of reservoir station and water residence time (WRT).

Taxonomic Category	Parameter	Source	df	SS	MS	F value	p value
Total Zooplankton	Abundance	Station	2	0.87	0.43	144.76	<0.0001
		WRT	7	4.93	0.70	234.74	<0.0001
		Interaction	14	0.65	0.05	25.18	<0.0001
		Error	48	0. 97	0.07		
		Total	71	6.91			
	Biomass	Station	2	3.15	1.57	845.15	<0.0001
		WRT	7	4.11	0.59	315.10	<0.0001
		Interaction	14	0.65	0.05	25.18	<0.0001
		Error	48	0. 09	0.00		
		Total	71	8.00			
Total Cladocera	Abundance	Station	2	7.65	3.82	1382.77	<0.0001
		WRT	7	10.04	1.43	518.97	<0.0001
		Interaction	14	12.16	0.87	314.12	<0.0001
		Error	48	0.13	0.00		
		Total	71	29.98			
	Biomass	Station	2	7.51	3.76	514.30	<0.0001
		WRT	7	10.85	1.55	212.23	<0.0001
		Interaction	14	14.26	1.02	139.47	<0.0001
		Error	48	0.35	0.01		
		Total	71	32.97			
Total Copepoda	Abundance	Station	2	6.58	3.29	7.46	0.0015
		WRT	7	8.11	1.16	2.63	0.0222
		Interaction	14	0.50	0.04	0.08	1.0000
		Error	48	21.17	0.44		
		Total	71	36.37			
	Biomass	Station	2	6.38	3.19	1446.13	<0.0001
		WRT	7	4.53	0.65	293.28	<0.0001
		Interaction	14	0.90	0.06	29.09	<0.0001
		Error	48	0.11	0.00		
		Total	71	11.91			

Table 3-Continued

Taxonomic Category	Parameter	Source	df	SS	MS	F value	p value
Total Rotifera	Abundance	Station	2	32.82	16.41	1008.71	<0.0001
		WRT	7	43.71	6.24	383.81	<0.0001
		Interaction	14	56.02	2.00	111.39	<0.0001
		Error	48	1.44	0.02		
		Total	71				
	Biomass	Station	2	22.71	11.35	1257.90	<0.0001
		WRT	7	22.68	3.81	422.26	<0.0001
		Interaction	14	8.26	0.59	65.37	<0.0001
		Error	48	0.43	0.01		
		Total	71	58.08			

Mean abundances of all organisms identified for each sampling date for each sampling location are included in Appendix I. Of the net-zooplankton observed 13 crustacean and eight rotifer taxa were identified (Table 4). Copepods were numerically dominant at most of the stations throughout most of the sampling period with the exception of station D3 in which rotifers dominated numerically on all sampling dates except for August 4 when rotifer abundance equaled that of cladoceran abundance.

Greatest mean abundance of total zooplankton occurred at station D2.5, an off-channel station (Figure 4). The station closest to the incoming Guadalupe River, station D4, located 9.03 km from the dam, showed the lowest mean total zooplankton abundance, however, zooplankton collection did not occur here on three consecutive sampling dates during the middle of the study due to impassable water or flows too high for zooplankton collection and was, as earlier stated, not included in statistical analysis. The second lowest total zooplankton mean abundance occurred at D1, the station closest to the dam (Figure 4). Highest total net zooplankton abundance occurred on August 13 while the lowest abundance occurred June 23. During the course of the study, *Bosmina longirostris* was the most abundant cladoceran species (Figure 5), copepod nauplii were the most abundant stage of copepods (Figure 6), and *Keratella* was the most abundant rotifer observed in Lake Dunlap (Figure 7). *Chaoborus punctipennis* was also observed on four consecutive sampling dates with the first observance occurring in the middle of the study (Figure 8). *C. punctipennis* was observed at stations D1, D2 and D2.5. The greatest number of observances occurred at D1 while the highest overall abundance occurred at D2.5. Instars I *C. punctipennis* were observed on June 23 (20/m^3), July 20 (59/m^3), August 4 (4/m^3), and August 13 (15/m^3) while instars II were observed on June

Table 4. Taxonomic list of net zooplankton collected in Lake Dunlap, Texas during Summer, 2004 by sampling date and reservoir location.

Phylum Rotifera
  Class Monogononta
    Order Ploima
      Family Synchaetidae
        Ploesoma
      Family Gastropodidae
        Ascomorpha
        Chromogaster
      Family Asplanchidae
        Asplancha
      Family Brachionidae
        Brachionus
        Keratella
      Family Euchlanidae
        Euchlanis
      Family Lecanidae
        Lecane
Phylum Arthropda
Subphylum Crustacea
  Class Branchiopoda
    Order Cladocera
      Family Bosminidae
        Bosmina longirostris
      Family Daphnidae
        Ceriodaphnia quadrangular
        Daphnia ambigua
        Daphnia galeata mendotae
        Daphnia lumholtzi
        Daphnia parvula
        Daphnia rosea
      Family Sididae
        Diaphanosoma birgei
  Class Maxillopoda
    Order Copepoda
        Suborder Calanoida
        Suborder Cyclopoida
        Suborder Harpactacoida
        Copepodid
        Nauplii
Subphylum Uniramia
  Class Insecta
    Order Diptera

Table 4. (Continued)

Family Chaoboridae
Chaoborus punctipennis

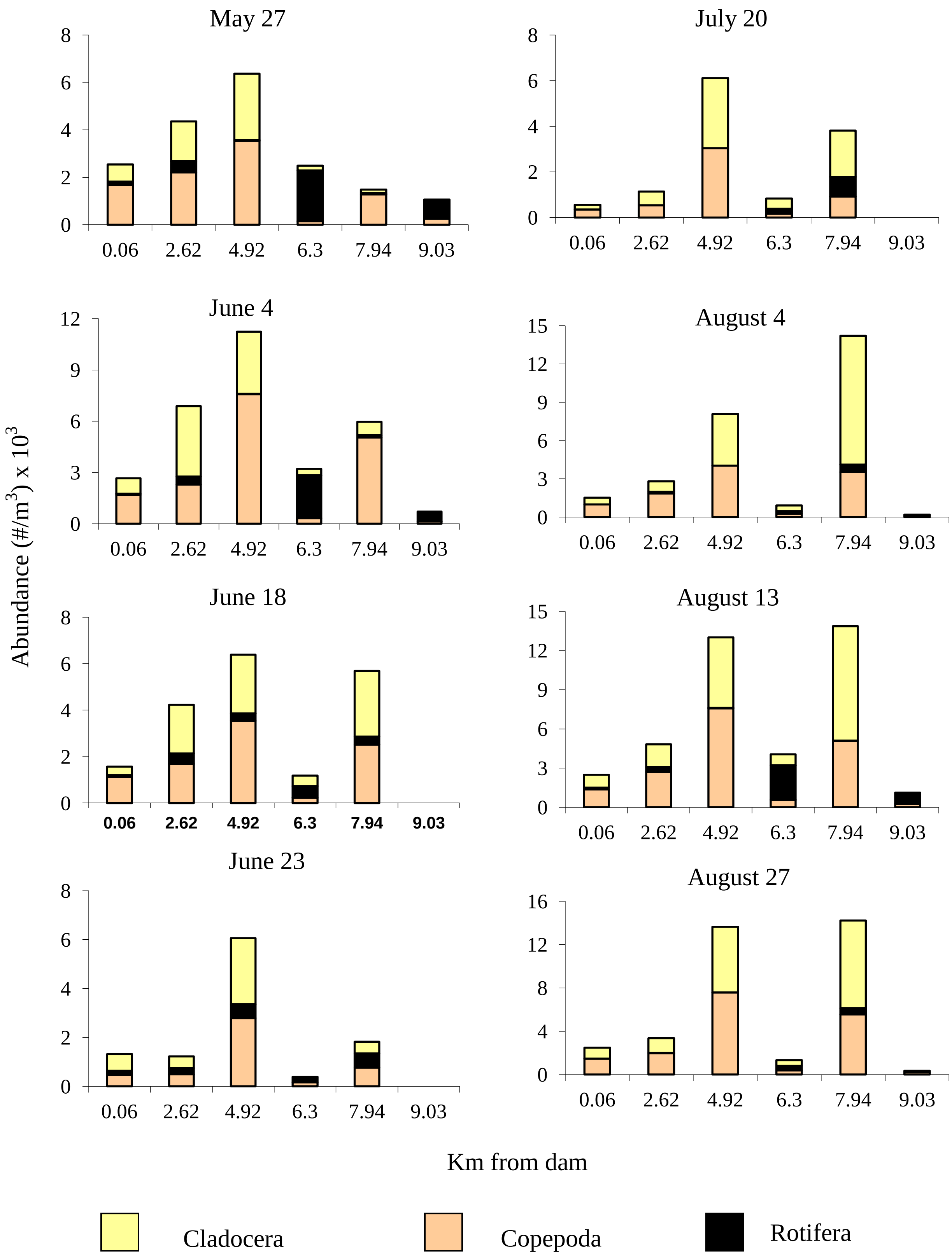

Figure 4 . The longitudinal distribution of mean abundance of dominant net zooplankton by sampling date.

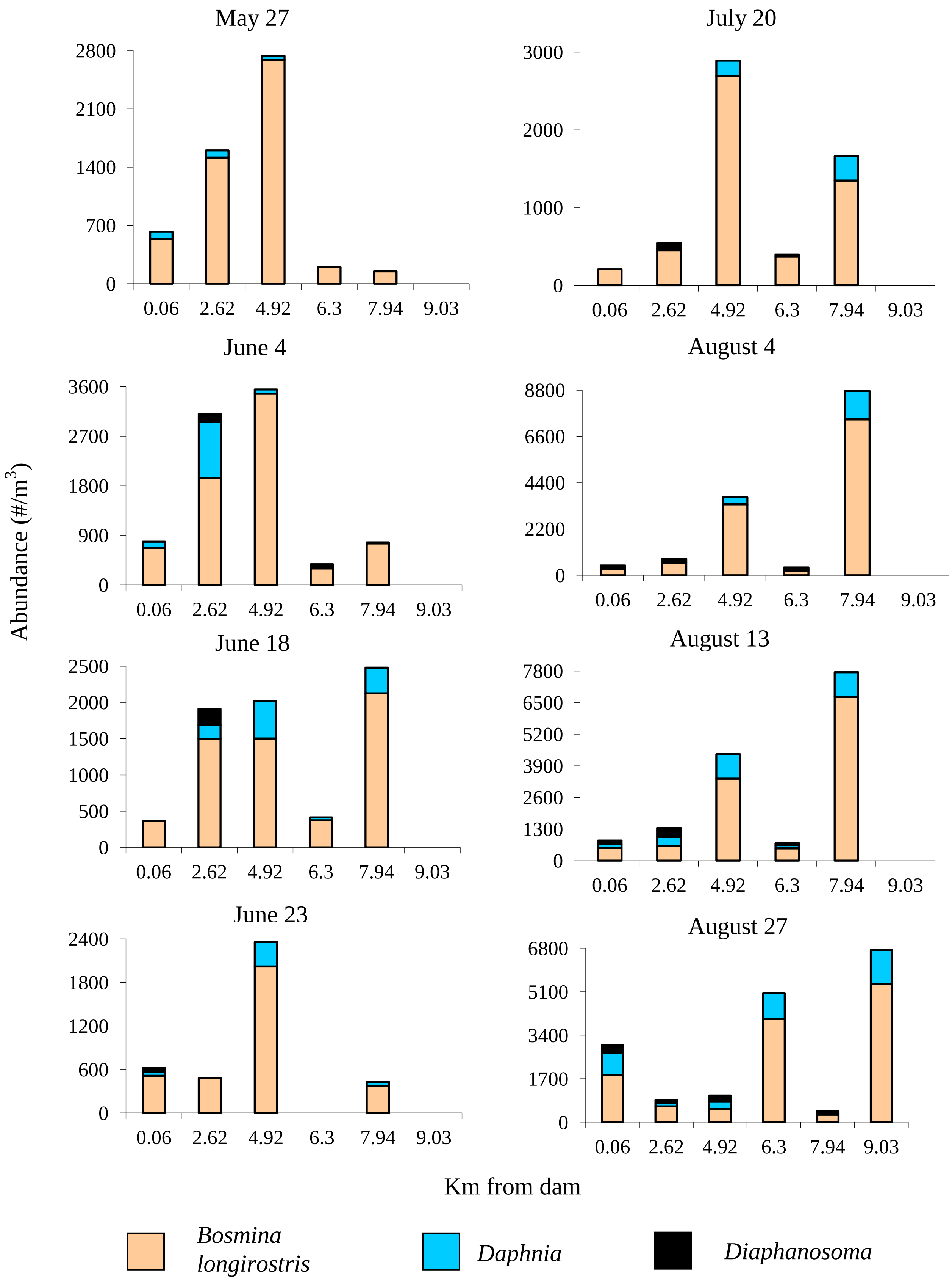

Figure 5. The longitudinal distribution of mean abundance of cladoceran zooplankton by sampling date.

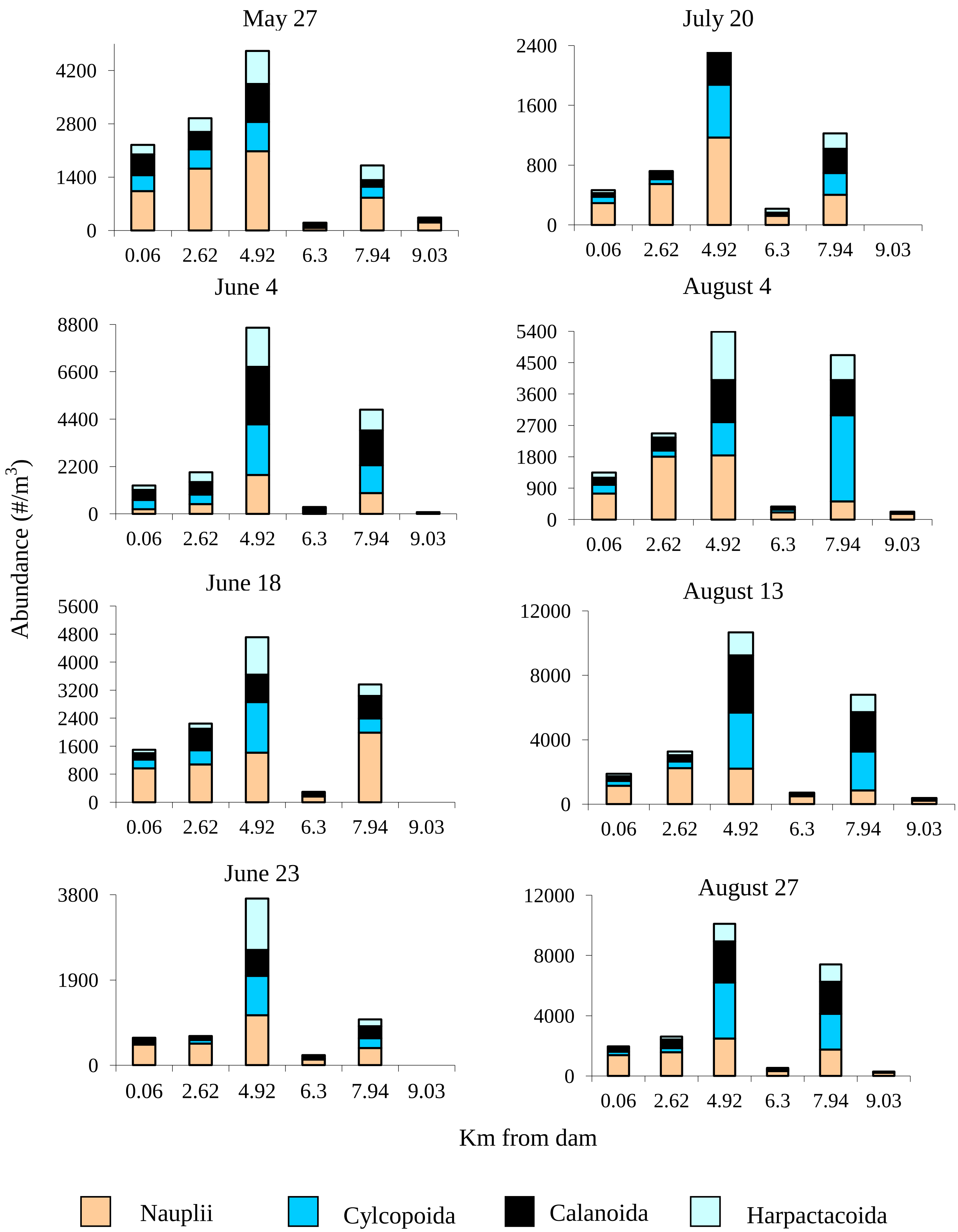

Figure 6. Longitudinal distribution of mean abundance of copepod zooplankton by sampling date.

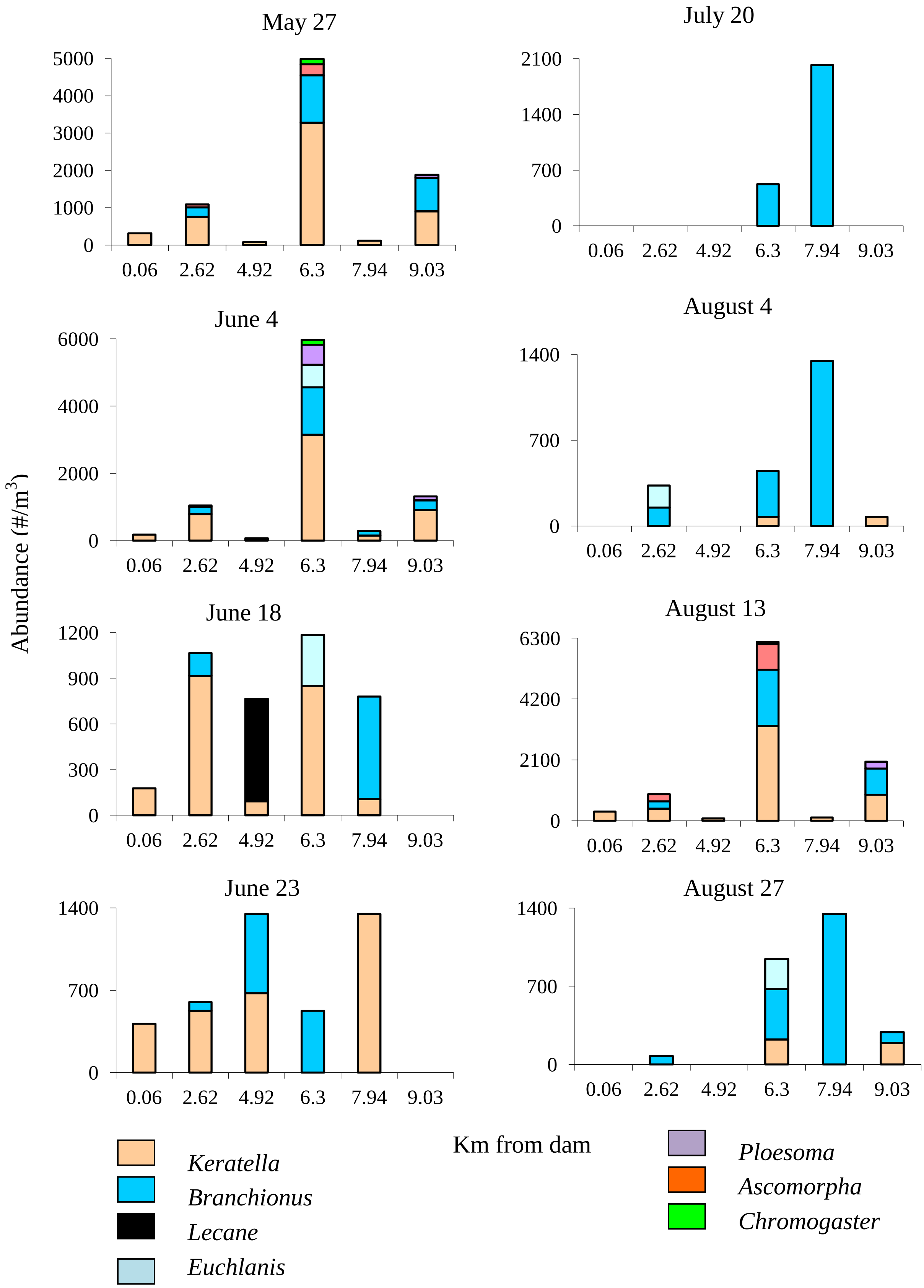

Figure 7. The longitudinal distribution of mean abundance of rotifer species by sampling date.

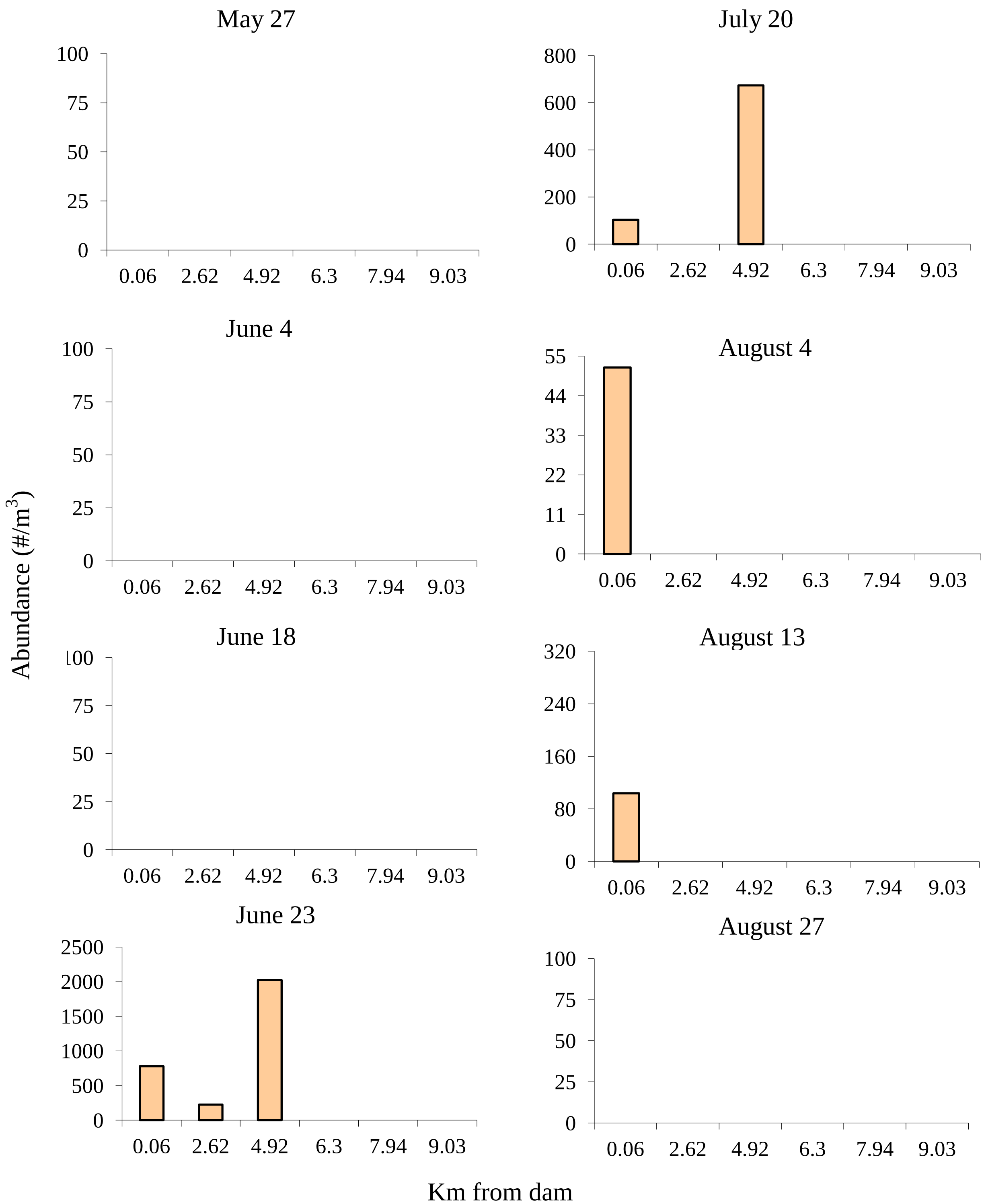

Figure 8. The longitudinal distribution of *Chaoborus punctipennis* mean abundance by sampling date.

23 in relatively high abundance (309/m^3) and July 20 (19/m^3), instars III were observed on June 23 (18/m^3), August 4 (22/m^3), and August 13 (18/m^3), and instars IVof *C. puntipennis* were observed on August 13 (18/m^3) at D1 (Figure 9).

Mean overall zooplankton biomass was greatest at D3.5 (an off-channel station) (Figure 10). Of the 5 stations that were sampled for the entire study period, the pelagic station D3, the most lotic-like site, had the lowest mean overall zooplankton biomass. The only station to have a lower mean biomass was the furthest upstream station D4, however, again, this station was only sampled on 5 out of the 8 sampling dates. The second lowest total zooplankton mean biomass, for the 5 stations that were sampled for the entire study period, occurred at D1, the site closest to the dam. Highest total net zooplankton biomass occurred on August 13, while the lowest biomass occurred on June 23. While copepods were numerically dominant in overall abundance for the sampling period, cladocerans made up the greatest overall biomass for the study period with an overall biomass nearly seven and a half times greater than that of copepods. Rotifers had the lowest overall total biomass. Mean biomass of all organisms, except *C. puntipennis,* identified for each sampling date for each sampling location are included in Appendix II.

Cladoceran distribution, abundance and biomass

Total whole-lake cladoceran abundance was greatest at D3.5 (Figure 5). No cladoceran species were found at the most upstream station D4 for any of the five dates that sampling occurred here. Station D3 had the lowest total cladoceran abundance for the stations that were sampled on all dates. Total cladoceran abundance was greatest on August 13 and was lowest on June 23. *Bosmina longirostris* dominated total overall

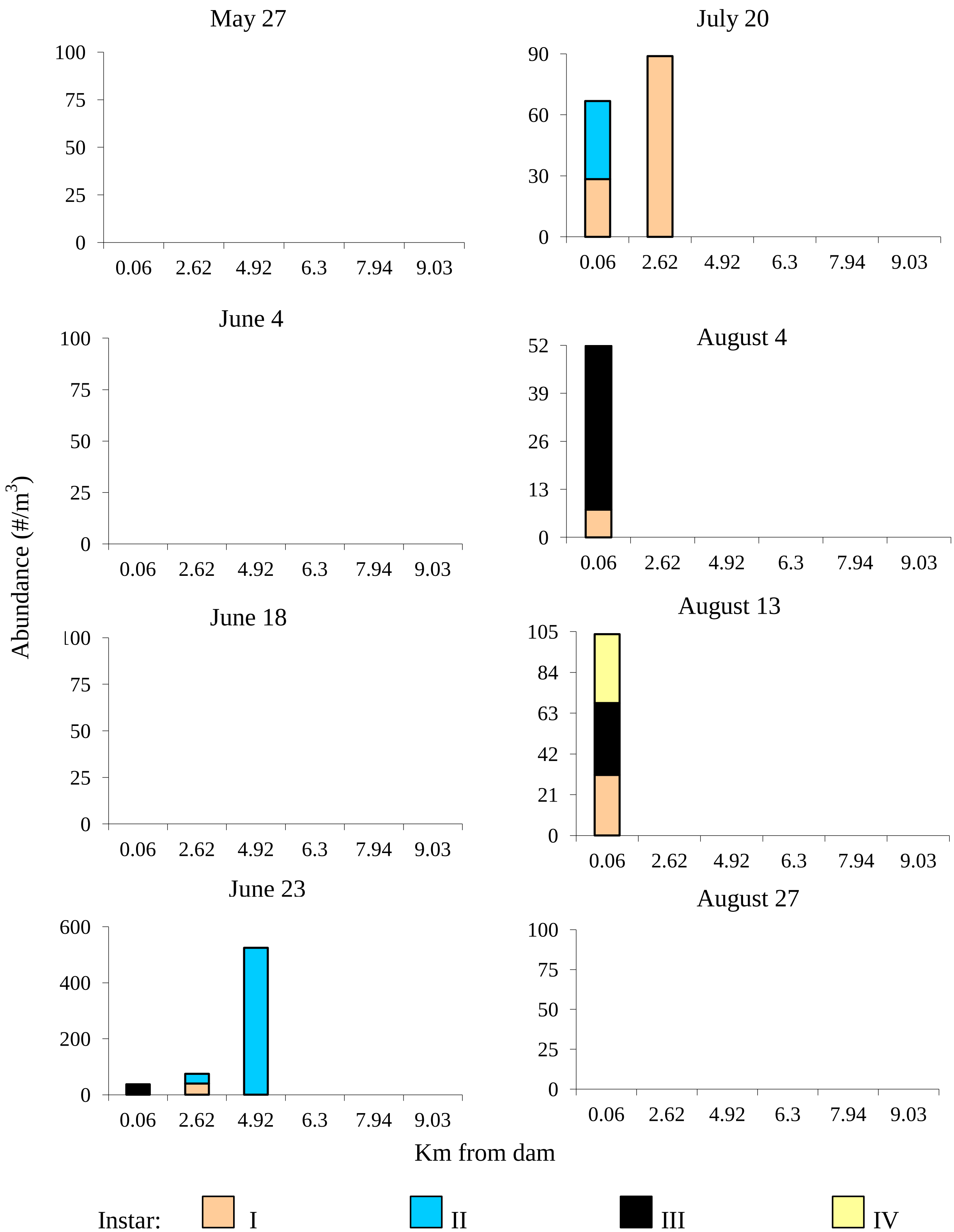

Figure 9. The longitudinal distribution of *Chaoborus punctipennis* larval instar mean abundance by sampling date.

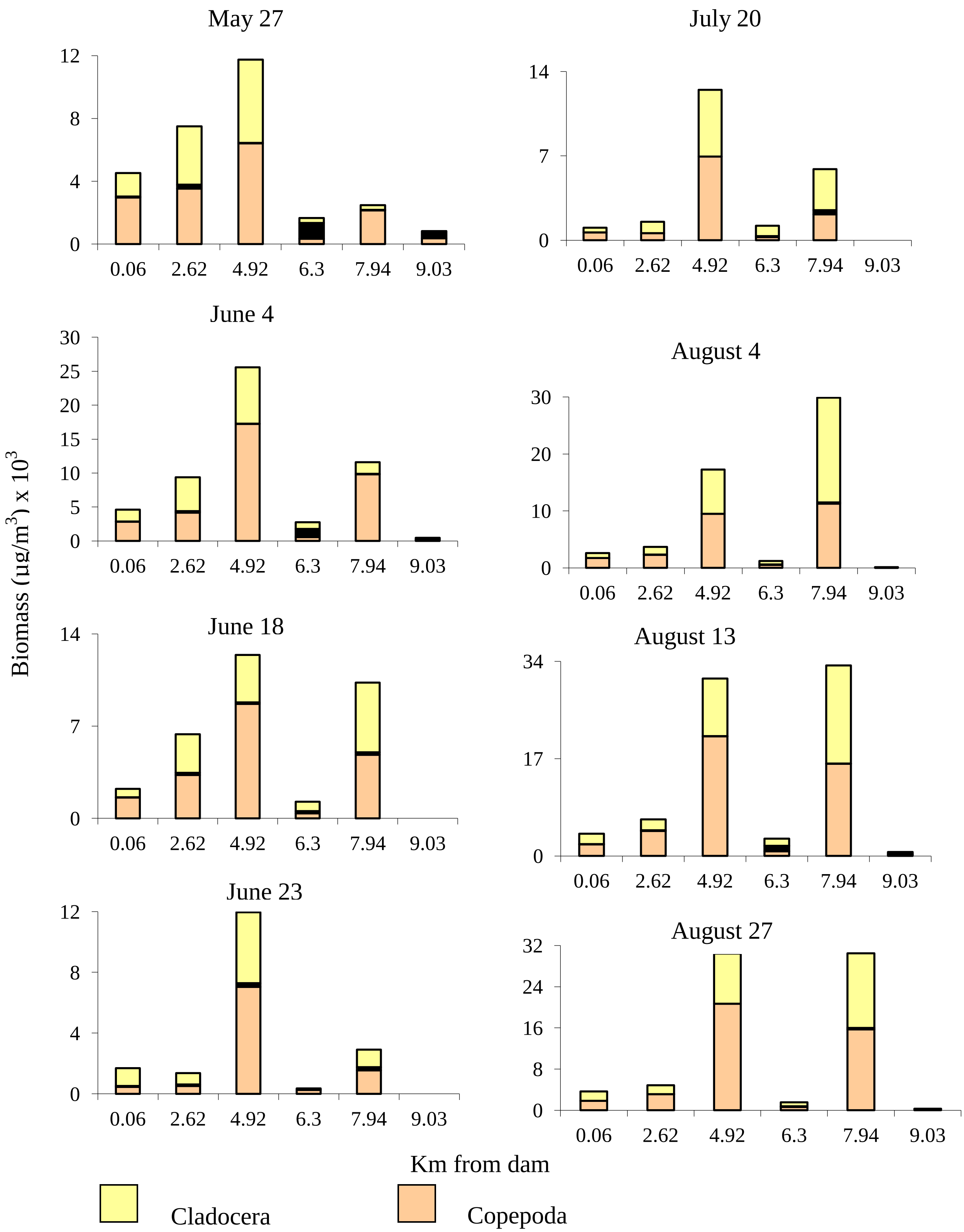

Figure 10. The longitudinal distribution of mean biomass of dominant net zooplankton by sampling date.

sampling date. Peak abundances of both *B. longirostris* and family Daphnidae occurred at D3.5 while the lowest abundance of both occurred at D3. Highest abundances of *B. longirostris* occurred on August 4 at off-channel station D3.5 (7.94 km from the dam) while *B. longirostris* abundance was lowest on May 27 at this same station. Peak abundances of *Daphnia* also occurred at D3.5 on both August 4 and August 27 while *Daphnia* abundance was lowest on June 4, at D3. Both *B. longirostris* and *Daphnia* overall abundance was higher at the off-channel stations (D2.5 and D3.5) than the pelagic stations. D*iaphanosoma* abundance was greatest on August 13 at D2 (pelagic site). No *Diaphanosoma* were collected from the off-channel stations.

Total whole-lake cladoceran biomass was higher at D3.5 than at all other stations and lowest at D3 for the 5 stations that were sampled on all 8 sampling dates (Figure 11). Total cladoceran biomass was highest on August 13 and lowest on June 23. *Bosmina longirostris* dominated cladoceran biomass for the entire study period, followed by *Daphnia* then *Diaphanosoma*. The off-channel station D3.5 had the highest overall *B. longirostris* biomass and the highest overall *Daphnia* biomass for the study period. Bosminidae biomass was highest on August 4 at D3.5 (off-channel station) while *Daphnia* biomass was highest on August 27 at the same site. *Diaphanosoma* biomass was greatest on August 13 at D2 (pelagic site). Overall, biomass for *Bosimina* and biomass for *Daphnia* for the study period was greatest at the off-channel sampling stations (D2.5 and D3.5) while overall *Diaphanosoma* biomass was greatest at D2 with no *Diaphanosoma* collected from the off-channel stations.

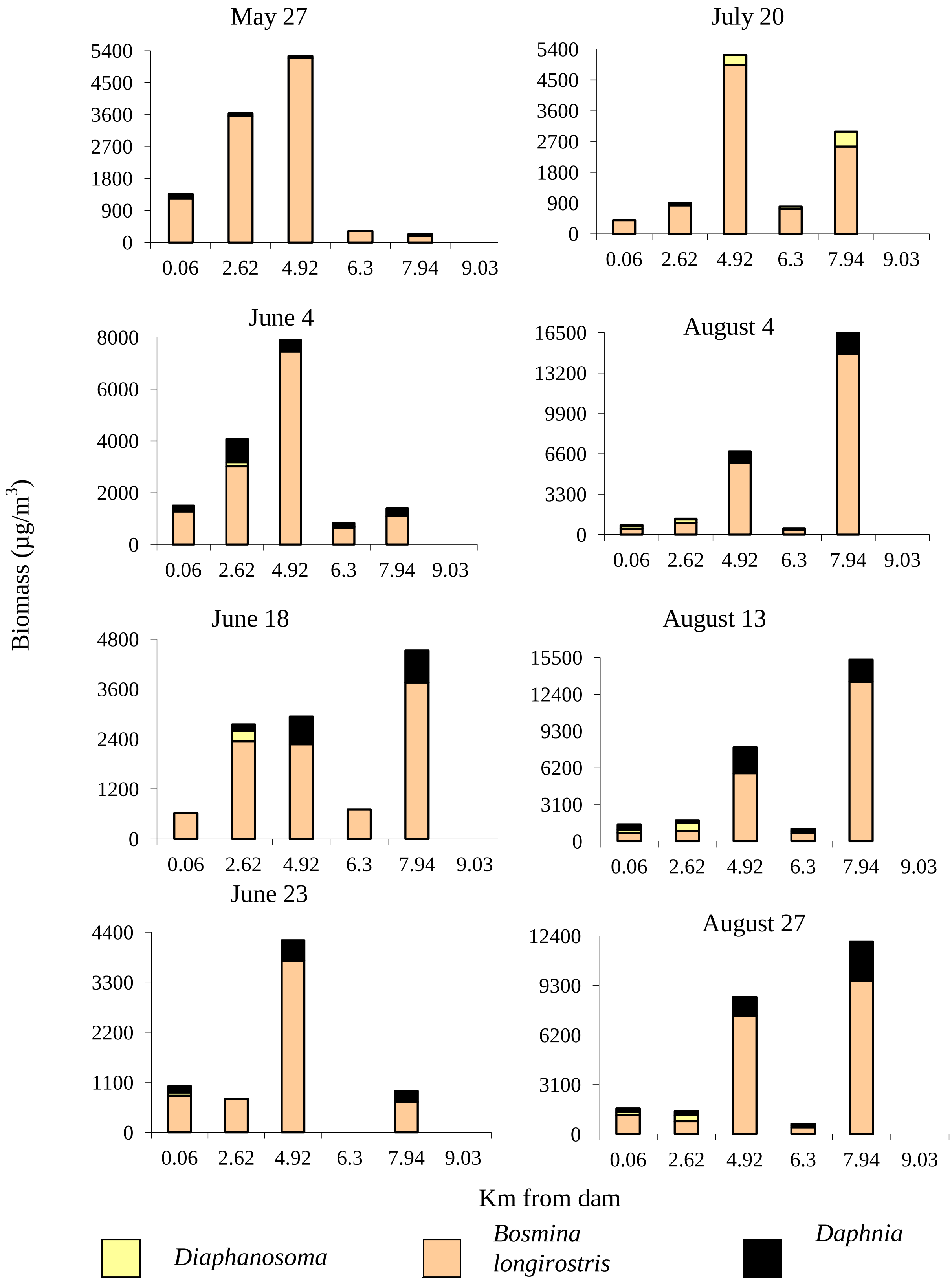

Figure 11. The longitudinal distribution of mean biomass of Cladoceran zooplankton by sampling date.

Daphnidae distribution, abundance and biomass

In this study, overall greater density of daphnids occurred at the off-channel stations than the pelagic stations. Total whole-lake daphnid abundance was greatest at D3.5 for the stations that were sampled on all eight sampling dates (Figure 12). No daphnids were observed at D4 on any of the five dates this station was sampled. *Daphnia rosea* was the most common species of *Daphnia* observed during this study. The greatest total overall abundance of *D. rosea* occurred at D3.5 with the second greatest total overall abundance occurring at D2.5, both of these stations being off-channel sampling sites. The lowest total overall abundance occurred at D3. *D. rosea* was observed on all sampling dates and at all sampling stations except the most upstream station D4. The highest abundance of *D. rosea* was observed on August 27 at D3.5 while the lowest abundance was observed on May 27 at the dam station, D1.

The remaining daphnid species collected in order of greatest to lowest abundance are as follows: *D. galeata mendotae, D. ambigua, D. lumholtzi, D. parvula, and Ceriodaphnia quadrangular. D. galeata mendotae* was observed on all sampling dates and at all stations except the most upstream station (D4). Mean overall abundance for *D. galeata mendotae* was greatest at D3.5 (off-channel) and was lowest at D3 (pelagic) where this species was found on only one sampling date, August 27. Peak abundance of *D. galeata mendotae* occurred on August 4. *D. ambigua, D. lumholtzi,* and *C. quadrangular* were all observed at stations D1, D2, D2.5, and D3.5, while *D. parvula* was observed at D1, D2.5, and D3.5. Mean overall abundance for *D. ambigua* and *D. parvula* was greatest at D3.5 while mean overall abundance for *D. lumholtzi* and *C. quadrangular* was greatest at D2.5, both off-channel stations. None of these four

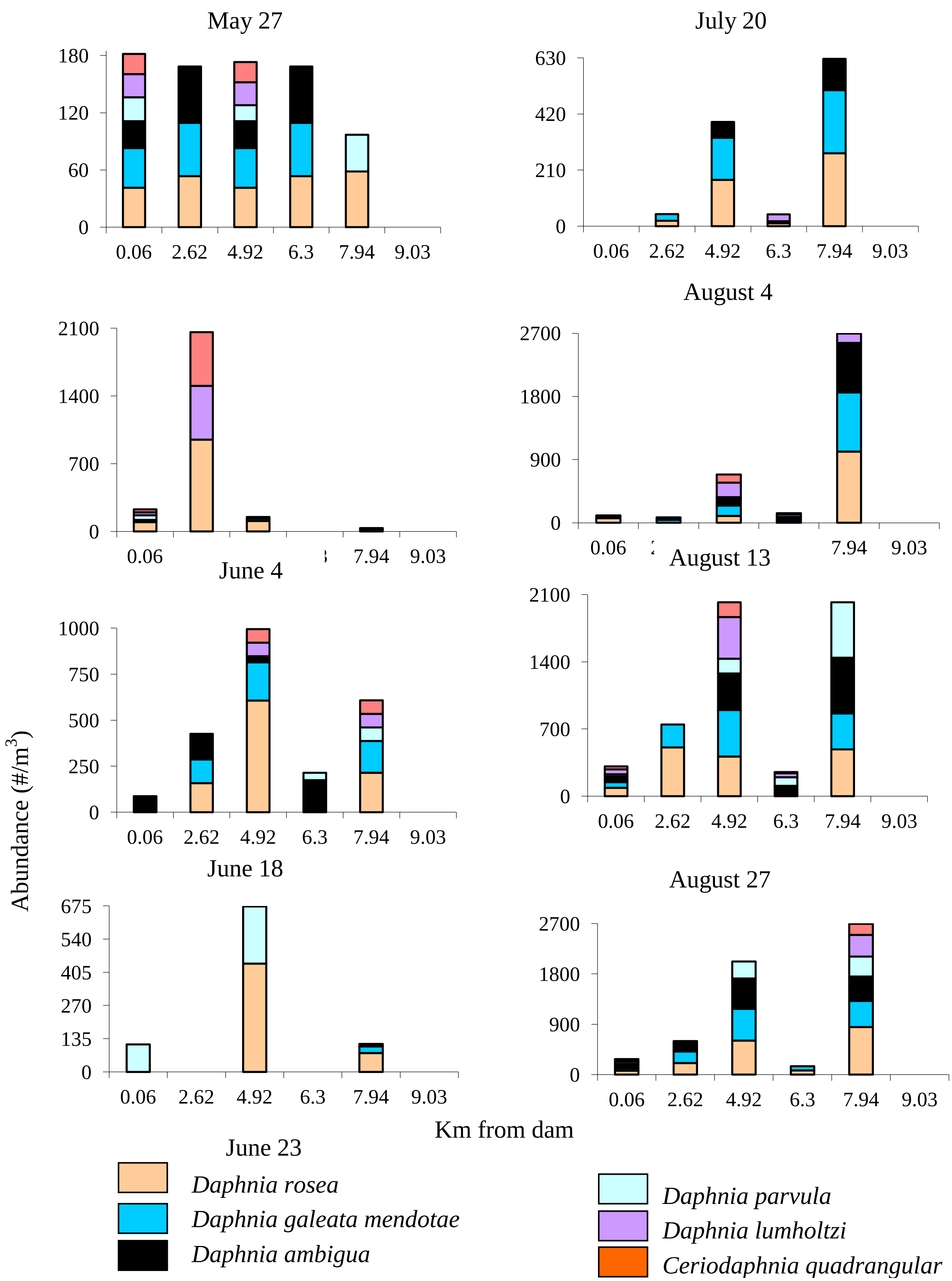

Figure 12. The longitudinal distribution of mean abundance of *Daphnia* species by sampling date.

species were observed at the pelagic station D3 for the period of this study. Total overall abundance for *D. ambigua* was greatest on August 27 and lowest on May 27, while the greatest abundance by sampling station and date occurred at D3.5 on August 13. Total overall abundance for *D. parvula* was greatest on August 13 at D.3.5. Total overall abundance for *D. parvula* was lowest on July 20 and August 4 when none were observed. *D. lumholtzi* and *C. quadrangular* had greatest total overall abundance values on August 4. Peak abundances for *D. lumholtzi* and *C. quadrangular* occurred on August 4 at D2.5. *C. quadrangular* was not observed on June 18 and neither *C. quadrangular* nor *D. lumholtzi* were observed on June 23 and July 20.

Total whole-lake *Daphnia* biomass was greater at D3.5 than at all other stations (Figure 13) and both off-channel stations were generally much higher than the pelagic sites. Total *Daphnia* biomass was highest on June 4 and lowest on July 20. *Daphnia* biomass was greater at the off-channel stations than the pelagic stations. No daphnids were observed at the most upstream station D4. *D. rosea* biomass was greater than for all other *Daphnia* species observed in this study. Total mean biomass for *D. rosea* for the study period was greatest at the off-channel station D2.5 but only slightly greater than mean biomass at the off-channel station D.3.5. Total biomass for *D. rosea* was highest on August 13 and lowest on May 27. Peak biomass occurred at the off-channel station D2.5 on August 13. *D. galeata mendotae* was second in total biomass behind *D. rosea.* Total mean biomass was greatest at the off-channel station D3.5. Total biomass was highest on August 27 and lowest on June 23. Total mean biomass for *D. ambigua* and *D. parvula* was also greatest at the off-channel station D3.5. Total biomass for *D. ambigua* was highest on August 13 and lowest on May 27. Total biomass for *D. parvula* was

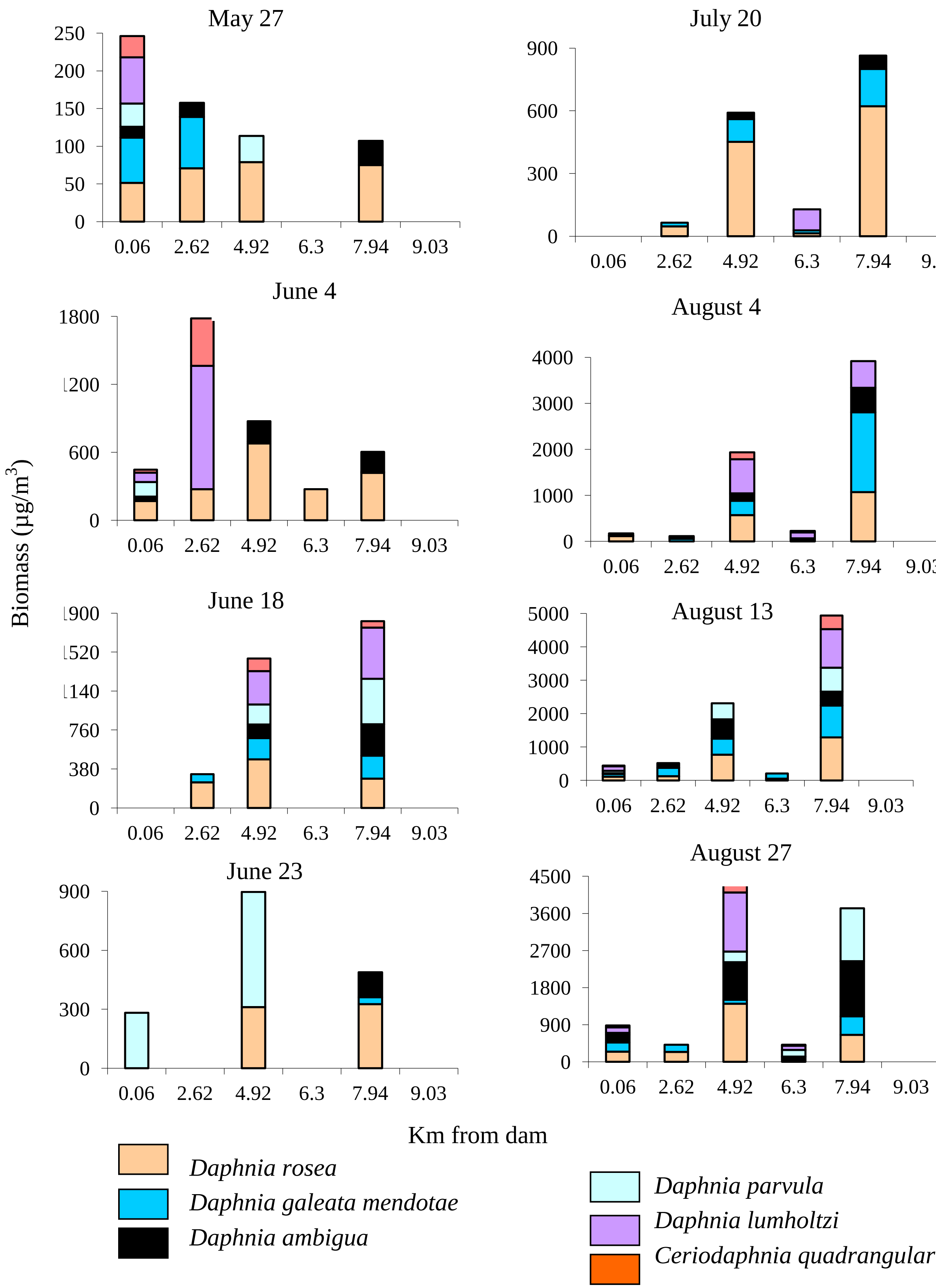

Figure 13. The longitudinal distribution of mean biomass of *Daphnia* species by sampling date.

highest on August 27 and lowest on July 20 and August 4 when none of this species was observed. Total mean biomass for *D. lumholtzi* and *C. quadrangular* was highest at the off-channel station D2.5. Total biomass for both species was greatest on August 4. As stated earlier, *C. quadrangular* was not observed on June 18 and neither *C. quadrangular* nor *D. lumholtzi* were observed on June 23 and July 20.

Rotifer distribution, abundance and biomass

Conversely, rotifer abundance and biomass was revealed to be greater in the pelagic versus the off-channel stations. Total rotifer abundance was greatest at D3 (pelagic station) and was lowest at the dam station D1 (Figure 7). Rotifer species were found at all sampling stations. Station D4 (upstream at the incoming Guadalupe River) had the third greatest total rotifer abundance. *Keratella* dominated total overall rotifer abundance for the study period and was found at all stations. The greatest abundance of *Keratella* was observed at D3. The lowest sampled abundance of *Keratella* occurred at D2.5, one of the off-channel stations. Among the sampling dates, *Keratella* abundance was greatest on May 27 and was lowest on July 20 when no *Keratella* were observed. *Keratella* was the only rotifer species observed at D1. *Branchionus* had the second greatest overall abundance of the rotifer species, was collected on all sampling dates, and was collected from all stations except the dam station, D1. The greatest abundance of *Branchionus* was observed at off-channel station D3.5 on July 20 while the lowest abundance was observed at off-channel station D2.5 on June 4. The greatest overall mean abundance of *Branchionus* occurred at station D3 while the lowest overall mean abundance occurred at the off-channel station D2.5. *Euchlanis* was observed on four of the sampling dates, June 4, June 18, August 4, and August 27, while *Chromogaster*, *Ascomorpha* and *Ploesoma* were observed on three sampling dates, May 27, June 4 and August 13. *Euchlanis* and *Ascomorpha* were observed at two pelagic stations, D2 and D3, both being in greater abundances at D3. *Ploesoma* and *Chromogaster* were also observed at station D3 while *Ploesoma* was also observed at station D4. *Lecane* was observed June 18 at off-channel station D2.5. *Euchlanis, Ascomorpha, Chromogaster, Ploesoma*, and *Lecane* rotifer species were found in much smaller numbers than *Keratella* and *Branchionus,*with C*hromogaster* being the least abundant rotifer of the study period.

Total mean rotifer biomass was greater at station D3 than all other stations (Figure 14). Total mean rotifer biomass was highest on May 27 and lowest on August 4. *Keratella* biomass was greater than for all other rotifer species observed in this study. Total mean biomass for *Keratella* was greatest at pelagic station D3. Total mean biomass for *Keratella* was highest on June 4 and lowest on July 20 when no *Keratella* individuals were observed. Peak mean biomass occurred at station D3 on June 4. *Branchionus* was second in total biomass behind *Keratella*. Total mean biomass was greatest at pelagic station D3. The off-channel station D3.5 had the second highest total mean biomass for *Branchionus* while D2.5 (off-channel station) had the lowest total mean biomass. Total *Branchionus* mean biomass was highest on May 27 and lowest on June 18. The remaining rotifer species collected in order of greatest to lowest biomass are as follows: *Euchlanis, Ascomorpha*, *Ploesoma*, *Lecane, and Chromogaster.* As with *Keratella* and *Branchionus*, total mean biomass for all these rotifer species, except for *Lecane*, was higher at station D3 than any other station. *Euchlanis* and *Ascomorpha* were collected at one other station, D2. Total biomass for *Euchlanis* was highest on June 4 while this

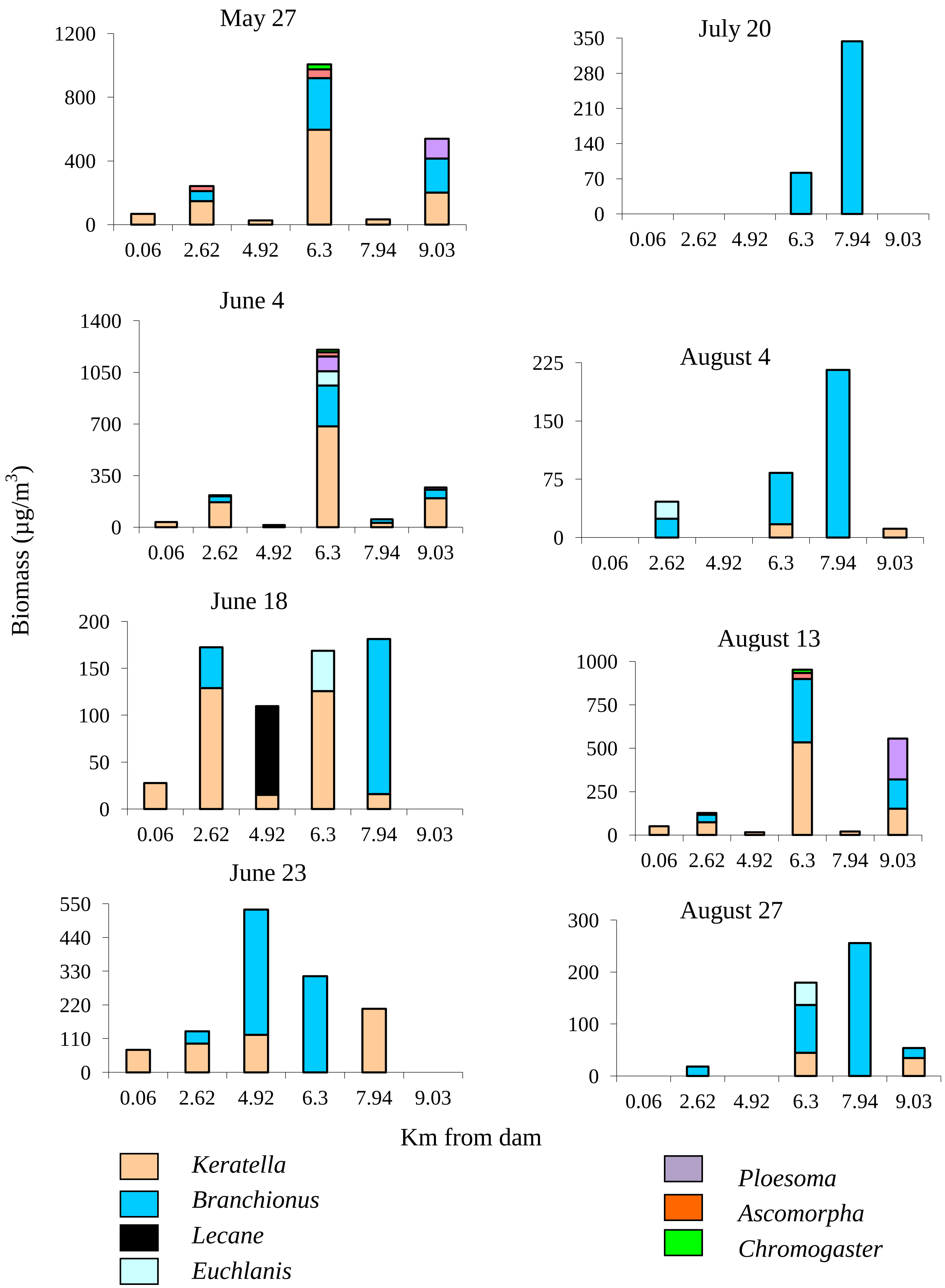

Figure 14. The longitudinal distribution of mean biomass of rotifer species by sampling date.

species was not observed on May 27, June 23, July 20, or August 13. Peak biomass occurred at station D3 on June 4. Total biomass for *Ascomorpha* was highest on May 27 while this species was not observed on June 18 and 23, July 20, and August 4 and 27. Peak biomass occurred May 27 at station D3. *Ploesoma* was also collected from one other station in addition station D3, the most upstream station D4. Total mean biomass for *Ploesoma* was highest on June 4 while this species was not observed on five of the eight sampling dates, May 27, June 18 and 23, July 20, and August 27. Peak mean biomass occurred June 4 at D3. Total mean biomass for *Chromogaster* was highest on May 27 for the three dates it was observed. *Chromogaster* was observed only at station D3 on May 27, June 4, and August 13. *Lecane* was observed on only one date, June 18, at the off-channel station D2.5.

Copepod distribution, abundance and biomass

Total copepod mean abundance was greatest at D2.5 (off-channel station) and was lowest at D4 (most upstream station that was sampled 5 out of 8 sampling dates) (Figure 6). Copepod individuals in each class were found at all sampling stations. Nauplii dominated total overall mean copepod abundance for the study period. The greatest mean abundance of nauplii was observed at station D2.5 on June 4 while the lowest mean abundance was observed at station D3 on May 27. Among the sampling dates, nauplii mean abundance was greatest on June 4 and was lowest on July 20. Cyclopoids had the second greatest overall mean abundance of the copepod classes with the largest overall mean abundance observed at station D2.5. The greatest total lake-wide mean abundance of cyclopoids was observed at station D2.5 on August 27 while the lowest total mean abundance was observed at station D3 on July 20. However, on June 4 and August 4, two of the five dates that station D4 was sampled, no cyclopoids were observed at this station. The greatest total lake-wide mean abundance of cyclopoids was observed on August 13 while the lowest lake-wide mean abundance was observed on July 20.

Calanoids made up the third greatest overall mean abundance of the copepod classes following relatively closely behind cyclopoids with a difference of only 941 individuals. The largest overall mean abundance of calanoids occurred at station D2.5. The greatest mean abundance of calanoids was observed at station D2.5 on August 27 while the lowest mean abundance was observed at station D3 on July 20. Among the sampling dates, calanoid mean abundance was greatest on August 13 and lowest on July 20. Harpactacoids had the lowest overall observed mean abundance of all the copepod classes with the greatest overall mean abundance observed at station D2.5. The greatest mean abundance of harpactacoids was observed at station D2.5 on June 4 and the lowest mean abundance was observed at station D4 on August 13. Among the sampling dates, harpactacoid lake-wide mean abundance was greatest on June 4 and lowest on June 23.

Total copepod mean biomass was greater at station D2.5 than all other stations (Figure 15). Total copepod mean biomass was highest on August 13 and lowest on June 23. Cyclopoid mean biomass was greater than for all other copepod classes observed in this study. Total mean biomass for cyclopoids was greatest at the off-channel station D2.5. Total mean biomass was highest on August 13 and lowest on July 20 with the highest mean biomass value being five times greater than that of the lowest mean biomass value. Peak mean biomass for cyclopoids was at station D2.5 on August 27.

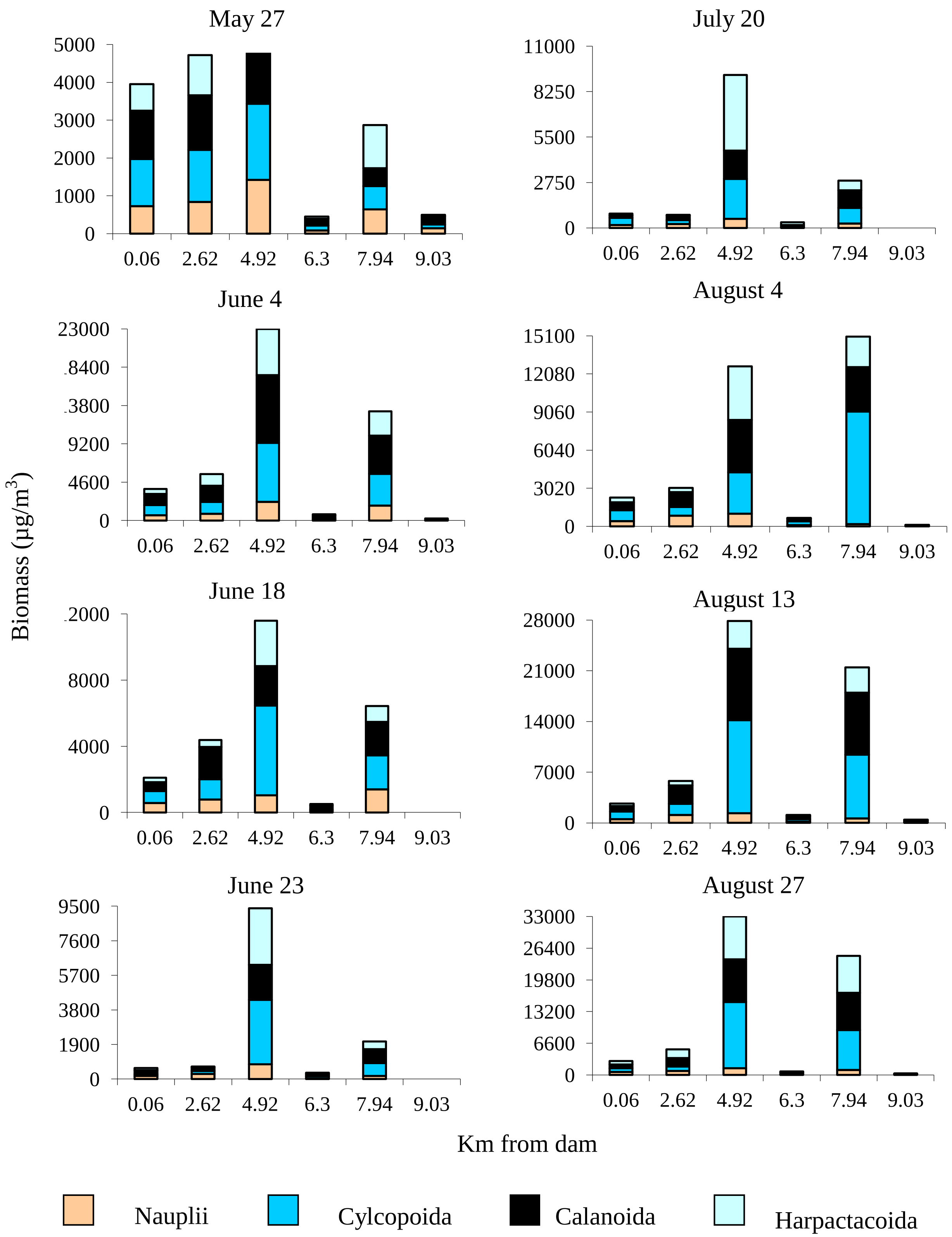

Figure 15. The longitudinal distribution of mean biomass of copepod zooplankton by sampling date.

Calanoid copepods were second in total mean biomass followed by harpactacoids. As with cyclopoids, total mean biomass for both calanoids and harpactacoids was greatest at station D2.5. Station D3.5 had the second highest total mean biomass for each cyclopoids, calanoids, and harpactacoids, respectively, while station D3 had the lowest mean biomass for each. However, there were more calanoids observed at this pelagic station than cyclopoids and harpactacoids. Total mean biomass for calanoids was highest on August 13 while total mean biomass for harpactacoids was highest on June 4. Total mean biomass for both calanoids and harpactacoids was lowest on June 23. Peak mean biomass for calanoids occurred at station D2.5 on August 13. Peak mean biomass for harpactacoids occurred at station D2.5 on June 4.

Physical and chemical parameters

Table 5 includes mean values for physical and chemical parameters by sampling date and reservoir station. These values are means of water column values from surface to bottom. The high inflows caused the chemical and physical characteristics of the reservoir to tend toward homogeneity. Mean values for the study period for temperature and turbidity were generally higher closer to the dam (0.06 to 4.92 km from the dam) and gradually declined upstream towards the headwater stations (6.3 to 9.03 km from the dam). Mean values for the study period for specific conductance gradually decreased from downstream to upstream and then increased again at the most upstream station, D4 (9.03 km from the dam). The most upstream station had a higher mean value for specific conductance over all other stations for the period of the study. Mean values for the study period for alkalinity generally declined from upstream to downstream within the

Table 5. Means (± 1 SD) of physical and chemical parameters by month and reservoir station.

	Temperature (ºC)	*Chlorophyll a (mg/L)*	*Alkalinity (meq/L)*	*Turbidity (NTU)*	*Dissolved Oxygen (mg/L)*
5/27/2004	*21.68 ± 0.67*	*0.05 ± 0.05*	*3.99 ± 0.06*	*8.88 ± 3.60*	*8.73 ± 0.52*
6/4/2004	*21.41 ± 0.89*	*0.15 ± 0.14*	*3.99 ± 0.10*	*6.70 ± 1.41*	*8.65 ± 0.61*
6/18/2004	*20.60 ± 0.51*	*0.33 ± 0.11*	*3.65 ± 0.19*	*12.78 ± 3.50*	*10.11 ± 1.06*
6/23/2004	*20.83 ± 0.35*	*0.21 ± 0.07*	*3.83 ± 0.31*	*10.30 ± 3.03*	*8.98 ± 0.55*
7/20/2004	*24.29 ± 0.80*	*0.34 ± 0.23*	*4.00 ± 0.18*	*5.23 ± 0.87*	*7.75 ± 0.39*
8/4/2004	*26.34 ± 0.87*	*0.42 ± 0.25*	*4.31 ± 0.29*	*4.63 ± 1.11*	*7.76 ± 0.93*
8/13/2004	*24.87 ± 2.09*	*0.63 ± 0.37*	*4.26 ± 0.05*	*4.68 ± 1.31*	*7.88 ± 0.85*
8/27/2004	*24.64 ± 0.83*	*0.30 ± 0.18*	*4.02 ± 0.04*	*4.58 ± 0.76*	*8.01 ± 0.73*
0.06	*23.40 ± 2.99*	*0.32 ± 0.24*	*3.99 ± 0.36*	*9.54 ± 4.81*	*7.96 ± 0.93*
2.62	*23.33 ± 2.16*	*0.21 ± 0.17*	*3.97 ± 0.25*	*7.06 ± 2.24*	*8.25 ± 0.82*
4.92	*23.18 ± 2.18*	*0.23 ± 0.12*	*3.96 ± 0.21*	*8.14 ± 3.79*	*8.52 ± 0.93*
6.3	*22.47 ± 1.84*	*0.23 ± 0.17*	*4.07 ± 0.30*	*6.63 ± 3.59*	*8.50 ± 1.00*
7.94	*22.48 ± 1.92*	*0.31 ± 0.18*	*4.07 ± 0.32*	*6.68 ± 4.09*	*8.85 ± 0.71*
9.03	*22.92 ± 2.07*	*0.52 ± 0.42*	*3.96 ± 0.15*	*5.30 ± 1.63*	*9.30 ± 1.15*
Entire Study Period	*23.04 ± 2.36*	*0.30 ± 0.25*	*4.00 ± 0.26*	*7.22 ± 3.60*	*8.42 ± 1.03*

	Secchi Disk (m)	*Conductivity (µS/cm)*	*pH*
5/27/2004	*0.61 ± 0.19*	*485 ± 1.41*	*7.80 ± 0.06*
6/4/2004	*0.74 ± 0.14*	*442 ± 13.33*	*7.89 ± 0.07*
6/18/2004	*0.48 ± 0.11*	*413 ± 1.11*	*7.79 ± 0.10*
6/23/2004	*0.71 ± 0.18*	*430 ± 0.70*	*7.83 ± 0.04*
7/20/2004	*0.83 ± 0.41*	*456 ± 31.42*	*7.71 ± 0.07*
8/4/2004	*1.27 ± 0.49*	*468 ± 5.05*	*7.79 ± 0.09*
8/13/2004	*1.12 ± 0.54*	*455 ± 2.40*	*7.74 ± 0.17*
8/27/2004	*0.86 ± 0.39*	*446 ± 13.94*	*7.85 ± 0.06*
0.06	*0.67 ± 0.26*	*448 ± 29.61*	*7.74 ± 0.14*
2.62	*0.89 ± 0.23*	*449 ± 18.51*	*7.82 ± 0.06*
4.92	*0.57 ± 0.11*	*447 ± 18.84*	*7.87 ± 0.08*
6.3	*1.34 ± 0.38*	*447 ± 18.54*	*7.79 ± 0.07*
7.94	*0.67 ± 0.22*	*444 ± 18.03*	*7.88 ± 0.07*
9.03	*1.90 ± 0.07*	*454 ± 9.42*	*7.85 ± 0.08*
Entire Study Period	*0.86 ± 0.42*	*448 ± 21.56*	*7.80 ± 0.11*

reservoir, however, the greatest values for alkalinity for the study period were found at D3 (pelagic station) and D3.5 (off-channel station) km from the dam. Mean values for the study period for dissolved oxygen were higher in the headwaters zone of the reservoir (6.3 to 9.03 km from the dam) and declined downstream towards the dam (0.06 to 4.92 km from the dam). Mean values for the study period for chlorophyll a were highest at station D4 and generally declined downstream, however the value for chlorophyll a increased at the dam station, D1(Figure 16). Chlorophyll a concentrations generally increased with increasing WRT (Figure 17), and overall were quite low.

Mulitple regression analyses

Multiple regression analyses were performed separately for the on-channel stations and the off-channel stations for longitudinal comparison. The on-channel and off-channel stations were segregated for these analyses to better show a true comparison between off-channel and on-channel stations since WRT would likely have a larger impact on the on-channel stations due to flooding during the study period. All nine variables included in the multiple regression models (WRT, chlorophyll a, temperature, alkalinity, pH, conductivity, dissolved oxygen, turbidity, and reservoir location) were (x+1) transformed for normality with the exception of temperature and pH. As shown in Table 6, 99.8% of the variability in zooplankton abundance and 84.2% of the variability in zooplankton biomass was accounted for at the on-channel stations by the combination of factors. Table 7 shows that 99.9 % of the variability in zooplankton abundance and 89.3% of the variability in zooplankton biomass was accounted for at the off-channel stations. In addition, whole-lake water residence time (WRT) was the only factor that

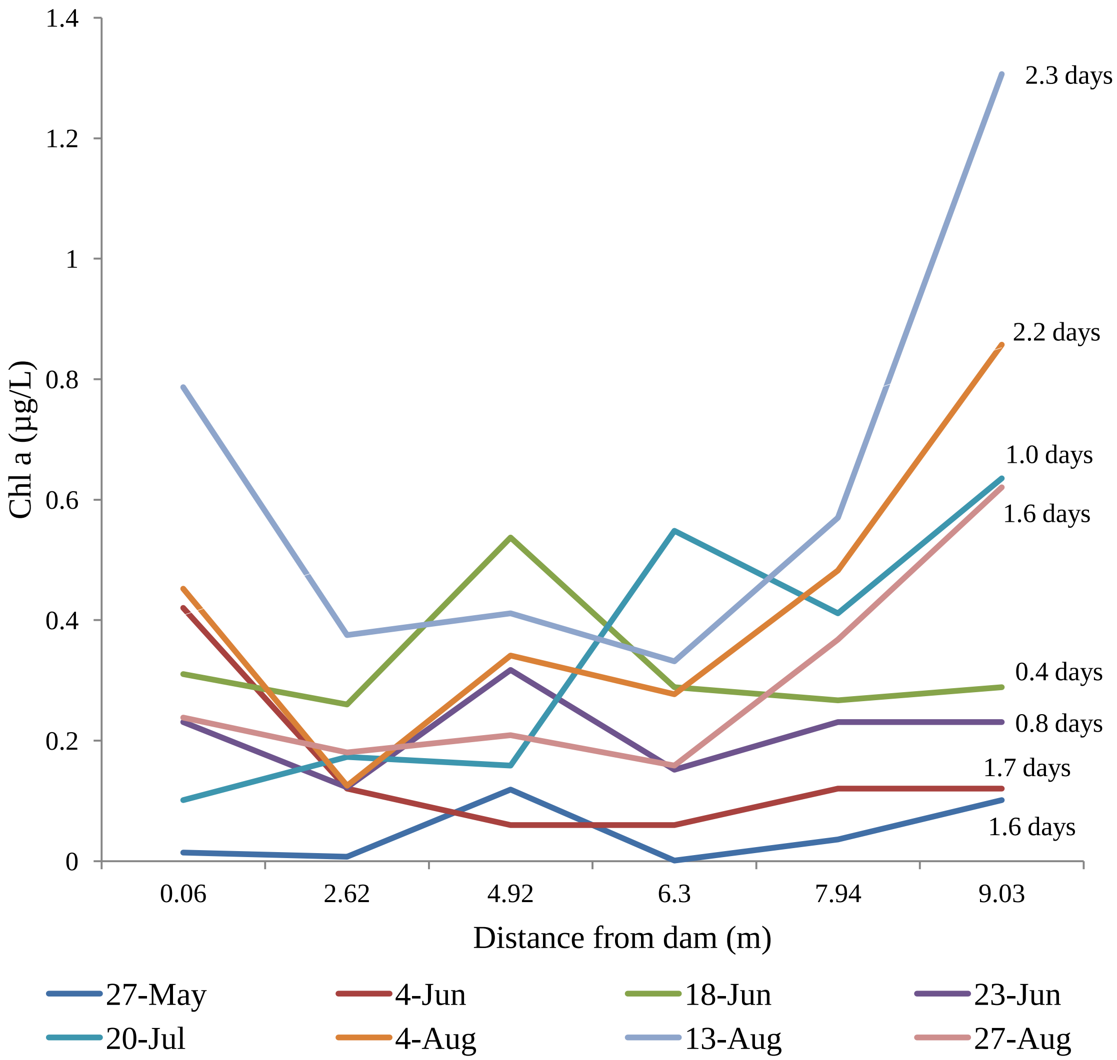

Figure 16. Chlorophyll a concentrations for each sampling date at each sampling site. Mean water residence time (in days) is shown within graph for each sampling date.

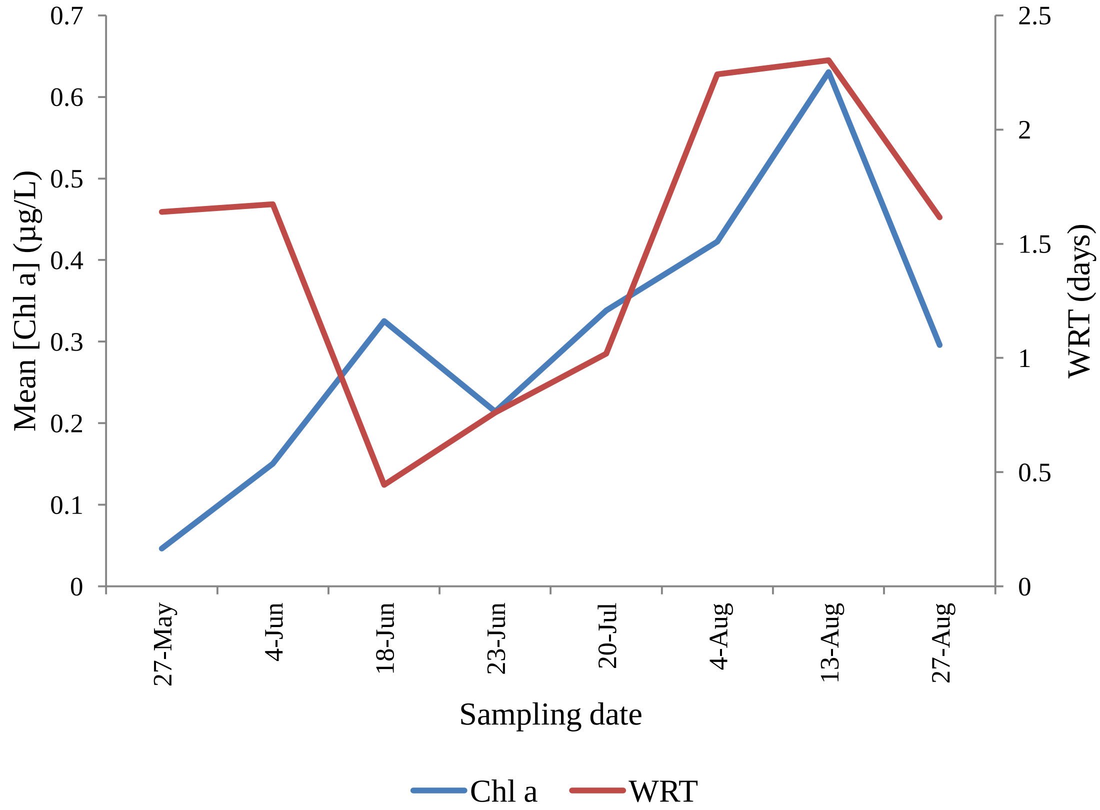

Figure 17. Mean chlorophyll a concentrations and mean water residence time for each sampling date.

Table 6. Multiple regression summary for zooplankton abundance (n = 24, r^2 = 0.998) and biomass (n=24, r^2=0.842) against eight potential predictors for on-channel stations.

	B	Standard Error	β	t	Partial r^2	p level
Abundance						
Intercept	-6.029	2.037		-2.960		0.010
Temperature	-0.005	0.005	-0.029	-1.163	-0.297	0.264
pH	0.138	0.101	0.028	1.362	0.016	0.195
Dissolve oxygen	0.114	0.320	0.011	0.355	0.095	0.728
Conductivity	0.589	0.500	0.030	1.178	0.300	0.258
Turbidity	-0.015	0.067	-0.006	-0.219	-0.058	0.830
Alkalinity	0.039	0.152	0.004	0.259	0.069	0.799
Chlorophyll a	0.145	0.169	0.021	0.855	0.223	0.407
Station	0.008	0.023	0.006	0.332	0.088	0.754
Water residence time	10.564	0.134	0.993	78.643	0.998	0.000
Biomass						
Intercept	-2.263	14.479		-0.156		0.878
Temperature	0.494	0.474	-0.045	-0.199	-0.015	0.845
pH	0.981	0.721	0.231	1.236	0.314	0.237
Dissolve oxygen	-2.737	2.277	-0.326	-1.202	-0.306	0.249
Conductivity	-0.930	3.553	-0.062	-0.262	0.070	0.797
Turbidity	0.494	0.474	0.261	1.042	0.268	0.062
Alkalinity	-1.487	1.078	-0.173	-1.380	-0.346	0.189
Chlorophyll a	0.342	1.203	0.062	0.284	0.347	0.781
Station	0.045	0.167	-0.047	-0.269	-0.072	0.792
Water residence time	7.093	0.955	0.855	7.429	0.893	≤0.001

Table 7. Multiple regression summary for zooplankton abundance (n = 16, r^2 = 0.999) and biomass (n=16, r^2=0.893) against eight potential predictors for off-channel stations.

	B	Standard Error	β	t	Partial r^2	p level
Abundance						
Intercept	-3.458	1.090		-3.173		0.019
Temperature	0.003	0.006	0.014	0.430	0.173	0.682
pH	0.066	0.118	0.010	0.562	0.224	0.595
Dissolve oxygen	0.301	0.336	0.027	0.897	0.344	0.404
Conductivity	-0.677	0.498	-0.031	-1.359	-0.485	0.223
Turbidity	-0.063	0.051	-0.026	-1.222	-0.446	0.267
Alkalinity	0.724	0.397	0.044	1.823	0.597	0.118
Chlorophyll a	-0.051	0.121	-0.007	-0.421	-0.169	0.689
Station	-0.073	0.064	-0.017	-1.142	-0.423	0.297
Water residence time	11.471	0.227	0.984	50.449	0.999	≤0.001
Biomass						
Intercept	16.434	14.188		1.158		0.291
Temperature	-0.027	0.079	-0.137	-0.344	-0.139	0.743
pH	-1.896	1.534	-0.271	-1.236	-0.450	0.263
Dissolve oxygen	-0.481	4.369	-0.042	-0.110	-0.045	0.916
Conductivity	-4.052	6.480	-0.182	-0.625	-0.247	0.555
Turbidity	0.765	0.667	0.311	1.147	0.424	0.295
Alkalinity	8.151	5.166	0.482	1.578	0.541	0.166
Chlorophyll a	1.626	1.578	0.223	1.030	0.388	0.343
Station	-0524	0.834	-0.118	-0.628	-0.248	0.553
Water residence time	11.682	2.959	0.968	3.947	0.850	0.008

had statistical significance at the 0.05 level for both models for both the on-channel and off-channel stations. Zooplankton abundance and biomass increased with increasing WRT as can be seen in Figures 2 and 3.

V. DISCUSSION

The trophic status of Lake Dunlap is sensitive to flow, with low-flow summers resulting in eutrophic down-reservoir areas (Groeger 2002). My study took place during a high-flow summer period and mean Secchi disk readings were in the hypereutrophic range (≤ 1.5 m) while chlorophyll a concentrations were in the oligotrophic range (≤ 2.5 µg/L) (OECD 1982; Wetzel 1983). The results of multiple regression analyses signify no relation between Secchi disk readings or chlorophyll a concentrations and zooplankton distribution within Lake Dunlap reservoir during this study. However, the study period proved to be an extremely wet one with heavy rains, flooding, and, thus, fast flowing water through the reservoir. The inflow temperatures during the spring and summer were also unusually low (Groeger, personal communication, April 18, 2012). These lower water temperatures were likely due to intermittent heavy bottom releases from upstream Canyon Reservoir and cooler flood waters from the upstream Guadalupe and Comal rivers. The Secchi disk readings obtained during the study were likely due to the input and stirring up of silt, soil, and dissolved organic matter from within and upstream of the reservoir, as well as from runoff into the reservoir from the surrounding local catchment due to rain and flooding. Likely for these same reasons, chlorophyll a concentrations were very low due to the washing-out of phytoplankton and the inability of phytoplankton to remain within the reservoir long enough to reproduce and accumulate.

Water residence time and zooplankton abundance and biomass

Water residence time varied significantly with the change in rainfall and the releases of water from the upstream Canyon Reservoir. As hypothesized, the results of this study showed that zooplankton abundance and biomass had a significant positive relationship with WRT. Results of a two-way ANOVA support these findings (Table 2). Other studies that have found similar results include Będzki & Ellison (2000), Baranyi *et al*. (2002), Rennella & Quirós (2006) and Obertegger *et al*. (2007). The findings of this study show that WRT plays a dominant role in structuring the zooplankton community within Lake Dunlap during periods of short WRT.

Zooplankton spatial distribution

Results showed that total zooplankton abundance and biomass in the pelagic regions of Dunlap Reservoir increased from upstream to downstream stations then decreased close to the dam. These patterns were observed for each sampling date except June 23, when both the total zooplankton abundance and biomass were nearly equal for the dam station D1 and station D2. This date was right in the middle of a heavy flooding period and, at this time, a large decrease in the number and biomass of cladoceran zooplankton was observed at pelagic station D2. This decrease was likely the result of advective loss (Pace *et al*. 1992; Walz and Welker 1998; Baranyi *et al*. 2002; Godlewski *et al*. 2003; Rennella & Quirós 2006) and increased mortality due to an increase in water velocity, turbidity, and turbulence as a result of the flooding that took place (Carvalho 1984; Kirk & Gilbert 1990; Sluss *et al*. 2008). My results also showed that overall zooplankton abundance and biomass were lowest at the most upstream site, D4, on each date of the five dates it was sampled. This is likely due to the high velocity of flow through this site which was visually evident and prevented sampling at this site during the heavy flooding period (Walz & Welker 1998; Baranyi *et al*, 2002; Godlewski *et al*. 2003).

While it did fluctuate, daily water residence time was less than 1 day for much of the time between June 9 and July 15, the time period in which heavy rains took place and inflow from the Guadalupe and Comal rivers into the reservoir was much higher. During this time, high releases from Canyon Reservoir were intermittent. On June 23, the lowest values for total zooplankton abundance and biomass for the study period. A sharp decrease in both these population parameters was observed from June 18 sampling date to June 23 sampling date likely due to advective loss and increased mortality as a result of high velocity flows, turbulence, and input and stirring up of particulate matter in the water column which can result in mechanical damage to planktonic organisms and, thus, increased mortality (Carvalho 1984; Geddes 1984; Maar 2003; Sluss 2008). In a mesocosm study by Sluss *et al*. (2008), it was observed that rotifer densities were greater overall in high turbulence tanks. In our study, overall total rotifer abundance and biomass were greater in pelagic (higher turbulence) versus off-channel (lower turbulence) stations, though, lowest during the highest periods of faster flows which would lead to increased turbulence and downstream loss. Rotifers were the numerically dominant group at the uplake sites D3 and D4, where velocities were highest and always visually obvious.

Results also showed that total zooplankton abundance and biomass was much greater at the two off-channel stations than the pelagic stations. These off-channel stations, similar to the “storage zones” of Reckendorfer *et al*. (1999), likely provided a more stable environment for zooplankton especially during the flooding period since flow velocity was likely decreased in these areas compared to the pelagic zone. These off-channel areas are also much shallower with the presence of macrophytes that may have been used for both shelter from high velocity water and predation (Shriver *et al*.1995; Lauridsen & Buenk 1996; Burks *et al*. 2002). It was also observed that while the off-channel station D2.5 further downstream had the greatest overall net zooplankton abundance and biomass for the study period, the off-channel station D3.5 further upstream showed a considerable increase in both zooplankton abundance and biomass after the period of flooding rains passed and water residence time increased. It also was the station highest in overall net zooplankton abundance for the last three sampling dates of the study period and highest in overall net zooplankton biomass for the last two sampling dates of the study period. These results suggest that the further upstream off-channel station may have better served as a zooplankton refuge as water residence time decreased. However, water residence time was still relatively short after the heavy rainfall period at this time (< 3 days) suggesting that the station (D3.5) was still active as a refuge preventing complete advective loss and mortality to zooplankton organisms. Zooplankton abundance and biomass remained higher at station D2.5 during the flooding period suggesting that this off-channel site may have provided a more stable environment for zooplankton to survive and reproduce. Both off-channel sites appear to have been safety zones for zooplankton during the study period and possibly provided a zooplankton community which could repopulate the channel stations when WRT increased.

As expected, cladocerans and copepods each exhibited much greater overall abundance and biomass than rotifers at downstream pelagic stations and at both off-channel stations. Also, as expected, overall rotifer abundance was much greater than that of cladoceran and copepod zooplankton at the upstream pelagic stations. My data showed, however, that rotifer biomass was less than that of both cladocerans and copepods at all sampling stations, even the most upstream ones with the greatest lotic-like conditions. While rotifers are generally much smaller than crustaceous zooplankton, this is surprising since rotifer abundance was 4 times greater than that of copepods at the most upstream sight located 9.03 km from the dam where the Guadalupe River enters the reservoir (no cladocerans were observed here during the study period) and was over 3 times greater than copepod and cladoceran abundance combined at station D3 (6.3 km from the dam) where conditions were very lotic-like for most of the study. The most common copepods found at these two sites were calanoid and cyclopoid species. The relatively large size of these copepods likely contributed to the greater copepod biomass over the much smaller *Branchionus* and *Keratella* rotifer species that made up most of the abundance of rotifers found at these two upstream sites. Exploitative competition with the larger crustaceans for food may also have had a negative impact on the biomass of rotifers (Sommer *et al*. 1986; Obertegger *et al*. 2007). *Branchionus* and *Keratella* were found at more sites, more often, and in much greater numbers than any other rotifer species. Both rotifer species have been found to thrive in turbulent conditions (Sluss 2008). Though these findings were observed in a mesocosm experiment, they may help to explain the rotifer population dominance of these two rotifer species in Lake Dunlap. *Keratella* was the only rotifer species to be found at D1, the station nearest the dam. Cladoceran abundance and biomass greatly increased after the flooding period when

WRT increased and became more stable allowing for the cladoceran population within the reservoir to recover (Talling & Rzoska 1967; Pourriot *et al*. 1997; Obertegger *et al*. 2007). This was the case for each cladoceran species observed. *Diaphanosoma birgei* were found to be more abundant in the pelagic zone with none collected at the off-channel sites. One study done at a medium-small warm temperate shallow polymictic lake showed that a species of *Diaphanosoma*, *D. brachyurum*, exhibited an abundance two to four times greater in the open water versus the shore (González Sagrario and Balseiro 2010). Their study suggests that these findings are the result of shore avoidance by *D. brachyurum* in an effort to avoid predation by macroinvertebrates and fish that are present in macrophytes along the shore. This could be a plausible explanation for observations of *D. birgei* at Lake Dunlap since the off-channel sites sampled had macrophytes present.

Nauplii were found in greater abundance than other copepods at all sampling stations.   During this study, conditions throughout the upstream reaches of Lake Dunlap were highly turbulent due to flooding in the incoming Guadalupe and Comal basins. This observation for the upstream lotic pelagic stations is contrary to the findings of Sluss, *et. al* (2008) where, in a mesocosm experiment, turbulent conditions favored the larger calanoid copepods which have greater swimming ability.

Observance of *Chaoborus punctipennis* first occurred during the flooding period on June 23 and was observed at the three most downstream stations, D1 and D2 (pelagic) and D2.5 (off-channel). The highest overall abundance of *C. puntipennis* occurred at D2.5 and may likely be attributed to the higher abundance of zooplankton prey species found here.

Considerations for future research

To further support the findings in this study, future research could include directly measuring water velocity at each of the sampling stations and comparing these findings to zooplankton abundance and biomass. Water velocity decreases with increasing WRT and would likely vary from station to station, especially between the inlet and pelagic stations, and especially during an extremely wet period like the one that occurred during this study. Velocity will also depend on the local reservoir morphometry, including depth, width, and roughness of the channel. With that in mind, another consideration would be comparing results of a similar study done during a period of little and/or average rainfall with results during a wet period. Whole-lake WRT may not affect zooplankton abundance and biomass as much or at all during a dry or average period. As well, inlet areas may not be as important to zooplankton for habitat use during average rainfall or dry periods.

APPENDIX I

Mean abundance (Individuals/m^3) of reservoir zooplankton in study collected by sampling date and reservoir station (km from dam) for May through August 2004.

May 27	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	314	754	77	3273	119	902
Branchionus	0	253	0	1276	0	902
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	0	0	0
Ploesoma	0	0	0	0	0	78
Ascomorpha	0	81	0	296	0	0
Chromogaster	0	0	0	145	0	0
Cladocera						
Bosmina longirostris	539	1516	2687	202	148	0
Daphnia rosea	41	53	58	0	0	0
Daphnia galeata mendotae	42	56	0	0	0	0
Daphnia ambigua	28	59	0	0	0	0
Daphnia parvula	17	0	39	0	0	0
Daphnia lumholtzi	24	0	0	0	0	0
Ceriodaphnia quadrangular	21	0	0	0	0	0
Diaphanosoma	0	0	0	0	0	0
Copepoda:						
Calanoida	545	458	998	67	176	82
Cyclopoida	287	402	3547	88	2457	72
Harpactacoida	252	358	866	21	388	11
Nauplii	1035	1624	2083	72	858	209
Chaoborus						
Chaoborus punctipennis	0	0	0	0	0	0

June 4	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	180	791	39	3150	150	911
Branchionus	0	216	34	1415	134	289
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	669	0	0
Ploesoma	0	0	0	592	0	114

AppendixI---(Cont.)

Ascomorpha	0	41	0	0	0	0
Chromogaster	0	0	0	147	0	0
Cladocera						
Bosmina longirostris	674	1946	3472	299	757	0
Daphnia rosea	95	950	109	0	21	0
Daphnia galeata mendotae	0	0	23	0	5	0
Daphnia ambigua	23	0	18	0	9	0
Daphnia parvula	48	0	0	0	0	0
Daphnia lumholtzi	32	555	0	0	0	0
Ceriodaphnia quadrangular	32	555	0	0	0	0
Diaphanosoma	0	150	0	75	0	0
Copepoda:						
Calanoida	466	580	2675	125	1609	37
Cyclopoida	428	439	2350	75	1297	0
Harpactacoida	215	456	1812	61	968	24
Nauplii	1136	1594	3267	189	2863	131
Chaoborus						
Chaoborus punctipennis	0	0	0	0	0	0

June 18	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	178	916	93	851	107	
Branchionus	0	150	0	0	674	
Lecane	0	0	674	0	0	
Euchlanis	0	0	0	334	0	
Ploesoma	0	0	0	0	0	
Ascomorpha	0	0	0	0	0	
Chromogaster	0	0	0	0	0	
Cladocera						
Bosmina longirostris	363	1497	1500	374	2125	
Daphnia rosea	0	158	607	0	214	
Daphnia galeata mendotae	0	128	207	0	174	
Daphnia ambigua	88	140	34	174	0	
Daphnia parvula	0	0	0	41	74	
Daphnia lumholtzi	0	0	74	0	74	
Ceriodaphnia quadrangular	0	0	74	0	74	
Diaphanosoma	0	225	0	0	0	
Copepoda:						
Calanoida	178	611	787	63	645	
	256	412	1442	35	408	

Appendix I---(Cont.)

Cyclopoida						
Harpactacoida	103	145	1069	33	328	
Nauplii	966	1077	1417	168	1987	
Chaoborus						
Chaoborus punctipennis	0	0	0	0	0	

June 23	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	415	524	674	0	1347	
Branchionus	0	75	674	524	0	
Lecane	0	0	0	0	0	
Euchlanis	0	0	0	0	0	
Ploesoma	0	0	0	0	0	
Ascomorpha	0	0	0	0	0	
Chromogaster	0	0	0	0	0	
Cladocera						
Bosmina longirostris	513	483	2021	0	368	
Daphnia rosea	0	0	441	0	77	
Daphnia galeata mendotae	0	0	0	0	26	
Daphnia ambigua	0	0	0	0	10	
Daphnia parvula	112	0	233	0	0	
Daphnia lumholtzi	0	0	0	0	0	
Ceriodaphnia quadrangular	0	0	0	0	0	
Diaphanosoma	52	0	0	0	0	
Copepoda:						
Calanoida	77	75	574	46	269	
Cyclopoida	34	79	880	31	215	
Harpactacoida	44	15	1149	25	154	
Nauplii	456	479	1112	123	383	
Chaoborus						
Chaoborus punctipennis	0	75	0	0	0	

July 20	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	0	0	0	0	0	
Branchionus	0	0	0	524	2021	
Lecane	0	0	0	0	0	
Euchlanis	0	0	0	0	0	
Ploesoma	0	0	0	0	0	

Appendix I---(Cont.)

Ascomorpha	0	0	0	0	0	
Chromogaster	0	0	0	0	0	
Cladocera						
Bosmina longirostri	207	449	2695	374	1347	
Daphnia rosea	0	21	174	11	274	

July 20	0.06	2.62	4.92	6.3	7.94	9.03
Daphnia galeata mendotae	0	25	158	8	236	
Daphnia parvula	0	0	0	0	0	
Daphnia lumholtzi	0	0	0	25	0	
Ceriodaphnia quadrangular	0	0	0	0	0	
Diaphanosoma	0	75	0	0	0	
Copepoda:						
Calanoida	51	97	510	25	321	
Cyclopoida	86	64	705	15	293	
Harpactacoida	38	12	1656	53	208	
Nauplii	291	549	1171	123	403	
Chaoborus						
Chaoborus punctipennis	104	0	674	0	0	

August 4	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	0	0	0	75	0	75
Branchionus	0	150	0	374	1347	0
Lecane	0	0	0	0	0	0
Euchlanis	0	181	0	0	0	0
Ploesoma	0	0	0	0	0	0
Ascomorpha	0	0	0	0	0	0
Chromogaster	0	0	0	0	0	0
Cladocera						
Bosmina longirostris	311	599	3368	225	7410	0
Daphnia rosea	66	0	98	0	1014	0
Daphnia galeata mendotae	13	42	147	0	840	0
Daphnia ambigua	25	21	104	82	706	0
Daphnia parvula	0	0	15	0	0	0
Daphnia lumholtzi	0	12	207	35	134	0
Ceriodaphnia quadrangular	0	0	118	18	0	0
Diaphanosoma	104	150	0	75	0	0
Copepoda:						

Appendix I---(Cont.)

Calanoida	201	372	1205	66	1008	34
Cyclopoida	249	172	954	79	2472	0
Harpactacoida	147	118	1389	21	715	25
Nauplii	750	1808	1842	208	520	166
Chaoborus						

August 13	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	314	421	77	3273	119	902
Branchionus	0	253	0	1940	0	902
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	0	0	0
Ploesoma	0	0	0	0	0	235
Ascomorpha	0	244	0	887	0	0
Chromogaster	0	0	0	78	0	0
Cladocera						
Bosmina longirostris	518	599	3368	505	6736	0
Daphnia rosea	87	508	414	0	488	0
Daphnia galeata mendotae	60	240	484	13	375	0
Daphnia ambigua	57	0	381	95	581	0
Daphnia parvula	25	0	155	91	577	0
Daphnia lumholtzi	52	0	434	39	0	0
Ceriodaphnia quadrangular	30	0	154	15	0	0
Diaphanosoma	155	374	0	84	0	0
Copepoda:						
Calanoida	287	402	3547	88	2457	72
Cyclopoida	304	409	3474	92	2409	82
Harpactacoida	147	226	1438	58	1069	10
Nauplii	1141	2226	2206	480	849	215
Chaoborus						
Chaoborus punctipennis	104	0	0	0	0	0

August 27	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	0	0	0	674	0	577
Branchionus	0	75	0	449	1347	96
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	269	0	0

Appendix I---(Cont.)

Ploesoma	0	0	0	0	0	0
Ascomorpha	0	0	0	0	0	0
Chromogaster	0	0	0	0	0	0
Cladocera						
Bosmina longirostris	617	524	4042	299	5389	0
Daphnia rosea	69	208	607	75	848	0
Daphnia galeata mendotae	43	206	569	75	470	0

August 27	0.06	2.62	4.92	6.3	7.94	9.03
Daphnia ambigua	79	184	543	0	434	0
Daphnia parvula	36	0	301	0	356	0
Daphnia lumholtzi	36	0	0	0	392	0
Ceriodaphnia quadrangular	12	0	0	0	195	0
Diaphanosoma	112	225	0	75	0	0
Copepoda:						
Calanoida	737	1698	8201	142	6416	77
Cyclopoida	224	280	3721	81	2371	37
Harpactacoida	114	198	1176	79	1156	14
Nauplii	1381	1576	2474	317	1744	211
Chaoborus						
Chaoborus punctipennis	0	0	0	0	0	0

APPENDIX II

Mean biomass (µg/m3) of reservoir zooplankton in study collected by sampling date and reservoir station (km from dam) for May through August 2004.

9.03		2.62	4.92	6.3	7.94	
Rotifera						
Keratella	68	148	27	596	33	202
Branchionus	0	62	0	324	0	213
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	0	0	0
Ploesoma	0	0	0	0	0	42
Ascomorpha	0	31	0	55	0	0
Chromogaster	0	0	0	32	0	0
Cladocera						
Bosmina longirostris	1241	3556	5195	322	182	0
Daphnia rosea	52	71	79	0	75	0
Daphnia galeata mendotae	60	68	0	0	0	0
Daphnia ambigua	14	18	0	0	32	0
Daphnia parvula	31	0	35	0	0	0
Daphnia lumholtzi	61	0	0	0	0	0
Ceriodaphnia quadrangular	28	0	0	0	0	0
Diaphanosoma	0	0	0	0	0	0
Copepoda:						
Calanoida	1277	1442	2405	175	475	228
Cyclopoida	1250	1376	2011	134	612	95
Harpactacoida	702	1061	2712	58	1138	28
Nauplii	724	837	1424	82	643	145

June 4	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	35	169	8	684	29	196
Branchionus	0	41	7	277	25	58
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	97	0	0

Appendix II---(Cont.)

June 4	0.06	2.62	4.92	6.3	7.94	9.03
Ploesoma	0	0	0	101	0	15
Ascomorpha	0	7	0	29	0	0
Chromogaster	0	0	0	16	0	0
Cladocera						
Bosmina longirostris	1275	3011	7454	648	1097	0
Daphnia rosea	169	275	678	274	420	0
Daphnia galeata mendotae	0	0	18	0	8	0
Daphnia ambigua	41	0	178	0	177	0
Daphnia parvula	128	0	0	0	0	0
Daphnia lumholtzi	84	1091	0	0	0	0
Ceriodaphnia quadrangular	24	419	0	0	0	0
Diaphanosoma	0	167	0	44	0	0
Copepoda:						
Calanoida	1351	1941	8106	348	4584	116
Cyclopoida	1208	1446	7105	179	3808	0
Harpactacoida	576	1395	5551	138	2910	75
Nauplii	651	805	2237	104	1807	58

June 18	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	28	129	15	126	16	
Branchionus	0	44	0	0	165	
Lecane	0	0	95	0	0	
Euchlanis	0	0	0	43	0	
Ploesoma	0	0	0	0	0	
Ascomorpha	0	0	0	0	0	
Chromogaster	0	0	0	0	0	
Cladocera						
Bosmina longirostris	622	2344	2278	704	3763	
Daphnia rosea	0	249	474	0	285	
Daphnia galeata mendotae	0	79	207	0	225	
Daphnia ambigua	0	0	133	0	308	
Daphnia parvula	0	0	65	0	147	
Daphnia lumholtzi	0	0	326	0	501	
Ceriodaphnia quadrangular	0	0	122	0	62	
Diaphanosoma	0	244	0	0	0	
Copepoda:						
Calanoida	551	1942	2378	241	2035	

Appendix II---(Cont.)

June 18	0.06	2.62	4.92	6.3	7.94	9.03
Cyclopoida	713	1241	5421	91	2041	
Harpactacoida	271	425	2747	91	951	
Nauplii	575	781	1044	92	1406	

June 23	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	74	94	123	0	208	
Branchionus	0	13	136	105	0	
Lecane	0	0	0	0	0	
Euchlanis	0	0	0	0	0	

Appendix II.---(Cont.)

Ploesoma	0	0	0	0	0	
Ascomorpha	0	0	0	0	0	
Chromogaster	0	0	0	0	0	
Cladocera						
Bosmina longirostris	808	741	3774	0	666	
Daphnia rosea	0	0	311	0	326	
Daphnia galeata mendotae	0	0	0	0	34	
Daphnia ambigua	0	0	0	0	127	
Daphnia parvula	281	0	585	0	0	
Daphnia lumholtzi	0	0	0	0	0	
Ceriodaphnia quadrangular	0	0	0	0	0	
Diaphanosoma	69	0	0	0	0	
Copepoda:						
Calanoida	208	194	1911	122	762	
Cyclopoida	95	175	3547	128	713	
Harpactacoida	128	42	3114	67	415	
Nauplii	176	274	813	31	170	

July 20	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	0	0	0	0	0	
Branchionus	0	0	0	82	344	
Lecane	0	0	0	0	0	
Euchlanis	0	0	0	0	0	
Ploesoma	0	0	0	0	0	

Appendix II---(Cont.)

July 20	0.06	2.62	4.92	6.3	7.94	
Ascomorpha	0	0	0	0	0	
Chromogaster	0	0	0	0	0	
Cladocera						
Bosmina longirostris	396	831	4939	732	2553	
Daphnia rosea	0	47	452	14	622	
Daphnia galeata mendotae	0	18	108	15	178	
Daphnia parvula	0	0	0	0	0	
Daphnia lumholtzi	0	0	0	100	0	
Ceriodaphnia quadrangular	0	0	0	0	0	
Diaphanosoma	0	48	0	0	0	
Copepoda:						
Calanoida	147	281	1713	96	1058	
Cyclopoida	437	241	2411	46	948	
Harpactacoida		109	30	4574	156	581
Nauplii		176	241	558	45	274

August 4	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	**0**	**0**	**0**	**17**	**0**	**11**
Branchionus	0	24	0	66	216	0
Lecane	0	0	0	0	0	0
Euchlanis	0	22	0	0	0	0
Ploesoma	0	0	0	0	0	0
Ascomorpha	0	0	0	0	0	0
Chromogaster	0	0	0	0	0	0
Cladocera						
Bosmina longirostris	508	978	5836	378	14747	0
Daphnia rosea	114	0	574	0	1071	0
Daphnia galeata mendotae	9	55	309	0	1734	0
Daphnia ambigua	51	35	151	68	534	0
Daphnia parvula	0	0	8	0	0	0
Daphnia lumholtzi	0	24	744	129	579	0
Ceriodaphnia quadrangular	0	0	148	29	0	0
Diaphanosoma	201	267	0	29	0	0
Copepoda:						
Calanoida	621	1172	4146	214	3525	0
Cyclopoida	871	681	3283	285	8919	0

Appendix II---(Cont.)

August 4	0.06	2.62	4.92	6.3	7.94	9.03
Harpactacoida	381	343	4246	75	2413	67
Nauplii	413	856	1003	104	176	51

August 13	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	50	73	16	534	20	151
Branchionus	0	43	0	365	0	170
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	0	0	0
Ploesoma	0	0	0	0	0	44
Ascomorpha	0	11	0	35	0	0
Chromogaster	0	0	0	19	0	0
Cladocera						
Bosmina longirostris	703	864	5736	677	13448	0
Daphnia rosea	245	237	1411	0	652	0
Daphnia galeata mendotae	225	178	96	0	448	0
Daphnia ambigua	186	0	908	128	1339	0
Daphnia parvula	48	0	258	161	1284	0
Daphnia lumholtzi	128	0	1434	101	0	0
Ceriodaphnia quadrangular	51	0	237	23	0	0
Diaphanosoma	249	659	0	166	0	0
Copepoda:						
Calanoida	739	2524	9838	433	8560	120
Cyclopoida	1058	1558	12854	324	8781	209
Harpactacoida	369	615	3855	161	3508	28
Nauplii	508	1075	1310	175	608	56

August 27	0.06	2.62	4.92	6.3	7.94	9.03
Rotifera						
Keratella	0	0	0	45	0	35
Branchionus	0	18	0	92	256	19
Lecane	0	0	0	0	0	0
Euchlanis	0	0	0	43	0	0
Ploesoma	0	0	0	0	0	0
Ascomorpha	0	0	0	0	0	0
Chromogaster	0	0	0	0	0	0
Cladocera						
Bosmina longirostris	1185	805	7417	432	9573	0

Appendix II---(Cont.)

August 27	0.06	2.62	4.92	6.3	7.94	9.03
Daphnia rosea	111	131	774	55	1291	0
Daphnia galeata mendotae	84	245	477	151	952	0
Daphnia parvula	67	0	486	0	725	0
Daphnia lumholtzi	134	0	0	0	1148	0
Ceriodaphnia quadrangular	24	0	0	0	410	0
Diaphanosoma	191	382	0	116	0	0
Copepoda:						
Calanoida	749	1774	8904	158	7728	59
Cyclopoida	811	951	13791	276	8313	116
Harpactacoida	281	612	3512	246	3858	40
Nauplii	607	811	1378	124	1039	104

APPENDIX III

Daily whole-lake water residence times (WRT) for Lake Dunlap for May through August 2004.

Date	WRT (days)
5/1/2004	0.7
5/2/2004	0.6
5/3/2004	0.6
5/4/2004	0.6
5/5/2004	0.6
5/6/2004	0.7
5/7/2004	1.3
5/8/2004	2.8
5/9/2004	3.0
5/10/2004	3.6
5/11/2004	3.7
5/12/2004	3.7
5/13/2004	3.6
5/14/2004	3.0
5/15/2004	2.9
5/16/2004	2.9
5/17/2004	3.4
5/18/2004	3.6
5/19/2004	3.7
5/20/2004	3.7
5/21/2004	3.7
5/22/2004	3.2
5/23/2004	3.0
5/24/2004	1.7
5/25/2004	1.7
5/26/2004	1.6
5/27/2004	1.6
5/28/2004	2.7
5/29/2004	3.1
5/30/2004	3.1
5/31/2004	3.1
6/1/2004	2.2

Appendix III--- (Cont.)

6/2/2004	0.8
6/3/2004	1.1
6/4/2004	1.7
6/5/2004	2.5
6/6/2004	3.1
6/7/2004	3.1
6/8/2004	2.5
6/9/2004	0.4
6/10/2004	0.9
6/11/2004	2.0
6/12/2004	2.3
6/13/2004	2.4
6/14/2004	1.3
6/15/2004	0.7
6/16/2004	0.5
6/17/2004	0.4
6/18/2004	0.4
6/19/2004	0.4
6/20/2004	0.4
6/21/2004	0.5
6/22/2004	0.7
6/23/2004	0.8
6/24/2004	0.8
6/25/2004	0.9
6/26/2004	2.6
6/27/2004	2.0
6/28/2004	1.3
6/29/2004	0.5
6/30/2004	2.0
7/1/2004	2.0
7/2/2004	2.2
7/3/2004	2.3
7/4/2004	2.4
7/5/2004	2.5
7/6/2004	1.9
7/7/2004	0.4
7/8/2004	0.4
7/9/2004	0.4
7/10/2004	0.4

Appendix III—(Cont.)

7/11/2004	0.4
7/12/2004	0.4
7/13/2004	1.3
7/14/2004	0.5
7/15/2004	0.5
7/16/2004	0.8
7/17/2004	2.7
7/18/2004	2.8
7/19/2004	1.9
7/20/2004	1.0
7/21/2004	1.1
7/22/2004	1.5
7/23/2004	2.9
7/24/2004	2.9
7/25/2004	2.4
7/26/2004	2.5
7/27/2004	2.0
7/28/2004	2.3
7/29/2004	2.5
7/30/2004	2.5
7/31/2004	2.5
8/1/2004	2.5
8/2/2004	2.5
8/3/2004	2.3
8/4/2004	2.2
8/5/2004	2.2
8/6/2004	2.3
8/7/2004	2.4
8/8/2004	2.5
8/9/2004	2.5
8/10/2004	2.3
8/11/2004	2.3
8/12/2004	2.3
8/13/2004	2.3
8/14/2004	2.5
8/16/2004	1.8
8/17/2004	1.8
8/18/2004	1.8
8/19/2004	2.2

Appendix III--- (Cont.)

8/20/2004	**2.9**
8/21/2004	**3.0**
8/22/2004	**2.9**
8/23/2004	**3.0**
8/24/2004	**2.2**
8/25/2004	**1.5**
8/26/2004	**1.3**
8/27/2004	**1.6**
8/28/2004	**2.9**
8/29/2004	**2.9**
8/30/2004	**3.0**
8/31/2004	**2.7**

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