Effects of a 31,000-cfs spike flow and low steady flows on benthic biomass and drift composition in the Lee's Ferry tailwater

Cooperative Agreement No. 1425-98-FC-40-22690 (Mod 3)

Final Report October 2003

*R. Scott Rogers, William R. Persons, Ted McKinney

*Arizona Game and Fish Department

1535½ S. Milton Ave.

Flagstaff, AZ 86001

Arizona Game and Fish Department

2221 W. Greenway Road

Phoenix, AZ 85023

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INTRODUCTION

Experimental spike flows and low seasonal steady flows (LSSF) were conducted during March-September 2000 in the Colorado River below Glen Canyon Dam (GCD), Arizona. Experimental releases were designed to enhance survival of endangered humpback chub *(Gila cypha)* residing in Grand Canyon (Gorman 1997) and are an element of the Reasonable and Prudent Alternative of GCD operations. Recommendations for the experimental hydrograph were made by SWCA Inc. (Valdez et al. 2000) under contract with the Grand Canyon Monitoring and Research Center (GCMRC). The GCMRC in turn funded studies to evaluate flow-related effects on other biota including the benthic community and drift in the Lee's Ferry tailwater.

Relationships between dam discharge and the dynamics of periphyton, aquatic macrophytes, benthic macroinvertebrates, and drift in the Lee's Ferry tailwater are well documented (Shannon et al. 1996; Ayers et al. 1998; McKinney et al. 1999a, 1999b, 1999c). Spike flows of short duration have reduced density and distribution of macrophytes and reduced chlorophyll *a* concentrations in periphyton (McKinney et al. 1999a). Earlier studies showed that steady flow rates reduced organic drift (Shannon et al. 1996).

We examined short-term effects of 878-m^3s^{-1} (31,000-cfs) spike flows and sustained low seasonal steady flows of 227 m^3s^{-1} (8,000-cfs) on the benthic community and drift in the Lee's Ferry tailwater. Specifically, we tested the following hypotheses:

878-m^{3}s^{-1} (31,000-cfs) spike flow treatment

H_{o1}: Mean mass of periphyton will not differ between April (prior to the 878-m^{3}s^{-1} [31,000-cfs] spike) and June (following the 878-m^{3}s^{-1} [31,000-cfs] spike).

H_{o2}: Mean chlorophyll *a* content in periphyton prior to April will not differ from that in June after the spike flow.

H_{o3}: Abundance and distribution of submerged macrophytes will not differ prior to and after the spike flow.

H_{o4}: Mean benthic densities of *Gammarus lacustris*, Chironomidae, and Gastropoda will not differ prior to and after the spike flow.

LSSF treatment

H_{o5}: Mean drift density will not vary during the LSSF treatment.

H_{o6}: Mean mass of periphyton will not vary during the LSSF treatment.

H_{o7}: Abundance and distribution of submerged macrophytes will not vary during the LSSF treatment.

H_{o8}: Mean benthic densities of *Gammarus lacustris*, Chironomidae, and Gastropoda will not vary during the LSSF treatment.

METHODS

Study area

Glen Canyon Dam impounds the Colorado River near the Utah-Arizona border and forms Lake Powell, a 653-km^2 warm, meromictic reservoir. Hypolimnial releases from the reservoir are perennially clear and cold (7^0-11^0C) (Stanford and Ward 1991). Lee's Ferry tailwater extends between the dam (15. 5 miles upriver of Lee's Ferry [-15.5 mi]) and Lee's Ferry (0 mi) and has no major tributaries.

The experimental hydrograph was designed to resemble a natural hydrograph, targeting species-specific life history stages of fish. High, steady releases during April and May 2000 (simulating historical peak runoff) were implemented to pond tributary inflows and provide thermal refugia for young fish throughout Glen and Grand Canyons. The spring 878-m^3s^{-1} (31,000-cfs) spike flow in 2000 was designed primarily to disadvantage small-bodied, non-native fish. Steady releases from June 6, through September 4, 2000 were designed to enhance growth and survival of young native fish by providing warm, low-velocity, near-shore areas. A second 878-m^3s^{-1} spike flow was done in September 2000 again to displace non-native fish that may have benefited from these enhancements. Following September 30, peak-power generation releases from GCD resumed.

The 2000 experimental flows (releases from the dam) schedule was:

1) 227 m^3s^{-1} (8,000 cfs) steady discharge—March 25 to April 6

2) upramp to 495 m^3s^{-1} (17,500 cfs)—April 6 – 8

3) 495 m^3s^{-1} (17,500 cfs) steady discharge—April 8 to May 2

4) upramp to 863 m^3s^{-1} (30,500 cfs)—May 3

5) 863 m^3s^{-1} (30,500 cfs) steady discharge—May 4 –7

6) downramp to 495 m^3s^{-1} (17,500 cfs)—May 8-9

7) 495 m^3s^{-1} (17,500 cfs) steady discharge—May 10 –26

8) downramp to 382 m^3s^{-1} (13,500 cfs)—May 27

9) 382 m^3s^{-1} (13,500 cfs) steady discharge—May 28-31

10) downramp to 227 m^3s^{-1} (8,000 cfs)—June 1

11) 227 m^3s^{-1} (8,000 cfs) steady discharge—June 2 to September 4

12) upramp to 878 m^3s^{-1} (31,000 cfs)— September 5

13) 878 m^3s^{-1} (31,000 cfs) steady discharge—September 6-8

14) downramp to 227 m^3s^{-1} (8,000 cfs)—September 9

15) 227 m^3s^{-1} (8,000 cfs) steady discharge—September 10-30

16) return October 1 to regulated discharge under the interim flow regime (U.S. Department of Interior 1995); flows generally were in the range of about 198 m^3s^{-1} (7,000 cfs) to 481 m^3s^{-1} (17,000 cfs) during the period following the experiment (Bureau of Reclamation, unpublished data)

Sampling Protocols

Periphyton and Aquatic Macrophytes

We collected periphyton samples from cobble substrates during periods of 227-m^3s^{-1} (8,000-cfs) steady flows throughout the experiment (April 2-3, June 1, July 18, August 21 and September 11). We randomly collected cobbles (10-25 cm diameter) at

river miles -14.0, -12.8, and –8.0 along transects parallel to river flow at the 170 m^3s^{-1} (permanently inundated) flow level. We scraped three areas of periphyton, within a 4.15-cm^2 template, from the upper surface of each cobble (Angradi and Kubly 1993). We determined pheophytin-corrected chlorophyll *a* content of periphyton (n= 5 / transect) spectrophotometrically (Tett et al. 1975) and biomass (grams ash free dry mass /m^2 [AFDM]; n = 5 / transect) by loss on ignition (550^{0}C, 2hrs).

We collected submerged macrophytes concurrently with periphyton samples from depositional substrate in the permanently inundated zone (n = 5 / transect from transects at river miles -14.0, -6.3, -3.5) using a Hess sampler (0.87-m^2, 0.25-mm mesh) at randomly located points along each transect parallel to river flow (170 m^3s^{-1} flow level). All macrophytes within the Hess sampler were collected. Loss on ignition (550^{0}C, 2 hrs) was used to determine AFDM of macrophytes.

We also surveyed submerged macrophytes along both shorelines between Lee's Ferry and GCD (river mile 0 to -15) on March 4, May 6 and August 20. Distribution and relative abundance were estimated visually and ranked ordinally (McKinney et al. 1999a): 1 = low vertical growth, patchy and sparse distribution; 2 = moderate vertical growth, moderate and occasionally patchy distribution; and 3 = higher vertical growth, extensive, generally continuous distribution.

Benthic Macroinvertebrates

We collected benthic macroinvertebrate samples (Hess sampler, 0.87-m^2, 0.25-mm mesh) during periods of 227-m^3s^{-1} (8000-cfs) steady flows throughout the experiment. We collected samples (n = 5 / transect) randomly during periphyton and

macrophyte sampling periods at all periphyton and macrophyte transect locations. We preserved samples in 10% formalin. We enumerated macroinvertebrates in the laboratory after placing samples in a sieve (0.25-mm mesh) and rinsing lightly with water.

Drift

We collected drift at river mile - 0.7 throughout the experiment. Samples (n = 3) were collected April 4, April 29, May 10, June 2, July 17, August 21, and September 11. We sampled drift using a metered (flow meter attached centrally and 20 cm inside of net mouth) net (0.5-m diameter, 1-mm mesh) while traversing a transect perpendicular to direction of river flow at minimal boat speed (McKinney et al. 1999a). We depth-integrated samples by slowly raising and lowering the weighted net (6.8-kg weight on a 1-m drop chain attached to a towline 0.6 m in front of the net). Sampling duration was generally 15 min with a mean volume of 75.27 m^3 (± 2.10 *SE*). We sorted samples into groups consisting of filamentous algae, bryophytes, *Potamogeton* spp., *Chara* spp., *Egeria densa, Gammarus lacustris,* and Chironomidae. We determined AFDM of drift by loss on ignition (550^0C, 2 hrs).

Data Analysis

Analysis of variance (ANOVA) was performed on all data sets except for the descriptive macrophyte survey and macroinvertebrate (*Gammarus* and Chironomidae) drift densities. A two-way ANOVA was performed on benthic macroinvertebrates in cobble and depositional zones to test for interaction between substrates and sample periods. Post-hoc analyses (Tukey HSD test) were used to explore patterns of differences between sample periods. We transformed all data sets to approximate normality (sqrt [x+1] for benthic macroinvertebrates, macrophytes, and drift; log [x+1] for periphyton,

AFDM, and chlorophyll *a*). Macroinvertebrate drift data were dominated by zeroes and were not statistically analyzed.

RESULTS

Periphyton and Aquatic Macrophytes

The periphyton AFDM concentrations did not differ significantly throughout the experiment (April - September) ($P > 0.10$) but tended to be higher in July - August (Figure 1). Chlorophyll *a* peaked in June, then decreased through September ($P < 0.01$; Figure 3).

The AFDM concentrations of macrophytes increased from April to July ($P < 0.05$) and peaked in July (Figure 1). Macrophytes were abundant and distributed throughout the river prior to spike flow in early April. Distribution and relative abundance were higher in June and September than in April (Table 1).

Benthic Macroinvertebrates

There was no significant interaction between substrate (cobble and depositional) and sample period for any of the measured macroinvertebrates ($P > 0.35$). All macroinverebrate analyses are for both substrates combined. Densities of *Gammarus,* Chironomidae, and Gastropoda did not decrease between samples taken in April (prior to spike flow) and June (after spike flow; Figure 4). *Gammarus* densities increased throughout the sample period and were significantly higher in September than in previous months ($P < 0.05$; Figure 4). Chironomidae densities peaked in July and were significantly higher in July than in April ($P < 0.05$) and in September ($P < 0.025$).

Gastropoda densities increased between April and June (P= 0.05), were lower in July and tended to increase through September (Figure 4).

Drift

Total AFDM of drift decreased after the spike flow in early May 2000 ($P < 0.02$), remained low until June, peaked in July, then decreased in August and September (Figure 6). Drift was generally dominated by filamentous algae, which determined the trends in total AFDM of drift (Figure 7). Macrophyte drift densities changed little or none over the sample period. *Gammarus* were absent from drift samples except those taken in late April and mid-May. Chironomidae were present only in drift samples taken in mid-May and in August, and densities were much lower in the August sample (Figure 7).

DISCUSSION

McKinney et al. (1999a) reported that a controlled flood of brief duration and moderate magnitude (1,278 m^3s^{-1} [45,000 cfs]) in March 1996 influenced phytobenthic dynamics in the Lee's Ferry tailwater by producing short-term reduction in macrophyte densities and distribution and reducing chlorophyll *a* concentrations in periphyton. We observed no short-term reduction in relative macrophyte distribution or effects on macrophyte densities or periphyton chlorophyll *a* after the 878 m^3s^{-1} spike flow in early May 2000. However, we were unable to sample periphyton in the permanently inundated zone until two months after the spike flow.

It is likely that any short-term reduction in chlorophyll *a* had recovered within two months of the spike flow. An acceleration or pulse of regrowth following release of persistent individuals or new immigrants from competitive constraint is common in many post-disturbance recovery sequences in lotic algal communities (Peterson and Stevenson

1992). Shannon et al. (2001) observed recovery of phytobenthos on hard substrata on some sites within one month after the 1996 test flood.

Lack of change in macrophyte density and distribution in the present study is probably because the 2000 spike flow was of lower magnitude than the 1996 flood. Changes in the macrophye community of the Lee's Ferry tailwater between 1996 and 2000 may also have influenced its vulnerability during spike flows in 2000. The macrophyte community in 1996 was dominated by *Chara* spp. (McKinney et al. 1999a) and is presently dominated by *Potamogeton* spp. and *Egeria densa* (Benenati and Shannon 2000). *Chara* spp., a predominantly fall and winter species in the Lee's Ferry tailwater (McKinney et al. 1999a, Shannon et al. 2001), was largely senescent at the onset of the 1996 spike flow. *Potamogeton* spp. and *Egeria densa* are both predominant spring and summer species (Barrat-Segretain and Amoros 1995) and were in the early stages of development during the 2000 spike flow.

Although periphyton AFDM was similar in both seasonal trend and magnitude to that observed from 1991 to 1997, macrophyte AFDM peaked in the summer during 2000 but peaked in the fall each year from 1994 to 1997. This change in seasonal pattern is best explained by the change in species composition from one dominated by *Chara* spp. in 1994 and 1995 to that currently dominated by *Potamogeton* spp. and *Egeria densa*. Macrophyte AFDM was much higher and distribution more extensive in 2000 than in 1994-1997. It is likely that the stable flows increased the amount of suitable shoreline for macrophytes in 2000.

Yearly and seasonal means of benthic macroinvertebrate densities from 1992 to 1997 are taken from McKinney et al. (1999d) to provide comparisons (Figure 5).

Gammarus and Chironomidae showed similar seasonal trends to those observed between 1992 and 1997. However, Chironomidae densities during the LSSF were much higher than those recorded between 1992 and 1997. Gastropoda densities varied throughout the LSSF and peaked at nearly 16,000 individuals / m^2. This was more than an order of magnitude higher than the highest annual density recorded between 1992 and 1997. This was probably the result of a change in species composition to one dominated by the exotic New Zealand mud snail (*Potamopyrgus antipodarum*) (Riley, 2002[1]) and was likely influenced by increased area of stable shoreline during the 2000 steady flows.

Our results were consistent with Shannon et al. (1996) and showed that organic drift was reduced by steady flows. Although benthic densities of macroinvertebrates, periphyton, and macrophytes were not diminished by the spike flow in early May, total drift AFDM, which was dominated by filamentous algae, was significantly reduced and did not recover until mid July.

It is likely that steady flows reduce the amount of invertebrate drift in the Lee's Ferry tailwater. This section of the Colorado River is considered a blue ribbon trout stream and understanding the link between flows and the trout population within this reach is important. *Gammarus* were only present in drift samples during the upramp prior to the spike flow and the downramp following the spike in May. *Gammarus* are an important food source for rainbow trout in the Lee's Ferry tailwater (Angradi 1994), and the peak in rainbow trout condition coincided with this period of *Gammarus* presence in the drift (Speas et al. *in review*). This observation is consistent with previous studies conducted during 1991-1997, in which rainbow trout condition and food consumption

[1] Riley L., 2002. Arizona Game and Fish Department press release: New Zealand mud snail. URL http.//www.gcrg.org/snails.html

were positively correlated with drift density of *Gammarus* (McKinney et al. 1999c, McKinney and Speas 2001).

RECOMMENDATIONS

1. Design simplified flow experiments comprised of fewer hydrologic treatments. Interpretation of data from multi-faceted experiments is difficult, particularly when magnitudes of effects and interactions among components are unknown.
2. Reinstate long-term monitoring of the food base in Lee's Ferry tailwater. Density of periphyton, macrophytes, benthic macroinvertebrates, and drift are all highly variable, requiring major perturbation to determine short-term effects. Long-term data allow for more accurate assessments of trends and patterns associated with dam operations. It is possible to determine some short-term changes in the benthic community during experimental flows, but it is difficult or impossible to interpret changes without a record of conditions between experiments. The benthic community may take months or years to reach new equilibrium after an experiment, and relative importance of short-term changes may remain unrecognized in the absence of long-term monitoring.
3. Design sampling protocols to enhance long-term continuity and develop information regarding relationships between food base and the rainbow trout population in Lee's Ferry tailwater.

ACKNOWLEDGEMENTS

Grand Canyon Monitoring and Research Center funded the present study under Cooperative Agreement No. 1425-98-FC-40-22690 (Mod 3). We are grateful to numerous AGFD personnel for their assistance in collection of field data and in laboratory analysis. We would like to thank Dave Speas and Mary Anne McLeod for their valuable insights in early reviews.

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Table 1. Distribution of the macrophytes *Chara spp*. (C), *Potamogeton spp.* (P), and *Egeria densa* (E) from river mile 0 to river mile –14 in the Lee's Ferry Tailwater (each cell represents 1 river mile and each letter represents presence of macrophytes in quarter mile reach)

	Lee's Ferry						**River Miles Upstream**							Dam Bar
	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14
Apr. 00	P	P E	PP E	PP	PPPP EE	PPP EE	PP	P E	PP	P	PPP	P		P
June 00	PPPP	PPPP EE	PPPP EEE	PPP EE	PP EEEE	PPP EEE	PP EE	PPPP EE	PPPP	PPPP	PPP	PPP	PPPP	P
Sep. 00	PPPP EEE	PPP EEEE	C PPPP EEEE	P	PPPP EEE	PPPP EEEE	PP EEEE	PPPP	PPPP E	PP	C PPPP	PPPP	PP	
May 95	C						C	C						C
Oct. 95	CCCC	CCCC	CCCC	CC	CC	CCCC	CC	CCCC	C	CC	CCCC		CCC	CCCC
July 96	PPPP E	C PP	PPP	PP	P EE	PP	PP	PP	P	PP	PP	C		
Oct. 96	PPPP	PPPP	PP E	CC PP EE	PPP EEE	CCC PPP EEEE	CCCC PP		C PP E	C	PP		PPP	CCCC P

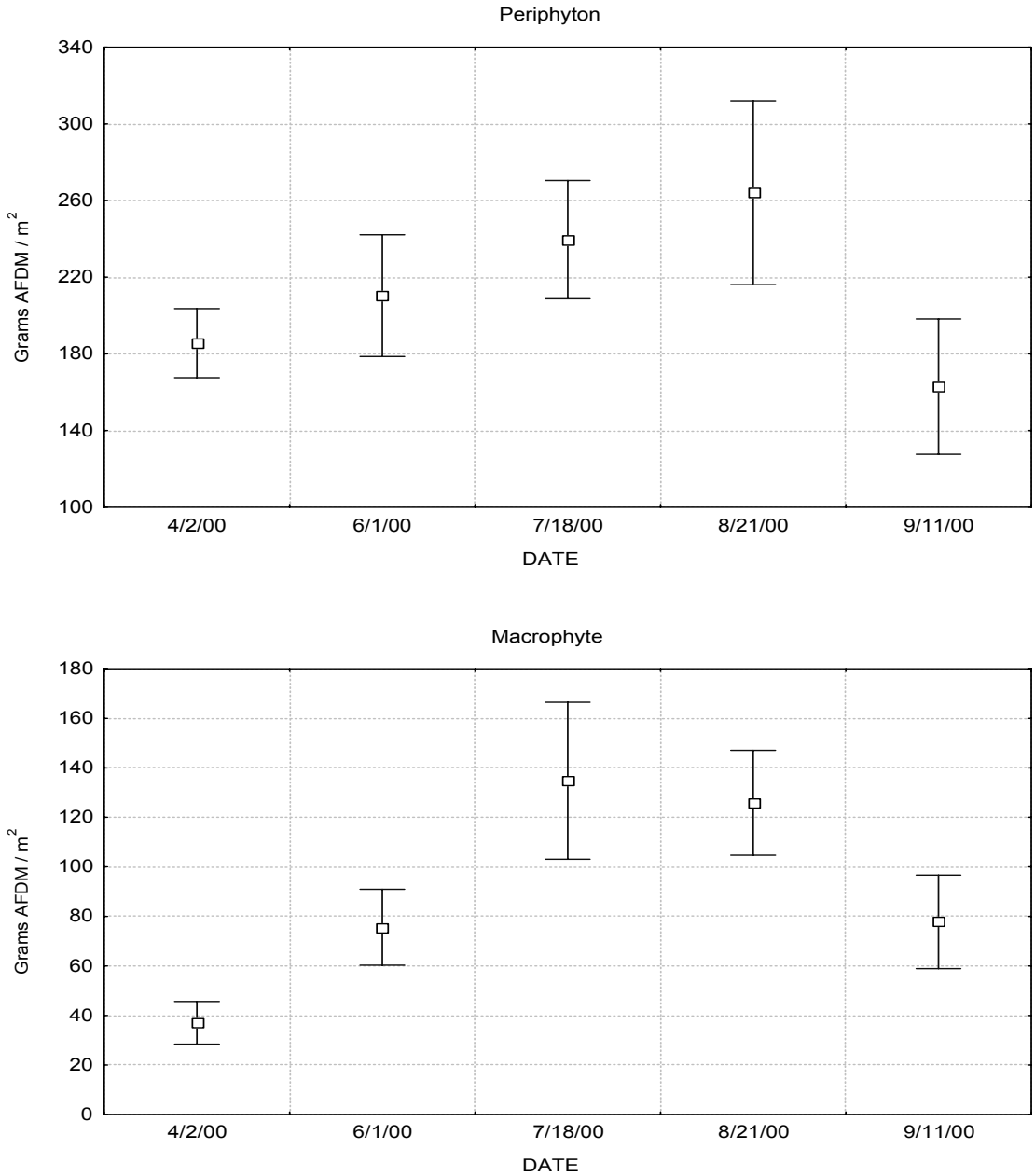


Figure 1. Mean (± SE) grams AFDM / m^2 for periphyton and macrophytes collected from the 170 m^3s^{-1} flow elevation (April – September 2000).

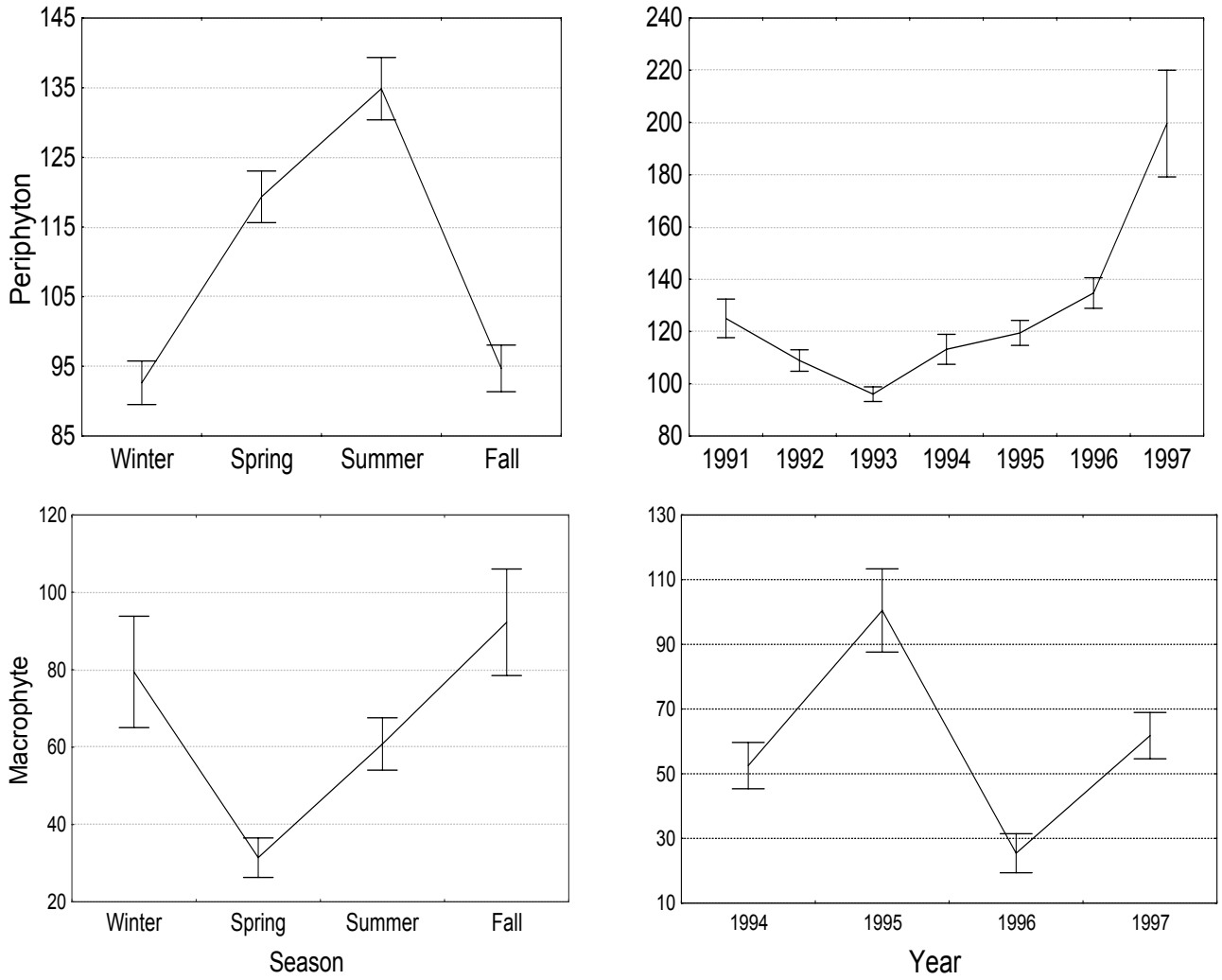


Figure 2. Seasonal and yearly mean (± SE) grams AFDM / m^2 for periphyton (1991 – 1997) and macrophytes (1994 – 1997) collected from the permanently inundated zone in the Lee's Ferry tailwater (McKinney et al., 1999d)

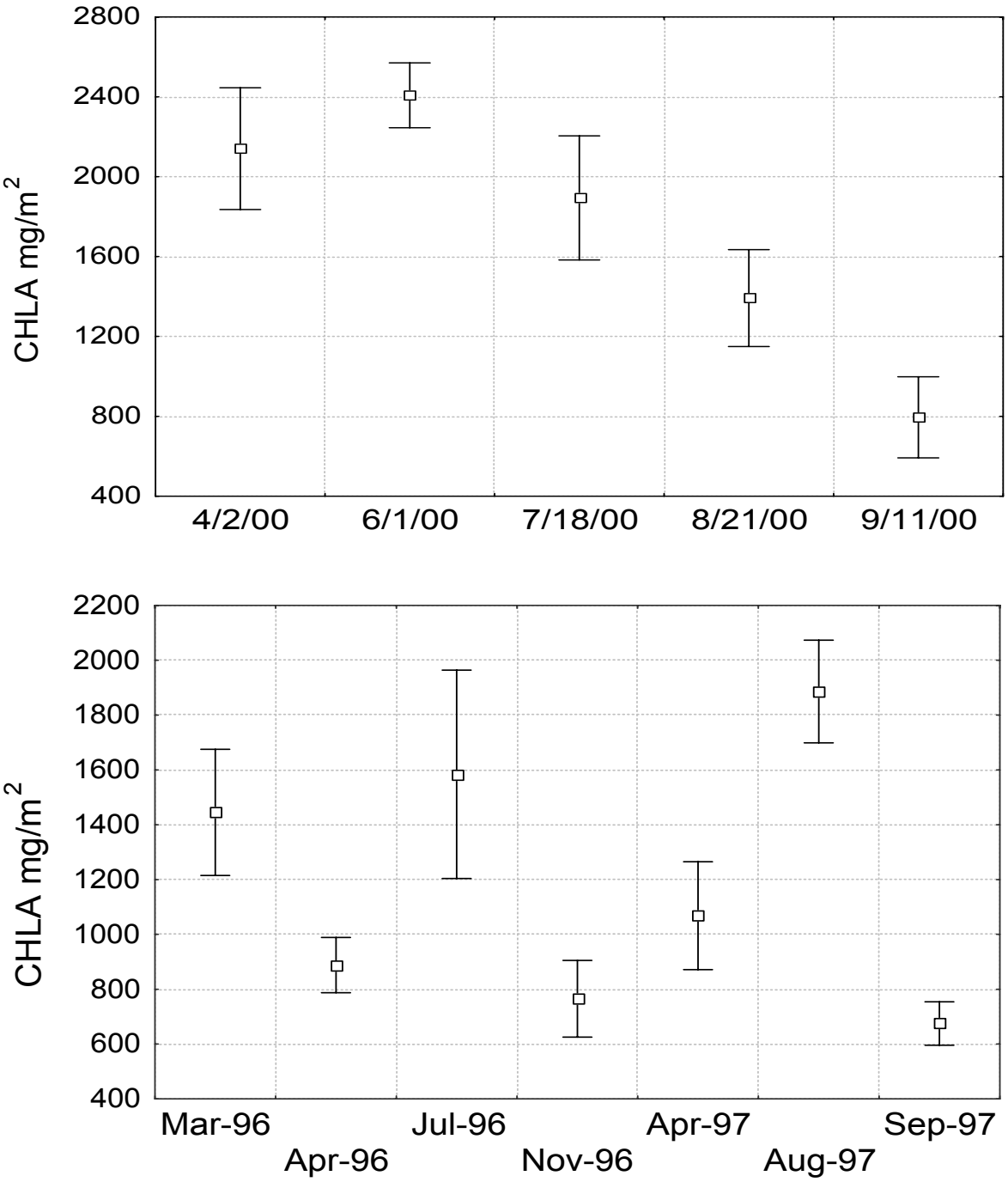


Figure 3. Mean (± SE) chlorophyll *a* mg/m^2 for periphyton collected from the 170 m^{3}s^{-1} flow elevation (April – September 2000) and in the permanently inundated zone (March 1996 – September 1997)

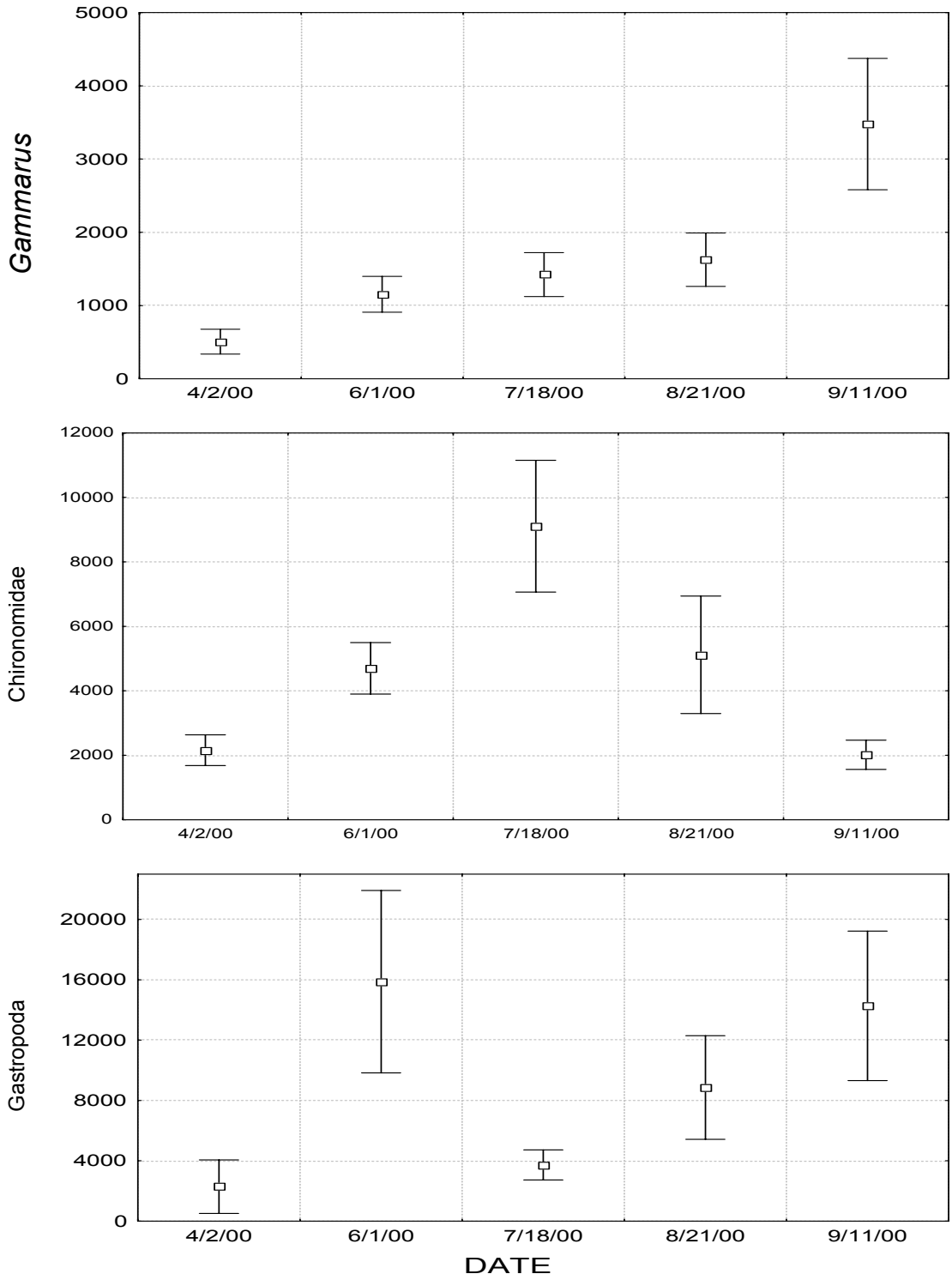
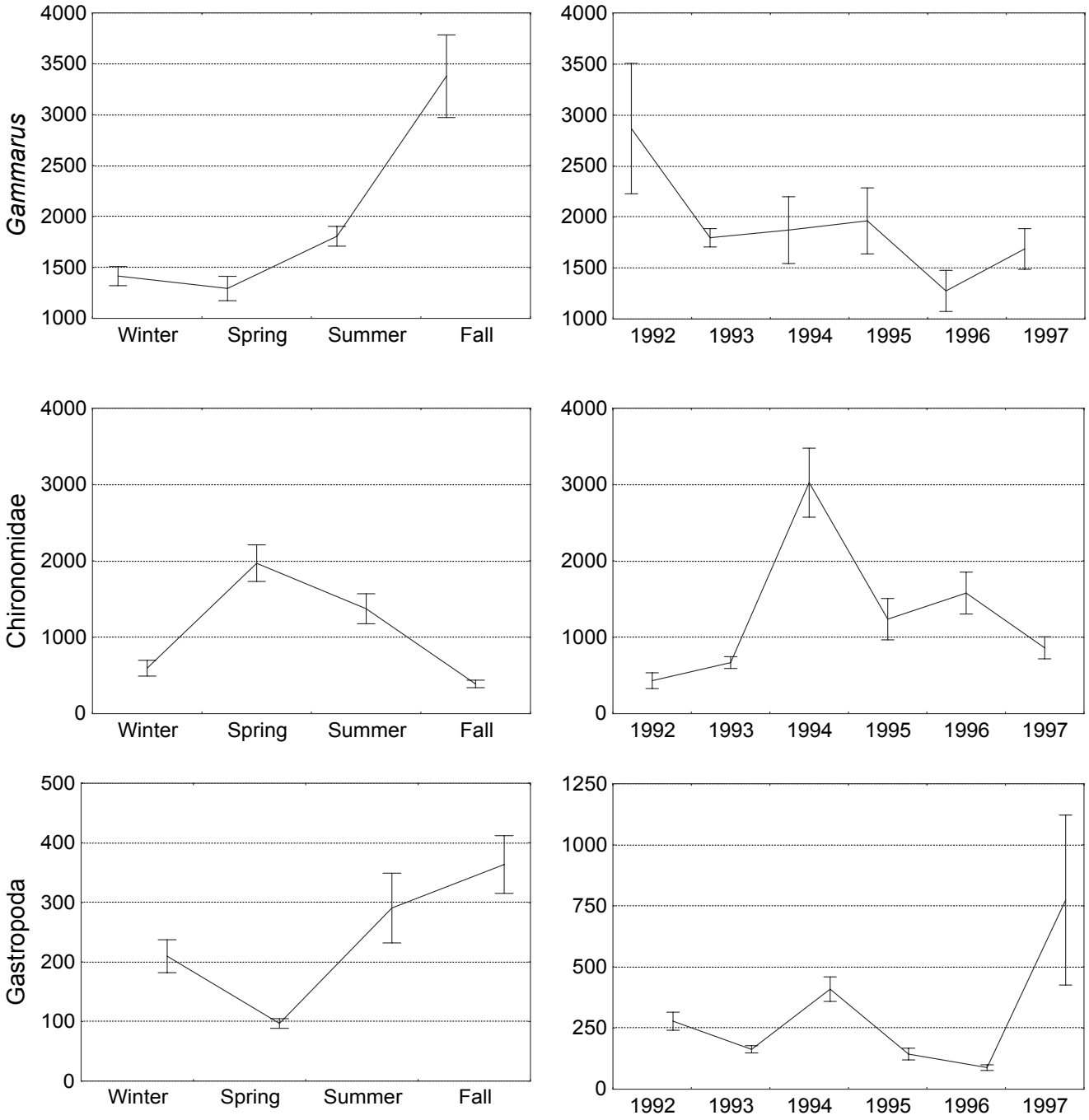


Figure 4. Mean (± SE) densities (number / m^2) *Gammarus*, Chironomidae, and Gastropoda collected from the 185 m^{3}s^{-1} flow elevation in the Lee's Ferry tailwater (cobble and depositional zones combined for each taxa) (April – September 2000).



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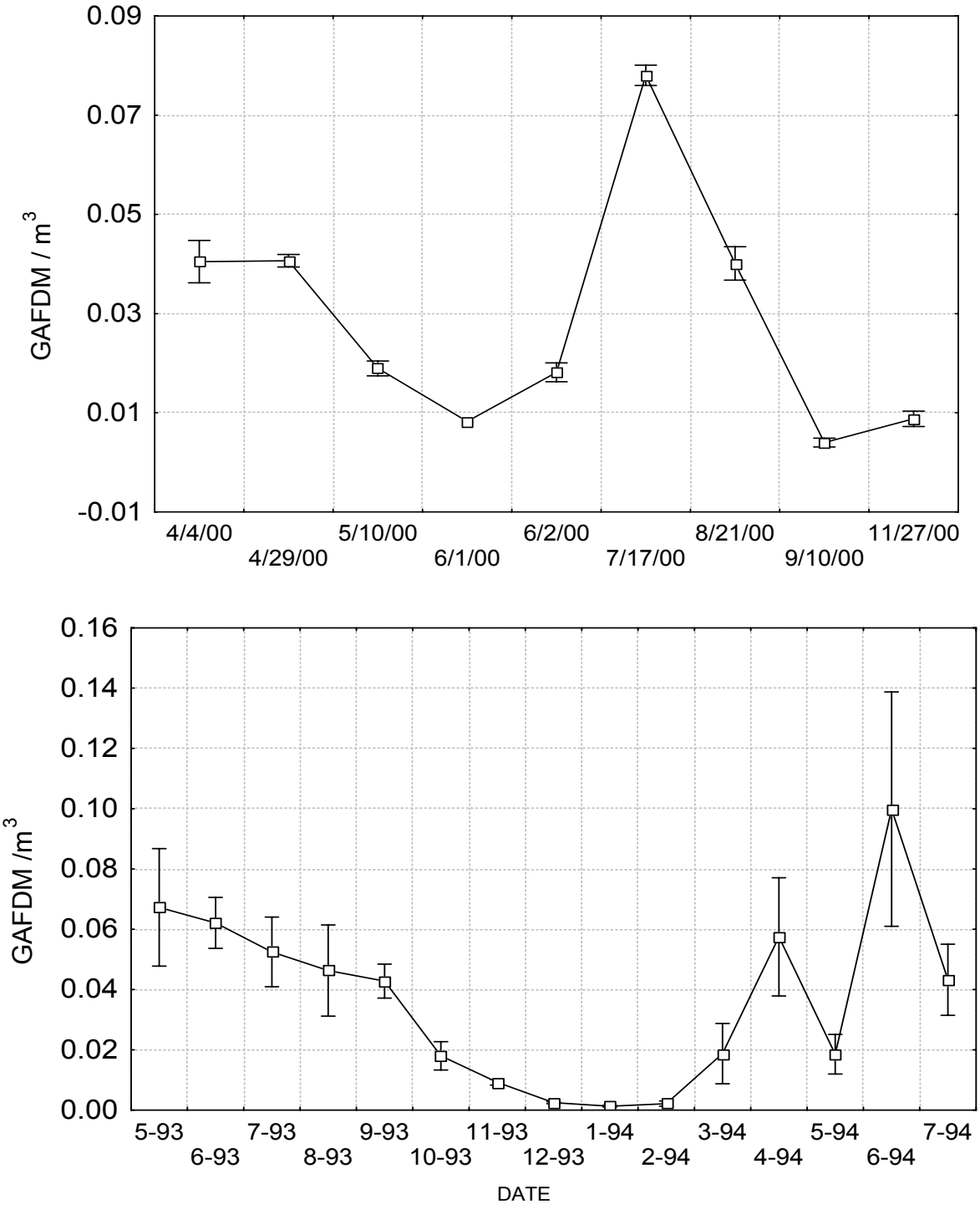

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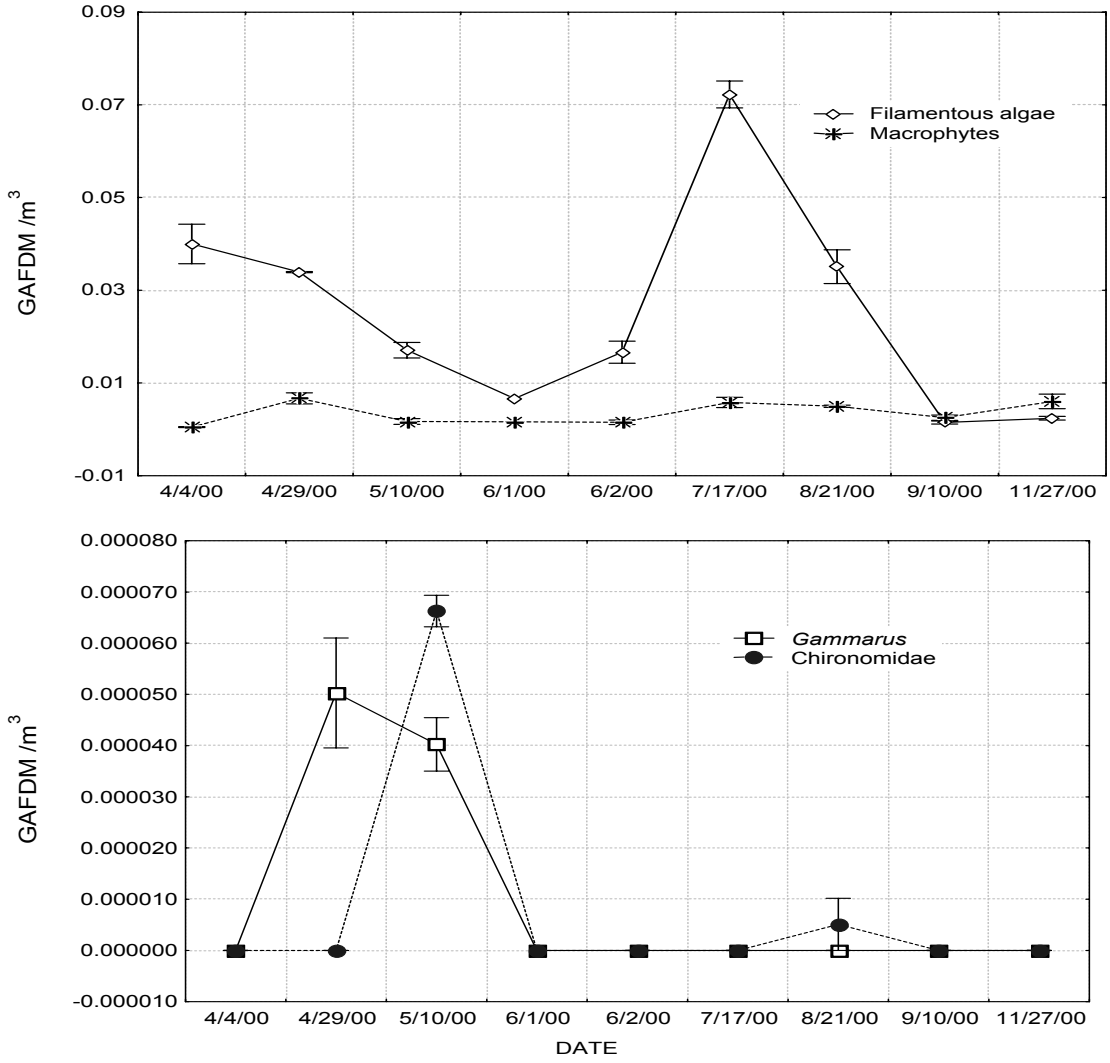

Figure 7. Mean (± SE) grams AFDM / m^3 for filamentous algae, Macrophytes, *Gammarus*, and Chironomidae collected in the drift from April through September 2000.