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Crustaceous Zooplankton Transfer between a Floodplain Wetland and the Missouri River

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ABSTRACT Floodplain interactions are a critical riverine ecosystem function, including zooplankton transfer. Floodplain alternations have had an assumed impact on zooplankton productivity. I assessed floodplain wetland and main channel densities of crustaceous zooplankton, alluding to organism transfer in the Missouri River, North Dakota. Significant *t*-test differences ($P < 0.05$) were present between backwater and channel habitat zooplankton densities in 83, 75, 83, and 50% of the sample periods for cyclopoid copepods, copepod nauplii, *Daphnia* spp., and *Bosmina* spp. respectively, suggesting the presence of uncoupled zooplankton dynamics during portions of each annual cycle. Two relationships with increased flows were found, including a biologically significant decrease ($P = 0.09$) of backwater copepod nauplii numbers and a significant increase ($P = 0.02$) in the channel density of *Daphnia* spp. During the highest flow periods, fewer significant differences in zooplankton densities were present between the backwater and channel habitats, indicating moderate homogenization.

KEY WORDS backwater, copepod, river channel, zooplankton

Research has repeatedly demonstrated that periodic exchange of organic material between floodplain wetlands and the main river channel is a critical ecosystem function (e.g., Fraser 1972, Copp 1989, and Heiler et al. 2001). During periods of connection, floodplain wetlands contribute a substantial portion of their biotic production, including both flora and fauna, to the main river channel (Bouvet et al. 1985, Amoros 1991). Eckblad et al. (1984) and Cellot and Bournard (1987) noted that moderate flushing of backwaters increased invertebrate densities in the drift below backwater connections by as much as 4,000%; however, invertebrate contributions were variable and depended on the intensity and frequency of flushing events. Fisher (1999) found that the energy resources from primary production in off-channel habitats were significant for the floodplain ecosystem of the upper Missouri River.

Historically, the Missouri River had a diversity of habitat types, including backwaters, or floodplain wetlands, with low or no flow (Hesse and Mestl 1993). Hydrograph alterations have disrupted the connectivity between much of the Missouri River and its floodplain leading to the degradation of biotic exchange processes. Hesse et al. (1989) determined that greater than 100,000 ha of permanent aquatic habitats and more than 150,000 ha of wetlands and riparian areas have been lost in the lower Missouri River basin due to channelization, agriculture, and human encroachment; however, some remnant habitats still remain. Portions of the upper Missouri River maintain their natural function because of discharge from the unregulated Yellowstone River. This results in substantial backwater areas that are utilized by numerous fishes, including rare, commercial, and sport fish species (Fisher 1999). Biologists often have discussed the potential that natural flood pulses contribute to the continued existence of abundant and stable invertebrate populations that subsequently support various rare and endangered lotic fish species (e.g., Reigh and Elsen 1979, Grady and Milligan 1998); however, direct relationships are not well understood.

Zooplankton production and transfer between floodplain wetlands and the Missouri River channel have been sparsely documented and because of decades of hydrologic alterations, baseline data are difficult to obtain. The continued functioning of the Missouri River below the Yellowstone River confluence, including backwater habitats, presented a rare observational opportunity. My objective was to compare the seasonal density of several crustaceous zooplankton community components between the Missouri River channel and an adjacent floodplain wetland. I hypothesized that during periods of isolation from the channel, backwaters would behave like lentic habitats and facilitate greater production of large zooplankton, such as *Daphnia* spp. and copepods. Additionally, I hypothesized that large zooplankton would decline in backwater habitats and increase in channel habitats during periods of increased flow as a result of flushing actions.

STUDY AREA

My study was conducted in the Missouri River below the Yellowstone River confluence at river km 2,538 in northwestern North Dakota during 4 hydrologic periods in 1997, 1998, and 1999 (Figs. 1 and 2). Erickson Island Slough (EIS), located approximately 5 km downstream from the Yellowstone River confluence, was selected as a backwater study site (Fig. 1). I defined a backwater as an off-channel habitat that contained water with limited or no flow when uncoupled from the river, but was connected during all or a portion of the annual hydrographic cycle. The EIS has a relatively stable surface area of approximately

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1,100 ha, but can increase by more than 2,000% or drop to less than 40% of normal depending upon the prevailing hydrologic conditions.

METHODS

To better understand the production and community dynamics of crustaceous zooplankton in the EIS and Missouri River channel during the annual hydrograph cycle, I selected 4 sample periods representing differential flow regimes and temporal intervals (Fig. 2). Between 1 April and 1 May 1997–1999, I completed sampling during period 1 (pre-connection period) after ice-out and during slightly rising water conditions due to local snowmelt. Similarly, I completed sampling during sample period 2 (connection period) from 10 May to 10 June 1997–1999); sampling period 2 encompassed the ascending limb of the primary flood-pulse caused by mountain snow melt. Sampling during period 3 (disconnection period) was to be completed during the descending water levels after peak flows had occurred and between 25 June and 15 July 1997–1999 when floodplain habitats were starting to uncouple from the river. I sampled period 4 (post-connection period) between 25 August and 15 September 1997–1999 during relatively static water conditions. Although the sample periods can be easily defined by hydrology, identifying the actual periods was difficult and targeted sample times varied among years (Fig. 2).

During the 3 years of this study, 3 substantially different hydrographs occurred. Further investigation indicated that more than 70% of the flow was a result of Yellowstone River discharge; however, the Missouri River flow regulated by releases from Fort Peck Dam (Fig. 1) also needed to be considered. Therefore, for the purpose of this study, I combined the daily mean flow rates for the Yellowstone River and Missouri River (USGS 1999) and used the cumulative hydrograph (cumulative flow index) during subsequent discussions. One caution about the cumulative hydrograph is that it is an index, as flow rates are a function of channel morphology, velocity, and groundwater inputs (Allan 1995); therefore, the flow rates of the Missouri and Yellowstone rivers are not truly cumulative.

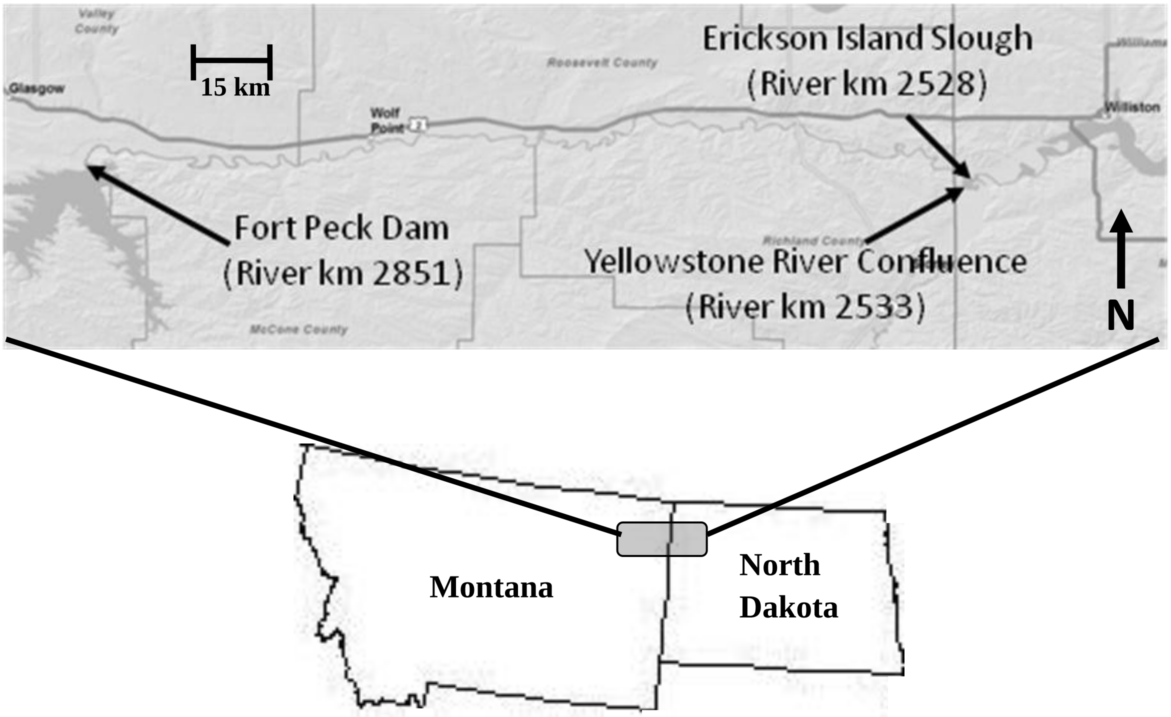

Figure 1. Location of the study area with reference to proximity of Fort Peck Reservoir. The study was completed at Erickson Island Slough and a 1 km downstream segment of the Missouri River. The Fort Peck Dam is approximately 323 river km from the study site.

I collected 8 zooplankton samples at randomly selected locations in the EIS backwater and within the study area channel reach during each period and year with a 1-m tube sampler (75-mm diameter; DeVries and Stein 1991). I collected all zooplankton samples between 1100 and 1400 hr. At each sample location, I collected, filtered through a

63-μm plankton net, and preserved in 4% sucrose-formalin solution 3, 1-m tube samples (Haney and Hall 1973). Due to relatively low densities, I enumerated all zooplankton in the samples in the laboratory. I expressed densities as number/L for the most abundant taxa groups.

For the purpose of this study, the comparison between EIS and the channel was my primary focus. Therefore, I compared each pair of data points (backwater and channel) during each collection period (N = 12) using a *t*-test (paired two sample on means). In addition, I assessed the potential correlations between flow and major zooplankton taxa densities and evaluated the relationship between flow and zooplankton densities using regression analyses (SigmaPlot 2010). Regression analyses where $r^2 > 0.4$ and $P < 0.1$ were assessed more closely. I used analysis of covariance to determine if the relationship between zooplankton densities and cumulative flows between the backwater and main channel differed for each taxonomic group. I considered results statistically significant for all tests when $P < 0.05$; however, biological significance up to $P < 0.10$ also was considered relevant (Heath 1995; SigmaPlot 2010).

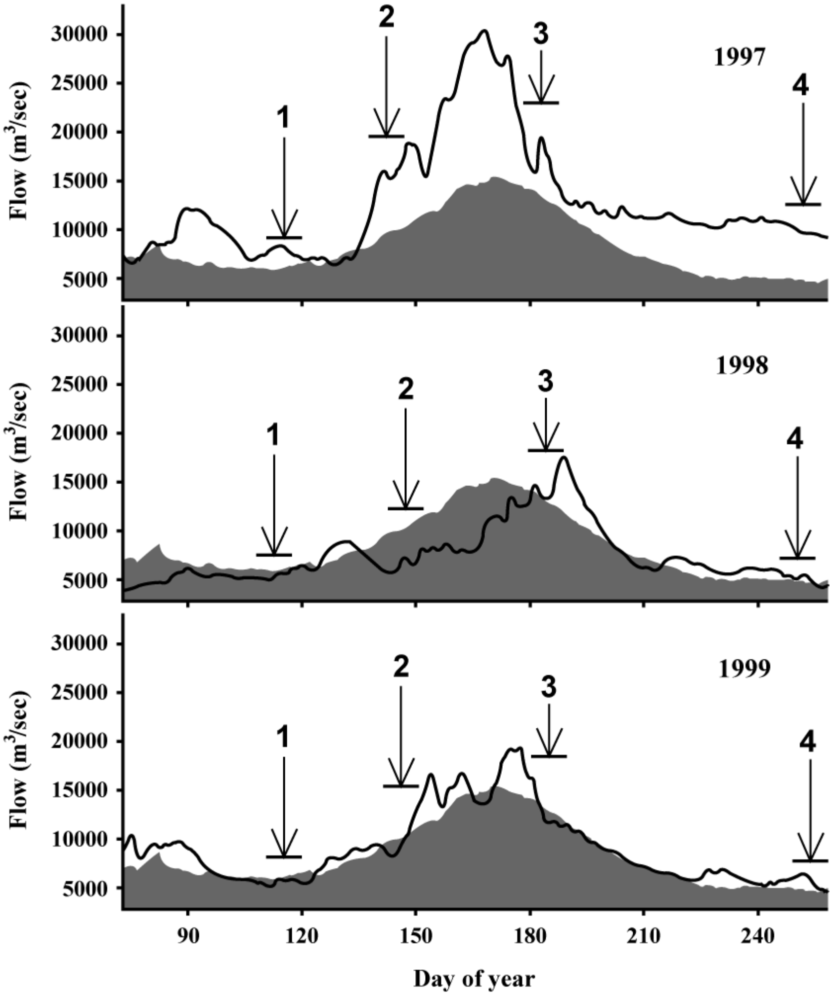

Figure 2. Cumulative flow index (m^3/sec) for the Missouri River below the Yellowstone River confluence and above the Lake Sakakawea headwaters in North Dakota from 15 March through 15 September of 1997–1999. The dates (day of year), sample periods, and years are denoted. The solid line indicates the indexed hydrograph for each year and the shaded area represents the mean 40-year indexed hydrograph (1959–1999).

RESULTS

Adult-stage cyclopoid copepods, copepod nauplii, *Daphnia* spp., and *Bosmina* spp. were the 4 numerically dominant taxa in the overall zooplankton collections (~99%). Rotifera, calanoid copepods, and other forms of cladocerans, for all samples combined, constituted approximately 1% by number and were not included in this assessment.

Cyclopoid copepod mean densities in EIS ranged from a low of 14.6/L (SE = 4.3) during period 3 of 1997 to a high of 2,280.7/L (SE = 386.6) in period 4 of 1998 (Table 1). Cyclopoid copepod densities in the main channel were generally below 5.0/L but reached a maximum mean density of 29.3/L (SE = 3.9) in period 1 of 1999. Copepod nauplii densities in EIS ranged from 23.6/L (SE = 8.5) in period 3 of 1997 to 4,765.4/L (SE = 353.5) in period 4 of 1998. Nauplii densities in the main channel ranged from nearly absent during period 4 in 1998 and 1999 to a high of 30.8/L (SE = 13.3) in period 2 of 1997. *Daphnia* spp. in EIS ranged from a low of 0.2/L (SE = 0.1) in period 2 of 1998 to a high of 431.4/L (SE = 42.7) in period 4 of 1998 (Table 1). *Daphnia* spp. densities in the main channel never exceeded 0.3/L (SE = 0.1) and were completely or nearly absent (<0.1/L) from a majority of samples. *Bosmina* spp. were found in EIS at a low density of 0.5/L (SE = 0.2) in period 1 of 1997 to a high density of 7,006.9/L (SE = 691.2) during period 4 of 1998. In the main channel, *Bosmina* spp. were nearly always present at a low level (usually less than 0.5/L), but peaked at 5.3/L (SE = 2.4) in period 3 of 1998 (Table 1). Paired *t*-test results indicated that significant differences ($P < 0.05$) were present in 10 of 12 sample periods for cyclopoid copepods and *Daphnia* spp., 9 of 12 sample periods for copepod nauplii, and 6 of 12 sample periods for *Bosmina* spp. (Table 1).

The regression assessment of zooplankton densities with cumulative flow index values indicated that when water levels were above average, such as in 1997, zooplankton densities in EIS declined; however, no significant density reduction relationships were noted for cyclopoid copepods ($P = 0.24$), *Daphnia* spp. ($P = 0.38$), or *Bosmina* spp. ($P = 0.51$). Copepod nauplii did not show a statistically significant relationship with cumulative flow, however, a biologically notable relationship was present ($P = 0.09$; Fig. 3). Main channel cyclopoid ($P = 0.47$), copepod nauplii ($P = 0.97$), and *Bosmina* spp. densities ($P = 0.12$) also did not show a significant relationship with cumulative flow. *Daphnia* spp. density did exhibit a significant positive relationship ($P = 0.02$) with increasing channel flows. The analysis of covariance did not reveal any significant differences ($P > 0.15$ in all cases) between the regression lines for each pairing.

DISCUSSION

Significant differences between main channel and EIS cyclopoid and nauplii copepod densities, along with the lack of substantial flow-density relationships, indicated that regardless of flow conditions, that EIS and the main channel were largely maintaining differential copepod densities. However, when water levels were above average, copepod densities also did not differ between the backwater and channel. It could be argued that in period 2 of 1997, for example, that the lack of significant differences in cyclopoid copepod and nauplii copepod densities suggested that the 2 habitats were in a state of copepod equilibrium and that some level of homogenization had occurred (Table 1). In 1997, the cumulative flow index was at its highest point during Period 2 and the channel was heavily connected with EIS. Therefore, it is possible that the EIS declines in copepod density were merely a dilution of available zooplankton by the increased water volume and may not have resulted in an actual transfer of copepods to the channel. In addition, timing could be critical if substantial flushing occurs at a rapid pace on the front limb of rising waters, reducing the opportunity to capture data that reflects copepod transfer into the channel. A review of the data also would suggest that transfer of copepods out of EIS was more probable in 1997 because during periods 2 and 3 of 1998 and 1999, copepod densities increased, even though water levels also increased (e.g., no dilution effect).

After the flood pulse had passed each year and the backwater habitats stabilized, zooplankton densities were significantly greater in the EIS than the main channel. This was particularly notable in 1998 when the backwater remained almost completely uncoupled from the channel for a longer period of time than was present in 1997 or 1999. Phytoplankton production in EIS was higher during this period, as was indicated by increases in chlorophyll-α, DO concentrations, and algal turbidity (Fisher 1999). During nearly all periods where the hydrology of the river was uncoupled from EIS, the density of zooplankton in the backwater habitats was statistically greater than those found in the main channel. Fisher and Willis (2000) documented similar copepod and *Bosmina* spp. densities in a perched upper Missouri River wetland, noting that at 3,200 organisms/L, floodplain wetlands exceeded other regional zooplankton density means by as much as 900%. Therefore, the backwaters likely behaved in a lentic fashion during the uncoupled periods and generated significant production potential.

Regardless of sample period, the EIS was highly productive, with zooplankton densities comparable to glacial lakes of the Dakotas (Fisher 1996). Zooplankton densities in the EIS and Missouri River channel greatly exceeded the densities reported for Lake Sakakawea (Power and Owen 1984), the Ohio River (Thorp et al. 1994), and the Missouri River segment below Garrison Dam (Mizzi 1994, Speas 1995), but were low in comparison to the zooplankton production reported by Persons (1979) for constructed floodplain ponds in the lower Missouri River basin, Iowa.

Table 1. Comparison of mean (±SE) zooplankton densities (no./L) by year from Erickson Island Slough (EIS) and the Missouri River channel (MC) in North Dakota for late April (Period 1), mid-May (Period 2), late June and early July (Period 3), and September (Period 4) of 1997–1999. Data pairs highlighted in bold were not significantly different (*t*-test *P* > 0.05).

		Period 1		Period 2		Period 3		Period 4	
Taxon	Year	EIS	MC	EIS	MC	EIS	MC	EIS	MC
Cyclopoid copepod	1997	106.0 (25.8)	5.3 (2.1)	**20.9** **(5.7)**	**13.1** **(3.3)**	14.6 (4.3)	3.8 (0.9)	306.7 (54.4)	2.2 (0.8)
	1998	**31.6** **(12.9)**	**9.8** **(2.4)**	80.6 (16.7)	3.6 (0.9)	296.2 (86.8)	0.3 (0.1)	2,280 .7 (386.6)	0.6 (0.1)
	1999	76.9 (17.9)	29.3 (3.9)	290.0 (26.6)	5.2 (1.3)	105.8 (33.0)	0.7 (0.2)	586.0 (86.6)	0.3 (0.1)
Copepod nauplii	1997	**399.2** **(65.7)**	**15.6** **(10.9)**	**48.0** **(11.1)**	**30.8** **(13.3)**	23.6 (8.5)	2.3 (0.6)	710.0 (168.5)	1.7 (1.1)
	1998	**146.0** **(56.1)**	**10.1** **(3.2)**	388.0 (121.1)	1.2 (0.3)	988.7 (233.0)	0.6 (0.3)	4,765.4 (353.5)	0.1 (0.1)
	1999	1,339.6 (5.4)	29.1 (5.4)	1,442.5 (283.6)	6.7 (1.2)	96.4 (27.4)	0.6 (0.2)	2,562.3 (283.3)	0.1 (0.1)
Daphnia spp.	1997	0.8 (0.2)	0.0 (0.0)	2.1 (0.7)	0.1 (0.1)	1.6 (0.7)	1.1 (0.5)	25.6 (11.2)	0.1 (0.1)
	1998	**0.5** **(0.2)**	**0.0** **(0.0)**	**0.2** **(0.1)**	**0.1** **(0.1)**	36.3 (12.4)	0.3 (0.1)	431.4 (42.7)	0.1 (0.1)
	1999	0.9 (0.4)	0.0 (0.0)	16.0 (3.8)	0.3 (0.1)	6.4 (2.1)	0.0 (0.0)	14.6 (3.1)	0.0 (0.0)
Bosmina spp.	1997	**0.5** **(0.2)**	**0.0** **(0.0)**	**0.6** **(0.2)**	**0.3** **(0.2)**	**4.5** **(1.0)**	**5.3** **(2.4)**	10.7 (3.2)	0.3 (0.2)
	1998	**0.7** **(0.3)**	**0.3** **(0.1)**	**1.5** **(0.6)**	**1.5** **(0.6)**	5.3 (2.4)	29.3 (8.2)	0.3 (0.2)	7,006.9 (691.2)
	1999	1.7 (0.9)	0.1 (0.1)	14.5 (1.3)	0.3 (0.2)	8.3 (4.0)	0.5 (0.1)	**0.7** **(0.5)**	**0.8** **(0.4)**

The influence of reservoir-produced zooplankton was a potential variable in this study. Fort Peck Dam on the Missouri River in northeast Montana (Fig. 1) is one of the world's largest earthen dams and Fort Peck Reservoir is the largest water body in Montana. Given the large size of the reservoir and because the dam is capable of releasing more than 30,000 cfs per day, the influence on downstream areas can be substantial. The discharge of zooplankton from Fort Peck Reservoir may have contributed to the channel zooplankton densities and composition. Hynes (1970) found that zooplankton originating in reservoirs can be found as far as 650 km downstream of the impoundment. Mohgraby (1977) and Repsys and Rogers (1982), however, noted that due to the mechanical damage caused to reservoir-released zooplankton, especially in a turbid river system, survival was poor and were depleted from the system at a high rate. Pourriot et al. (1997) also found that although reservoirs provided significant sources of zooplankton, densities dissipated rapidly downstream. Thus, it might be assumed that the Fort Peck influence would be minimal given that there is > 190 river km between Fort Peck Reservoir and the study site.

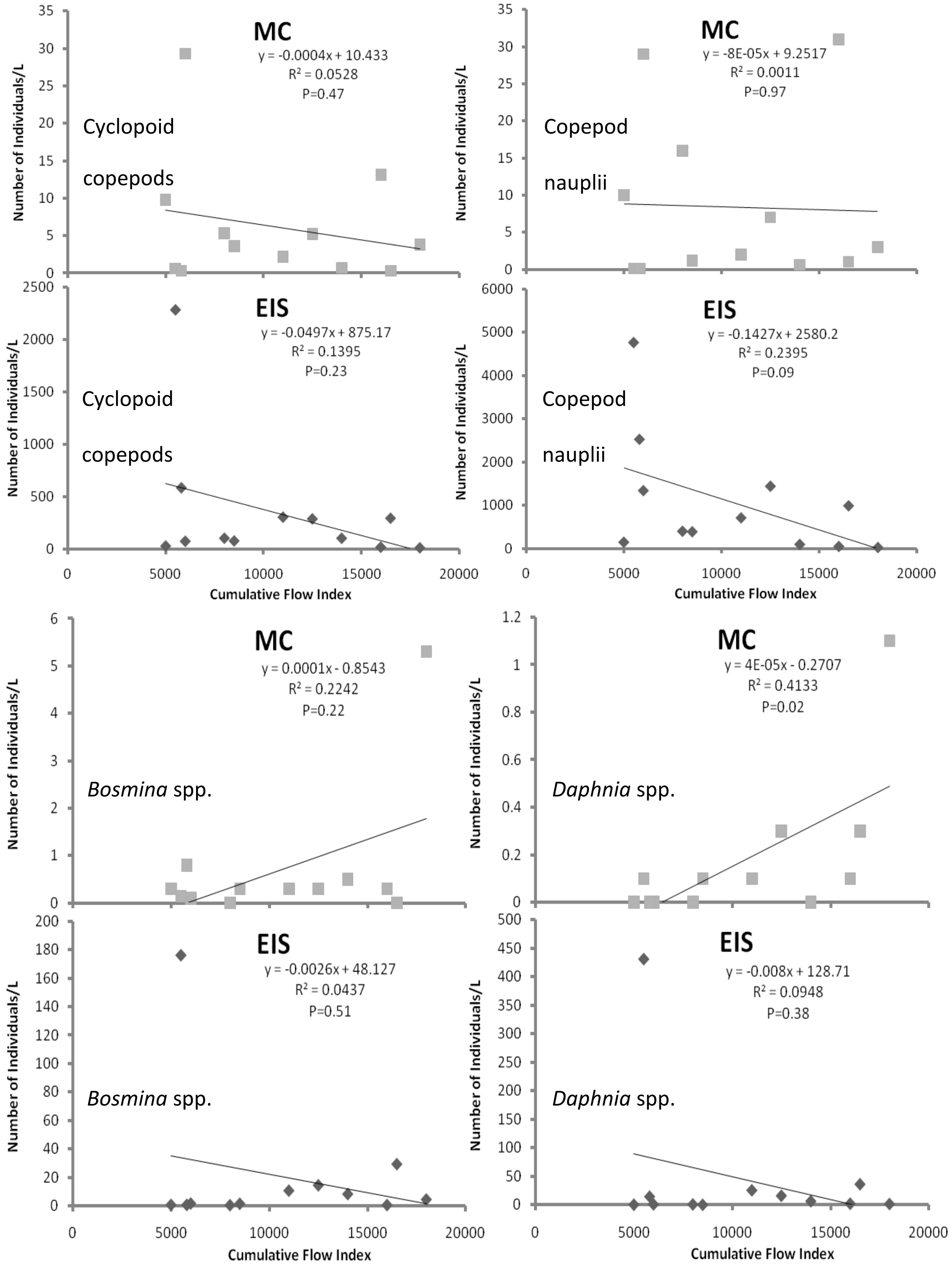

Figure 3. Relationship between four taxonomic groups of zooplankton (no./L) and cumulative flow index (m^3/sec) for the Missouri River below the Yellowstone River confluence and above the Lake Sakakawea headwaters in North Dakota for samples collected between 15 March through 15 September 1997–1999. Regression analyses results are included for both Erickson Island Slough (EIS) and the main channel (MC) areas sampled.

During period 1 of 1998 and 1999, backwater zooplankton contributions to the channel were likely limited due to nearly absent connectivity. However, during this period, significantly higher densities of copepods were detected in the Missouri River channel compared to other periods and years (Table 1). Missouri River flow records (USGS 1999) indicated that during this period of 1998 and 1999 releases from Fort Peck were higher than during other periods in an effort to lower water levels to retain mountain snow melt. In 1997, Fort Peck releases were lower during period 1 than they were in 1998 and 1999 to alleviate anticipated flood conditions downstream from the Yellowstone River confluence. These observations would support the contention that zooplankton found in the study site may have originated from Fort Peck Reservoir. Cowell (1967) found that reservoirs on the Missouri River system had significant impacts on downstream zooplankton standing stocks, thus the potential of a Fort Peck influence cannot be fully dismissed.

Although the influence of reservoir inputs from Fort Peck should be considered, substantial research would suggest that channel zooplankton in the study area were not likely reservoir generated. Speas (1995) noted that below the Garrison Dam in the Missouri River system, more than 39% of all zooplankton dissipated within the first 20 km. Likewise, Williams (1971) indicated that below Lewis and Clark Dam on the Missouri River, 51% of zooplankton had disappeared from the channel within the first 16 km. Maslikov et al. (1992) noted that a typical average zooplankton depletion rate was 3.1% per km below a dam. If we apply this depletion rate to this study, only 0.004% of the zooplankton discharged from Fort Peck reach the study area near EIS. During high Fort Peck release periods, however, these numbers could still be relatively substantial. Mohgraby (1977) and Thorp and Mantovani (2005) also noted that crustaceous zooplankton losses in turbid rivers tended to be higher due to the challenges faced by organisms poorly equipped to deal with abrasive environments. The study area stretch of the Missouri maintained NTU readings between 35 and 216 during the present study, classifying it as a highly turbid system (Fisher 1999).

Documented increases in invertebrate densities below backwater connections (e.g., Cellot and Bournard 1987, Eckblad et al. 1984) bring to question the importance of localized sources of zooplankton for riverine fish communities. Nogueria et al. (2008) recognized that in a large tropical river, zooplankton do not maintain a regular continuum, thus periodic replenishments from local sources are important. Counahan (2004) discovered in the Ohio River that naturally-reproducing populations of paddlefish (*Polyodon spathula*) were located in areas with high densities of zooplankton. In addition, Counahan (2004) found that backwater habitats had the greatest concentrations of zooplankton. Reckendorfer et al. (1999) noted that transfer of zooplankton to the main channel can occur at various levels of flushing. In 1998, two separate observations of at least five adult paddlefish were observed holding in the EIS outlet channel that was <5 m wide. Given the open mouths of these paddlefish, they appeared to be feeding on items being flushed from the backwater. In addition, flathead chubs (*Platygobio gracilis*) in the main river channel were found to be feeding on organisms produced in the EIS backwater habitat (Fisher et al. 2002). Reckendorfer et al. (1999) and Baranyi et al. (2002) also found that zooplankton numbers were significantly correlated with the availability of adjacent storage zones and water retention.

MANAGEMENT IMPLICATIONS

The data and observations presented here highlight the importance of zooplankton in the upper Missouri River system; however, the mechanisms in which zooplankton from the floodplain interact with the river remain somewhat elusive. Given the mixed case presented regarding Fort Peck zooplankton reaching the study site, the importance of floodplain invertebrate production in the study area as a repeating function of the landscape may be critical for the creation of continuous habitat and ecological function.

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