EFFECTS OF HYDROLOGIC PULSING AND VEGETATION ON INVERTEBRATE COMMUNITIES IN WETLANDS

A Thesis

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By

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ABSTRACT

Forty 1-m^2 wetland mesocosms at the Olentangy River Wetland Research Park at The Ohio State University were used to investigate the impact of wetland plant communities and hydrologic regimes on benthic populations. Twenty mesocosms were planted in May 2007 with a monoculture of *Typha* spp. and twenty with a more diverse plant community of *Schoenoplectus tabernaemontani*, *Juncus effusus*, and *Sparganium eurycarpum.* Four hydrologic regimes were also established: steady state, pulsing, deep spring/shallow fall, and shallow spring/deep summer. Macroinvertebrates were collected in August 2008 using Hester-Dendy samplers and activity traps, and from vegetation surfaces. Statistically significant differences were found between taxon diversity indices by hydrology. Highest diversity was found in mesocosms with deep water in spring and shallow water in fall. Mixed vegetation mesocosms did not have higher diversity indices for macroinvertebrates than did *Typha* mesocosms. Statistically significant relationships between individual taxa and vegetation were found.

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Ecological Engineering
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CHAPTER 1

INTRODUCTION

Once dismissed as wastelands in the U.S., wetlands are increasingly recognized as complex ecosystems, which make significant, irreplaceable contributions to the global ecosystem and to human society. Even so, over 50% of the wetlands in the contiguous U.S. have likely been lost over the past 200+ years, and many of the remaining wetlands are significantly affected by human activities (Dahl, 1990, 2000, 2006). Increasing numbers of wetlands are created to mitigate for wetlands that are being destroyed (Spieles, 2005). More and more wetlands can be considered to be humanly managed by virtue of their design and/or manipulation. The influx of invasive plants raises a variety of issues regarding the causes, consequences and implications of this influx (Zedler and Kercher, 2004; Kosteke et al. 2005). Wetland hydrologies have long been controlled to support the hunting of waterfowl and other human activities (Fredrickson and Taylor, 1982; Galat et al., 1998). The impact of these activities on wetland ecosystems remains a matter of ongoing investigation and concern.

Macroinvertebrates are a key component of wetland ecosystems. They both contribute to nutrient processing systems and are important food for a variety of organisms—notably fish and waterfowl (Swanson and Meyer, 1973).

The role of plant communities and wetland hydrology in shaping macroinvertebrate populations has significant implications for wetland management. This study builds on the body of data collected thus far on the relationships between macroinvertebrate populations and the macrophyte communities and hydrology of wetlands.

Previous research has indicated that macroinvertebrate populations are affected by vegetation and hydrology (Smock and Stoneburner, 1980; Gilinksy, 1984; Murkin and Kadlec, 1986; Neckles et al., 1990; Stagliano et al., 1998; Batzer et al., 2004; Bedford and Powell, 2005; Kostecke et al., 2005; MacKenzie, 2005; Wrubleski, 2005; Liston, 2006). The relationships may be indirect, as when macrophytes provide protection from fish predation (Gilinsky, 1984) or in cases when spring flooding makes macroinvertebrates inaccessible to migrating ducks (Murkin and Kadlec, 1986). Direct effects of hydrology are evident in the case of seasonal ponds (Brooks, 2000; Batzer et al., 2004), where short-lived ponds had lower biodiversity than ponds with longer hydroperiods. Other studies demonstrate differences between insect populations, reflecting different vegetation patterns (Stagliano et al., 1998; Wrubleski, 2005).

Kostecke et al. (2005) examined macroinvertebrates in the context of a wetland dominated by *Typha* spp. Their study indicated that macroinvertebrates were found at far lower densities in *Typha* spp. dominated wetland as compared with densities from previous years, when *Typha* spp. was not the predominant macrophyte. Similarly, Kulesza et al. (2008) found there to be a higher density of

macroinvertebrates in *Phragmites australis* stands as compared that measured in stands of *Typha angustifolia.* They attributed the difference to reduced periphyton densities on *Typha* stems as compared to those on *Phragmites* stems, possibly the result of phytotoxic leachates produced by *Typha*. Other studies note the positive effects of saltgrass (*Distichlis spicata* (L.) Greene) cover on macroinvertebrate diversity (De Szalay and Resh, 2000), and the positive correlation between macrophyte diversity for macroinvertebrate diversity (Zimmer et al., 2000; Balcombe et al., 2005). In a 1996 review of the literature, Batzer and Wissinger (1996) maintain that the relationship between macrophytes and macroinvertebrates is complex.

Studies on hydrology and macroinvertebrates present a similarly diverse collection of results as those discussed above regarding macrophytes. Batzer and Wissinger (1996) note that the stability of water levels in a wetland impacts both macroinvertebrate population composition and productivity. Shifts in length of flooding periods shape community composition, while excessively short flooding periods and long droughts reducing productivity. Riley and Bookhout (1990) note that lower water levels in the spring in wetlands increases the concentrations of some macroinvertebrates in the spring, only to note later declines in these populations later in the summer. De Szalay et al. (2003) compared macroinvertebrate populations in California wetlands drawn down in the spring, those flooded in the spring, and those perennially flooded, finding the highest macroinvertebrate populations in the wetlands flooded in the spring.

Robinson et al. (2003) found that flooding affected macroinvertebrates in streams, reducing density immediately after floods and shifting population composition. However, they noted that these changes occurred over a period of years, rather than a period of months. Caiazza et al. (2005) identified changes in macrophyte communities as a result of pulsing but were not able to demonstrate changes in macroinvertebrate communities.

1.1 Goals and objectives

This study focuses on a comparison of macroinvertebrate communities between a *Typha* monoculture and a more diverse macrophyte assemblage. consisting of *Schoenoplectus tabernaemontani* (C. C. Gmel.) Palla, *Juncus effusus* (L.), and *Sparganium eurycarpum* (Engelm). The influences of steady state, pulsing and seasonally varied hydrological regimes on macroinvertebrates are also compared, using a 2x4 full factorial design. The goal is to determine whether or not these differences in vegetation and hydrology significantly affect macroinvertebrate communities in wetlands.

Specific objectives of the study include:

1. Develop a controlled wetland system that allows for the comparison of four different hydrologic regimes and two different vegetation assemblages. Mesocosms at the Olentangy River Wetland Research Park have been used effectively for multiple studies (Mitsch et al., 2009) and were used to provide a controlled environment for this study.

2. Compare the impacts of these eight (2 vegetation compositions x4 hydrologies) wetland configurations on resident macroinvertebrate populations.
3. Compare the data collected in these systems with results obtained in two neighboring, 1-ha whole-ecosystem experimental wetlands. Ahn and Mitsch (2002) and Petersen et al. (2003) noted a variety of scale effects that result from using mesocosms and recommend comparing the results obtained from mesocosm experiments with research done at larger scales. Whole-ecosystem wetlands located near the mesocosms offer the opportunity to do this comparison.

1.2 Research hypotheses

Wetlands established in multiple mesocosms were used to test several hypotheses related to macroinvertebrates, water levels, and emergent plants.

1. Pulsing water flows produce more diverse macroinvertebrate communities than steady water flows.
2. A greater diversity of invertebrates is found in wetlands featuring a diverse plant community compared to a *Typha* spp. monoculture.
3. Invertebrates will show different preferences for emergent plants by species.

Two 1-ha whole-ecosystem experimental wetlands located near the mesocosms allowed for comparisons to be made between results obtained in small, 1 m^2 wetlands and those from much larger wetland systems, suggesting a fourth hypothesis.

4. Macroinvertebrate communities' dynamics in the whole-ecosystem wetlands (10,000 m^2) are similar to those in experimental mesocosms (1 m^2).

CHAPTER 2

METHODS

The research was done at the Olentangy River Wetland Research Park (ORWRP) at The Ohio State University (for a complete description see Mitsch, 2005). The site includes a mesocosms compound with eighty mesocosms (1 m^2 each) and other small experimental basins; two whole-ecosystem experimental wetlands (1-ha each), a created 3-ha oxbow, and a 5-ha restored bottomland hardwood forest. Forty of the mesocoms in the mesocosm compound and both experimental wetlands were used in the study (Figure 1). The systems are all fed by water pumped from the adjacent Olentangy River. The mesocosms were designed to function in parallel to the wetlands. Previous research using the mesocosms at the ORWRP has included studies of different genotypes of *Juncus effusus* (Weihe and Mitsch, 2000), the effects of using coal combustion products as a mesocosm liner (Ahn and Mitsch, 2001; Ahn et al., 2001), competitive growth of macrophytes in high and low nutrients (Svengsouk and Mitsch, 2001), effects of hydrologic pulsing on productivity and nutrient cycling (Anderson and Mitsch, 2005), and the effect of hydrology and hydric soils on methane emissions (Altor and Mitsch, 2008; Mitsch et al., 2009).

2.1 Mesocosms

The bottom 10 cm of the mesocosms was filled with pea gravel. In May 2007, the remainder of the mesocosm was filled with topsoil with some composted leaves mixed in, purchased from a local topsoil company. The soil substrate sloped from a low point in the SW to a high point in the NE. When the tubs were filled, the SW corner was approximately 20 cm deep, while the NE corner was 2 cm deep. The mesocosms were randomly assigned to be planted with two different plant communities.

2.2 Mesocosm vegetation

Twenty mesocosms were planted solely with *Typha* spp., collected from Odum Pond, west of the Heffner Research Building. The other half was planted with a mixture of wetland plants, *Schoenoplectus tabernaemontani*, *Juncus effusus*, and *Sparganium eurycarpum*, purchased from Wildlife Nurseries, Inc. (Figure 1). Three small *Typha* spp. plants were transplanted from Odum Pond into each monoculture mesocosm, while three rhyzomes of each of the other aforementioned species were planted in the mixed mesocosms. A stratified pattern was used in the mixed mesocosms, with *Sparganium eurycarpum* planted in the deepest water, *Juncus effusus* in the shallowest water and *Schoenoplectus tabernaemontani* in the water between the other two species. Stem counts were made in November 2008. In 2007, both plants and individual stems were counted. In 2008, *Typha* spp. and *Sparganium eurycarpum* plants

were treated as “stems,” while individual stems were counted for both *Schoenoplectus tabernaemontani* and *Juncus effusus* plants.

2.3 Mesocosm hydrology

River water is pumped continuously into the 1-ha experimental wetlands, while it was stored in two, elevated 1150-L tanks for use in the mesocosms. The tanks were shaded to reduce algae growth and sun-driven temperature increases. Water was filtered through a household sediment filter, allowed to settle in a 375-L tub, filtered through two more sediment filters, and then delivered to the mesocosms via a drip irrigation system. Flow rate was controlled by drippers, which were calibrated by timing the length of time it took to fill a container of known volume. The drippers were reset whenever they were observed to have stopped or slowed significantly. Weekly resetting was required, whenever one of the filters in the system had to be changed. Outflow from the mesocosms passed through the base layer of pea gravel and out a drain through a stand pipe, which controlled water depth in the mesocosms.

During the first growing season, all of the mesocosms were maintained at a steady water depth. Water was delivered to the mesocosms at a constant rate. Each mesocosm was then randomly assigned one of four hydrologic regimes—deep (20 cm with steady inflow rate) in the late summer and shallow (5 cm with steady inflow rate) in the spring (“wet summer”), deep (20 cm with steady inflow rate) in the spring and shallow (5 cm with steady inflow rate) in the fall (“wet spring”, pulsing (10 cm with inflow rate varied according to river stage)

("pulsing"), and steady flow (10 cm with steady inflow rate) ("steady"). At the end of November 2007, the different hydrological treatments of the mesocosms were implemented. Water depth in five of the monoculture mesocosms and five of the mixed mesocosms was increased. Five mesocosms from each vegetation community (10 total) were maintained at a steady water depth. Ten mesocosms were managed so as to have low water level in the spring and a high water depth in the fall. Ten had fluctuating water flows, paralleling the pulsing water flows of the neighboring whole-ecosystem wetlands. As a result of an error in assignment, these last two hydrologic regimes were not evenly divided between vegetation types. Six mixed mesocosms were assigned a wet summer hydrological regime and only four monoculture mesocosms were assigned the same, while the reverse was the case for the pulsing hydrology.

At the end of July 2008, the change from spring to late summer hydrology was made. The mesocosms that had been deep in the spring were switched to shallow levels. The mesocosms that had been low in the spring were switched to high levels. At the same time, the outflow was changed to a surface outflow, so that the water left the mesocosms via a surface drain, rather than through a drain at the bottom of the tubs. The change in outflow was made to reduce the number of mosquitoes in the mesocosms. Water depths were measured using a meter stick and recorded monthly throughout the study.

2.4 Mesocosm macroinvertebrates

All of the mesocosms were seeded with mactoinvertebrates collected from the 1-ha experimental wetlands at the ORWRP in July 2007. Dip net samples from both 1-ha experimental wetlands were combined into a single sample, which was split into 48 sub-samples. Forty were distributed randomly to the mesocosms, while eight were retained for statistical analysis. The correlations between the taxa compositions of the retained samples were highly significant ($p<0.01$, mean $r=0.88$). The average number of organisms by taxa introduced to the mesocosms are listed in Table 1.

2.5 Mesocosm sampling

Hester-Dendy type plate samplers were placed in the mesocosms at the end of July 2008. The samplers had only four plates (surface area=200 cm^2)—contrasted with the usual eight (surface area=400 cm^2)—so that the plates would all be covered at low water levels. At the end of August, the plate samplers were removed, and the plates scraped off. The organisms and substrate removed were filtered through 250μ Nitex cloth and preserved in 70% ethanol. Samples were then examined under a stereo microscope at 15X, and the macroinvertebrates were removed, counted, and identified to the family level (Merritt and Cummins, 1996). Chironomidae were measured under the stereo microscope at 15X, rounding the length to the next lowest millimeter. A sample of Chironomidae was then measured using ImageJ software to double check the hand measurements. A linear regression analysis indicated a highly significant

relationship between the two sets of measurements (R^2= 0.973). Another regression equation, dry mass (mg) = 0.0018*length(mm)$^{2.617}$(Benke et al., 1999), was then employed to calculate biomass for the Chironomids, using the original, hand measurements of length.

In late August 2008, funnel/activity traps (18 cm by 5 cm tubes constructed from window screen with screen inward funnels on each end with 2 cm openings) were placed in sixteen, randomly selected mesocosms—two in each mesocosm type. The traps were left in place for twenty-four hours then removed and returned to the lab. Once in the lab, any plants or organisms on the traps were washed into a container and filtered through a piece of 240μ mesh Nitex fabric. They were then backwashed with 70% alcohol into a storage bag and processed as were the Hester-Dendy samples.

In early September 2008, 12 sets of macrophyte stems—six sets of three plants/stems from each plant taxon—from four randomly selected mesocosms were cut at their base and approximately 10 cm above the water surface, a 240μ mesh Nitex net was placed under and around the macrophyte stem piece, and the stem piece was removed from the mesocosm. The piece was placed in a plastic bag and the net rinsed into the same bag. Once in the lab, the contents of the bag were rinsed into a tray, and anything on the surface of the macrophyte stem was washed into the same tray. If there were loose layers on the stem, outside layers were removed and the same procedure followed as above, until a solid stem core remained. Any macroinvertebrates visible to the naked eye were

removed live from the sample and preserved in 70% alcohol. These samples were then processed in the same manner as the Hester-Dendy samples.

2.6 Experimental wetlands sampling

Six, traditional, eight plate Hester-Dendy samplers were placed in the experimental wetlands at the end of July 2008 according to a pattern that has been used for at least 10 years (Spieles and Mitsch, 2000; Gamble et al. 2005). They were removed at the end of August 2008 and processed as described above.

Funnel/activity traps were also placed in each wetland in August 2008, with six placed in each wetland, eight in *Typha* spp. stands and six among mixed vegetation (*Schoenoplectus tabernaemontani* and/or *Sparganium eurycarpum*). These were processed as above. Six sets of macrophyte stems – three sets of three mixed plants and three sets of three *Typha* stems – from each experimental wetland were also collected and processed as described for the mesocosms.

2.7 Data parameters and statistical analysis

Five indices were used for invertebrate taxa comparisons—three indices of diversity, an index of evenness, and an index of richness. The Simpson index of diversity (λ) is the probability that two individual organisms selected at random from a population will be from the same taxon. For a sample of n individuals from s species, where n_i is the number of individuals from the ith species and $n \neq N$, an unbiased estimator of the Simpson index is

$$\lambda(\text{est.})=\sum_{i=0,s} n_i(n_i-1)/n(n-1)$$

Since the index approaches zero as the diversity of the sample increases, $1/\lambda$ (N2) is normally used as the index of diversity.

The Shannon-Wiener index (*H*') "is a measure of the average degree of 'uncertainty' to predicting what species an individual chosen at random from a collection of *S* species and *N* individuals will belong." (Ludwig and Reynolds, 1988) An estimate of *H*' based on a sample of *n* individuals from *s* species is

$$H'(\text{est.})=\sum_{i=0,S} (n_i/n)\ln(n_i/n)$$

where n_i is the number of individuals from the *i*th species. The Shannon index can be converted to Hill's N1, which is the number of species of equal abundance that would yield a given Shannon index value.

$$N1=e^{H'}$$

As a measure of evenness, Hill (1973) proposed the index E4, where

$$E4=1/\lambda/e^{H'}=N1/N2$$

This index is the ratio of very abundant to abundant species. This index is commonly recalculated as

$$E5=((1/\lambda)-1)/(e^{H'}-1)$$

which is known as the "*modified Hill's ratio*" (E5). This index approaches zero as a single species increases in dominance, while E4 approaches 1 under the same

conditions, making E5 preferable to E4 as an index of evenness. The richness of a sample is indicated by the number of species in the sample (R0).

The data were analyzed using Hutcheson t-tests (Zar, 1996), independent sample t-tests, one-way ANOVAs, generalized linear equations, chi-square analysis, correlations, cluster analysis and nonparametric tests, as calculated by SPSS 17.0.

CHAPTER 3

RESULTS

3.1 Hydrology

From June through November 2007, all of the mesocosms were maintained at a steady water level, (mean depth=11.09±0.18 cm (SE)). Water was delivered to the mesocosms at a hydrologic loading rate of 0.18 cm/hr (Figure 2). With the change in hydrological regimes in November 2007, the same flow rate was maintained, when the Olentangy River was at normal levels. When the river level rose, the delivery rate was increased to two or three times normal for the pulsing mesocosms only, depending on the pumping rate to the whole-ecosystem wetlands. Maintaining water flow to the mesocosms throughout the winter proved impossible because of freezing so the water system was shut down at the end of January. Because of pump problems, water flow to the mesocosms was erratic throughout the spring of 2008. Relatively consistent flow was not reestablished until late April 2008. As a result of interruptions in flow and leaks in the tubs, several mesocosms had no standing water at times during the course of the spring. These mesocosms were distributed among all of the hydrological groups and did not yield statically different diversity indices, and thus were kept in the study.

In May 2008, the loading rate to the mesocosms was increased to 0.38 cm/hr to better match the loading rate to the nearby experimental wetlands. Hydrological loading for the remainder of the study reflected this base rate of water delivery.

The differences between depths with mesocosm treatments were significant ((p<0.001; F=26.67; df=279; Figure 3). The average spring depth of the wet summer mesocosms was lower and the average summer depth was higher than the average depths of all other treatment times during both spring and summer. The average spring depth of the wet spring mesocosms was higher than the average spring depths of the pulsing and steady mesocosms, while the average summer depth for the wet spring mesocosms was lower than the pulsing and steady mesocosm average summer depths.

3.2 Vegetation

Stem counts by species were different by species type. No non-*Typha* species invaded the *Typha* mesocosms, while few *Typha* plants were found in the mixed mesocosms (Table 2).

3.3 Macroinvertebrates and hydrology

Wet spring mesocosms had the highest macroinvertebrate diversity in the Hester-Dendy samples (Figure 4). They had greater diversity than the wet summer mesocosms (p<0.01) and the pulsing ones (p<0.01) on all three diversity indices, and with the steady flow ones on two of the three diversity indices (N2 and N1, (p<0.05). Wet summer hydrology resulted in significantly lower

Shannon-Wiener diversity (H') and Hill's N1 than in the steady flow ones ($p<0.05$).

For mixed vegetation mesocosms, significant differences remained between hydrologic regimes for all three diversity indices ($p<0.05$). Higher diversity was found in the wet spring mesocosms compared to the wet summer, pulsing and steady flow mesocosms (H', N2, and N1, $p<0.01$). The significance of the difference between the wet spring and steady mesocosms remains for two indices (H and N1, $p<0.05$). There were no significant differences among the *Typha* spp. mesocosms, although the trends match those of the mixed mesocosms.

No significant differences in diversity, evenness or richness were identified between mesocosms for the activity trap samples by hydrology. There were too few activity trap samples to do an analysis of hydrology broken out by vegetation types.

When the mesocosm invertebrate counts are aggregated by treatment type (all organisms in by taxa in samples from each treatment type), Hutcheson t-tests indicate that the wet spring hydrologic regime produced higher Shannon-Wiener diversity indices than any other regime ($p<0.001$), while the wet summer and steady flow regimes yielded larger diversity indices than did the pulsing regime ($p<0.01$) (Figure 5). Within vegetation types, the wet spring hydrology produced a higher diversity index than did any other hydrology in the mixed mesocosms ($p<0.01$) and all but the wet summer hydrology in the *Typha*

mescosms ($p<0.05$). In mixed mesocosms the diversity index for the wet summer mesocosms and the steady mesocosms was higher than that for the pulsing mesocosms ($p<0.01$). This was also true in the *Typha* mesocosms ($p<0.05$).

There were no significant differences in diversity, evenness, or richness between mesocosms that had gone dry in the spring and those that had not. However, a Mann-Whitney test indicates that Physidae ($Z=-2.355$; $p<0.05$) and Hydracarina ($Z=-2.001$; $p<0.05$) were most common, and Chironomidae ($Z=-2.003$; $p<0.05$) least common in mesocosms that had not gone dry in February (Table 3). The mesocosms that were dry in February were also dry in March and April, and no mesocosms that were dry in March or April were dry in March. The dry mesocosms were evenly distributed between vegetation treatments ($\chi^2=0.107$; $p>0.05$; $df=1$). However, they were significantly more prevalent in wet summer mesocosms than they were in mesocosms with other hydrologic regimes ($\chi^2=10.296$; $p<0.05$; $df=3$).

3.4 Macroinvertebrates and vegetation

No significant differences in diversity, evenness or richness were found between vegetation types in the Hester-Dendy samples as a whole or with hydrology controlled. Other sampling methods revealed few differences between the mesocosms by vegetation. No significant differences in diversity, evenness or richness were identified for the activity trap samples by vegetation.

Organism samples collected from plant stems were significantly different in taxa richness between the two vegetation communities sampled, with significantly more taxa obtained from mixed plant stems (6.8±0.75) compared with those from the *Typha* spp. stems (4.5±0.34) ($p<0.05$; $t=2.834$; $df=7$). Nine taxa appeared more frequently in the mixed samples, while four taxa appeared more frequently in the *Typha* samples (Figure 6).

Aggregating the sample data to explore vegetation impacts using a Hutcheson t-test, the Shannon-Wiener diversity index for the mixed mesocosms was lower than the index from the *Typha* mesocosms ($p<0.05$) (Figure 7). When hydrology is held constant, H' was higher for the *Typha* mesocosms ($p<0.05$) under all but the wet spring regimes.

3.5 Individual taxa and vegetation

In taxa-specific analyses using a Mann-Whitney test, three taxa, Coenagrionidae ($p<0.05$; $Z=2.373$), Curculionidae ($p<0.05$; $Z=2.080$) Culicidae ($p<0.01$; $Z=3.357$), and Chironomidae ($p<0.05$; $Z=2.035$), were found to be present in significantly different numbers by vegetation community (Figure 8), with more Curculionidae, Culicidae and Chironomidae being found in the mixed mesocosms, and more Coenagrionidae in the *Typha* mesocosms. In wet spring mesocosms, Coenagrionidae ($p<0.05$; $Z=2.362$) are found most frequently in *Typha* mesocosms, while in pulsing mesocosms, Physidae ($p<0.05$; $Z=2.566$) and Stratiomyidae ($p<0.05$; $Z=2.537$) are most common in mixed vegetation

mesocosms. In steady mesocosms, Collembola are found most frequently in *Typha* mesocosms ($p<0.05$; $Z=2.003$).

Correlations with stem counts indicate that *Juncus* stem counts were positively correlated with the number of Isopoda ($r=0.533$, $p<0.05$) and the number of Sciomyzidae ($r=0.698$, $p<0.01$). The number of Collembola was negatively correlated with the *Sparganium* stem counts ($r= -0.473$, $p<0.05$). In *Typha* spp. mesocosms, Hydrophilidae were negatively correlated with the number of stems of *Typha* ($r=-0.464$, $p<0.05$), while Sciomyzidae numbers were positively correlated with stem counts ($r=0.458$, $p<0.05$).

A variety of significant correlations between taxa emerge under the different experimental conditions (Figure 9). Pyralidae are highly correlated with Ephydridae under most experimental conditions. The only negative correlation is between Chironomidae and Physidae. Coenagrionidae have significant correlations with a variety of taxa. Physidae have several correlations that occur under more than one experimental condition. Sciomyzidae are significantly correlated with Physidae in five of seven experimental conditions.

Because Chironomidae and Physidae are such important components of the diets of migrating waterfowl, additional analyses were done on the size of these organisms in the samples. Chironomidae were found to be significantly longer in mixed community mesocosms than in *Typha* mesocosms ($p<0.001$; $t=4.463$; $df=486$). If one multiplies the mean biomass times n for each vegetation

assemblage, the biomass was 4.4 times greater in mixed mesocosms (55.5 mg) than it is in *Typha* mesocosms (12.7 mg).

A one-way ANOVA indicates that Chironomidae length is significantly different by hydrology as well, with those in wet spring mesocosms being significantly smaller than those in mesocosms from any other hydrologic regime ($p<0.001$; $F=10.709$; $df=469$). When the lengths are converted to biomass, wet summer (27.4 mg), pulsing (18.9 mg), and steady (20.9 mg) mesocosm samples had between 18 and 28 times more biomass than the wet spring mesocosms (1.0 mg).

Chironomid length is significantly related to three of the sets of vegetation clusters (*Schoenoplectus* cluster ($p<0.001$; $F=7.992$; $df=308$), mixed vegetation density cluster ($p<0.05$; $F=2.481$; $df=308$), and *Typha* cluster ($p<0.01$; $F= 5.164$; $df=160$)). In the mixed mesocosms, the longest average Chironomid length is found in the middle density clusters. In the *Typha* mesocosms, the longest larvae are found in the highest density *Typha* clusters.

The difference in size between Physidae samples approached significance between vegetation communities ($p<0.10$; $t=1.917$; $df=468$). However, if hydrology is held constant, Physidae are significantly longer in mixed mesocosms than in *Typha* mesocosms with wet spring hydrology ($p<0.01$; $t=2.676$; $df=66$), while they are longer in *Typha* mesocosms than mixed with steady hydrology ($p<0.001$; $t=5.156$; $df=190$).

3.6 Comparison whole-ecosystem experimental wetlands

Analysis of the activity trap samples and the samples of organisms scraped from vegetation in the whole-ecosystem wetlands yielded no significant differences in macroinvertebrate populations between vegetation communities in the experimental wetlands. Hester-Dendy samples from the experimental wetlands had a higher average Shannon-Wiener diversity index ($p<0.05$), N1 ($p<0.01$) and taxa richness ($p<0.001$) for the Hester-Dendy samples than did the mecososms.

Combining sample data from all sampling methods, a total of 34 taxa were collected from the experimental wetlands and the mesocosms – 29 in the experimental wetlands and 23 in the mesocosms (Tables 4 and 5) Seven taxa were not found in mesocosm samples that did appear in the experimental wetland samples: Hirudinae, Nematomorpha, Baetidae, Caenidae, Aeshnidae, Dytiscidae, and Haliplidae (Figure 10). The average organism density by Hester-Dendy sample was higher in the mesocosms than in the experimental wetlands, ($p<0.05$), when the sample size from each mesocosm is doubled to adjust for the difference in surface area between the Hester-Dendy traps in the mesocosms and those in the experimental wetlands. In the activity trap samples, taxa richness, and organism density were higher in the mesocosms than in the experimental wetlands ($p<0.01$), while E5 (a measure of evenness) was higher in the experimental wetlands than in the mesocosms ($p<0.05$).

CHAPTER 4

DISCUSSION

4.1 Effects of hydrology on macroinvertebrates

Deep water levels in the spring—normal hydrology for Ohio—produced higher diversity indices than the wet summer and steady hydrologies—both artificial hydrologic regimes. This suggests that the macroinvertebrates are well adapted to the local hydrology. The findings are consistent with the work of de Szalay et al. (2003) in that their study found higher numbers of macroinvertebrates in wetlands with wet spring hydrologies. However, that study was done in California, where the wet spring hydrology is actually a reverse hydrology—analogous to the wet summer hydrology in Ohio.

Other research regarding seasonal hydrology has indicated that a spring marsh drawdown results in increased macroinvertebrate densities, especially among midge larvae (Batzer and Wissenger, 1996; Anderson and Smith, 2000; Batzer et al., 2006). While Anderson and Smith (2000) indicate that these wetlands also have the highest diversity of macroinvertebrates, Whiles and Goldowitz, (2005) found that perennial wetlands had at least as high diversity as intermittent ones, noting that the relationship between hydrology and macroinvertebrates in their study was complex. The results of this study

reinforce the complexity of this relationship, finding higher diversity in the wet spring mesocosms, but lower Chironomid biomass.

The original hypothesis of the thesis that the pulsing hydrology would produce greater diversity in the macroinvertebrate community was not supported by the data from the mesocosms. The diversity indices in pulsing mesocosms were consistently lower than those from wet spring mesocosms and significantly so for two of the three indices (the reciprocal of the Simpson's (N2) and Hill's N1). However, there were a variety of problems with maintaining pulsing in these small mesocosms.

4.2 Macroinvertebrates in a monoculture and in mixed vegetation

The hypothesis that a mixed plant assemblage would produce higher macroinvertebrate diversity than a *Typha* monoculture was not supported by the data. The only significant difference between vegetation communities was produced by combining the samples from the separate mesocosms into a single sample, which indicated higher diversity in *Typha* mesocosms. This analytical step has the advantage of transforming the data to level out the patchy nature of macroinvertebrate distribution—a patchiness that is reflected in differences between meocosms with the same experimental conditions.

The difference in diversity between the vegetation types is not echoed by a difference in taxa richness. Macroinvertebrates collected from stem samples indicated a higher richness among macroinvertebrate populations on mixed stems as compared with those on *Typha* stems. However, no significant differences were found between activity trap samples from different vegetation

stands or samples taking from stems of different species in the whole-ecosystem wetlands.

In a review of the literature, Batzer and Wissenger (1996) note that a variety of factors besides emergent macrophytes can affect macroinvertebrate populations, such as plant density and submersed plant communities. Gathman et al. (1999) reinforce the complexity of the relationship between macrophytes and macroinvertebrates, noting the effects of macrophyte density and submersed plants are not consistent in studies of coastal wetlands of the upper Great Lakes. In a later synthesis of the data, Batzer et al. (2006) note the importance of algae and detritus as food sources for macroinvertebrates, particularly algae.

4.3 Specific macroinvertebrate taxa and vegetation

Here the data do support the original hypothesis that there would be species specific relationships between macroinvertebrates and vegetation. Hydrology contributes to these differences and some differences may reflect hydrologic differences alone. Vegetation density, floating vegetation (such as *Lemna* spp.), organism habitat requirements, organism food preferences, and inter-organism interaction likely all interact to contribute to differences in taxa (see Batzer et al. 2006).

The significant differences between organism numbers by taxa and vegetation were for Coenagrionidae, Culicidae, and Chironomidae. Coenagrionidae may be limited by the density of the stems in the mixed mesocosms, which would have restricted the movement of relatively large flying insects. The absence of Anisoptera from all of the mesocosm samples is

consistent with the hypothesis that stem density may physically limit access to the mesocosms by large flying insects.

Orians and Wittenberger (1991) provide indirect confirmation of the preference of Odonata for sites with lower vegetation density over those with high density, noting that female yellow-headed blackbirds settle in wetlands with more Odonata and that their choice of nesting site is inversely related to vegetation density. While some studies have linked larger insects with vegetation density (Armstrong and Nudds, 1985; Tolonen et al., 2003), these studies were undertaken in settings with open water and fish. The former would give the larger insects access to the water, while predation by the latter would reduce large insect numbers in areas with low vegetation density.

Knight et al. (2003) note that the density of macrophytes can significantly affect the presence of Culicidae larvae, with more larvae present in dense plant stands. This is consistent with the data indicating that more mosquitoes were present in the mixed than in the *Typha* mesocosms. However, Knight et al. (2003) also provide a list, rating plants as to their predicted production of mosquitoes. According to this list, *Typha* has the highest rating for mosquito production, with *Juncus* having the lowest rating of the macrophytes used in this study. Collins and Resh (1989), developed these ratings based on four parameters: the intersection line value (an indicator of the menisci created when the plant stems break the water surface), crayfish food value, waterfowl food value, and fish obstruction value. The data in this study are not consistent with

these ratings, recognizing that crayfish, waterfowl and fish were not present in the mesocosms.

Water movement could also affect Culicidae populations. With the water flowing out of the mesocosms via surface flow at the end of the summer, larvae were washed out through the overflow. The switch to overflow hydrology appeared to reduce Culicidae populations more in *Typha* mesocosms than in mixed mesocosms (P. Yadav, personal conversation). Mixed mesocosms had many more stems than did the *Typha* mesocosms, which may have provided refuge from the limited water current, reducing the number of organisms washed out from the mixed mesocosms. The dense vegetation may also slow the current in portions of the mixed mesocosms.

Some Chironomidae used plants in the mixed mesocosms as a protective habitat. They were frequently found inside senescent *Schoenoplectus* stems (see below) but not in *Typha* stems, which suggests that mixed mesocosms may have provided a more diverse habitat for Chironomids than do *Typha* mesocosms. There are also appeared to be differences in the rate of senescence among macrophytes. Hargeby (1990) notes that differences in the timing of senescence between submersed plants can affect macroinvertebrate populations.

The clearest relationship between organisms and vegetation based on habitat is that between Pyralidae, some Ephydridae, and *Lemna* (Duckweed)—a floating plant that was variably present in the mesocosms. The Pyralidae larvae in the mesocosms commonly construct tubes out of *Lemna*, in which they live.

Most of the Ephydridae in the samples are leaf miners as larvae and live within the *Lemna* spp. leaves (Keiper et al., 2002). The high correlations between Ephydridae frequencies and Pyralidae numbers under virtually all experimental conditions likely reflects this shared relationship to *Lemna*. Some of the Ephydridae in the samples are from genera that live among the roots or wetland plants, which could explain the few conditions under which the organism frequency from the two families are not significantly correlated.

The differences in average length of Chironomidae from mixed vegetation as compared with those from *Typha* mesocosms may reflect another dynamic based on habitat. It was observed that senescent *Schoenoplectus tabernaemontani* appear to decay more quickly than do *Typha* or *Sparganium*. The latter retain sturdy integuments after senescence and the internal aerenchyma walls remain intact. By contrast, the external walls of *Schoenoplectus* appear to become soft fairly quickly and the internal structure breaks down as well, leaving a largely tubular interior, with longitudinal strands. Large Chironomidae were found within these stems and were never found inside the stems of *Typha* or *Sparganium*, although small Chironomidae were found in these other stems on rare occasions.

The higher number of Stratiomyidae in mixed mesocosms with pulsing hydrology likely reflects a habitat preference. McCafferty (1981) indicates that aquatic Stratiomyidae larvae are frequently found in dense vegetation along shorelines of ponds. In light of this, Stratiomyidae could be expected to be found

among *Juncus* stems in greater numbers than among *Typha* stems given the relative density of the two plants.

The significant relationships between plant stems and Collembola, Isopoda, and Hydrophilidae do not lend themselves to clear interpretations. Hydrophilidae were frequently observed in green algae mats, which probably grow more readily among less dense *Typha* rather than denser *Typha* stands as a result of more shading in the dense stands. A relationship between a genus of Hydrophilidae (*Laccobius*) and filamentous green algae has been identified in the literature (Furth, 1983).

In research on nutrients and algae, McCormick and O'Dell (1996) found green algae particularly responsive to intermediate levels of phosphorus. Green algae also seem to have been present in greater quantities at the edges of *Typha* stands than in the middle of the stand. While it is conceivable that phosphorus levels were higher in less dense *Typha* stands than in more dense stands, it is more likely that the density effect is linked to shading and reflected in the presence of more green algae at the edges of Typha stands in the McCormick and O'Dell (1996) study. Hasler and Jones (1949) suggest that filamentous green algae may have an inhibitory effect on macrophyte density.

The number of Physidae was correlated with the Sciomyzidae numbers, which were also correlated with *Typha* plant density and the number of *Juncus* stems. Sciomyzidae are predators on Physidae (McCafferty, 1981) and the significant correlation likely reflects this relationship. The relationship between Sciomyzidae and plant stems may indicate that plant density facilitates this

predation. Coenagrionidae numbers are correlated with a variety of taxa across experimental conditions, which may reflect their role as generalist predators.

Predation effects are one form of inter-taxa interaction. The negative correlations between Physidae and Chironomidae may reflect another such interaction—competition for food. Both Physidae and some Chironomidae are scrapers. The significant negative correlation between the two may reflect competition for a shared resource. Lovvorn et al. (1999) suggest that this dynamic may be a consequence of competition for food and/or physical displacement of Chironomids by snails. Analysis of the Chironomidae at a species level may provide further evidence regarding this relationship.

4.4 Mesocosms and whole-ecosystem wetlands

Comparisons between the data collected in the whole-ecosystem wetlands and the mesocosms are yielded mixed results. The increased diversity of habitats in the experimental wetlands compared to the mesocosms likely led to the differences between the two in macroinvertebrate diversity and richness. The presence of some open water has been identified as a particularly important feature for enhancing macroinvertebrate diversity (Batzer et al., 2006). The high stemdensity of vegetation in the mesocosms likely limited access by larger flying insects and may have been similarly inhospitable to rapidly swimming organisms like Dytiscidae and many Hemiptera. Studies indicating increased prevalence of these taxa in dense vegetation (Armstrong and Nudds 1985; Tolonen et al., 2003) have been done in settings where open water is a significant component of the habitat.

CHAPTER 5

CONCLUSIONS

1. High water levels in the spring (normal Ohio hydrology) yielded higher macroinvertebrate diversity than other hydrologic regimes.

2. The three species macrophyte mesocosms did not produce higher macroinvertebrate diversity than did the *Typha* mesocosms.

3. Specific macroinvertebrate taxa composition of the mesocosms was affected by the vegetation communities, as was organism size and density for key prey taxa.

4. Chironomidae were more productive in the mixed vegetation mesocosms compared to the Chironomids in the *Typha* mesocosms.

5. Macroinvertebrate diversity and richness were generally higher in the adjacent whole-ecosystem wetlands compared to the mesocosms.

Future Research

1. The effects of pulsing on macroinvertebrates under more natural conditions than the mesocosms offer should be explored. Whole-ecosystem wetlands provide an ideal context for this research.

2. Further quantitative analysis of the relationship between Culicidae and specific macrophytes is needed to test rankings that have been developed to assist those choosing macrophytes for wetland systems, who are concerned about mosquito production in those systems.

3. The impact on diversity indices of identifying macroinvertebrates beyond family level needs to be assessed.

4. The relationships between *Lemna*, green algae, and periphyton, and macrophytes and macroinvertebrates deserve further study.

5. The relative value of different sampling methods for macroinvertebrates in wetlands should continue to be studied, since there is not clear consensus regarding sampling methods. Plate samplers have been excluded from such studies and assumed to be ineffective but may have more value than they have been accorded.

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APPENDIX A

TABLES

Taxa	Avg. Number of Organisms per Sample
Oligochaeta	12.29±2.63 (n=7)
Physidae	22.71±3.13 (n=7)
Lymnaeidae	2.14±0.40 (n=7)
Planorbidae*	1.00±0.44 (n=7)
Corbiculidae	0.14±0.14 (n=7)
Sphaeriidae	7.29±1.70 (n=7)
Hydracarina	0.71±0.36 (n=7)
Caenidae*	0.14±0.14 (n=7)
Coenagrionidae	2.57±0.53 (n=7)
Libellulidae	0.14±0.14 (n=7)
Dytiscidae*	0.71±0.29 (n=7)
Haliplidae*	0.29±0.29 (n=7)
Pyralidae	0.14±0.14 (n=7)
Ceratapagonidae	0.43±0.20 (n=7)
Chironomidae	11.57±1.49 (n=7)
Ephydridae	2.00±0.87 (n=7)

*-Taxa not found in final samples from mesocosms

Table 1 – The average number (± standard error) of organisms by taxa in sub-samples used to seed mesocosms in July 2007.

Species	*Typha* mesocosms	Mixed mesocosms
Typha spp.	103±5.00	2.7±1.3
Sparganium eurycarpum	0	36.9±4.1
Schoenoplectus tabernaemontani	0	201±23
Juncus effusus	0	1046±160
Other	16.5±12.1	0.55±0.46

Table 2 – Mean macrophyte stem counts (± standard error) in November 2008 by vegetation treatment in mesocosms.

Taxon	Hydrology by Month	February	March	April
Physidae	Dry	7.00*	6.82*	4.50*
	Not dry	25.04*	22.62*	22.87*
Hydracarina	Dry	.93*	1.00	1.10
	Not dry	3.28*	2.93	2.83
Chironomidae	Dry	17.53*	17.91	19.60
	Not dry	9.36*	10.34	10.03

*-Differences significant, $p<0.05$

Table 3 – Average number of organisms by taxa in all mesocosms that were affected by dry and wet conditions by month in 2008

Year	2008					
Sample Type	HD		AT		VS	
Location	EW	MES	EW	MES	EW	MES
Taxon						
Horse Hair Worm (Nematomorpha)	X					
Leech (Hirudinea)	X					
Aquatic Worm (Oligochaeta)	X	X	X	X	X	X
Apple Snail (Viviparidae)			X			
Physid Snail (Physidae)	X	X	X	X	X	X
Lymnaeid Snail (Lymnaeidae)	X	X	X	X	X	X
Planorbid Snail (Planorbidae)			X			
Asian Snail (*Corbicula fluminea*)		X	X		X	
Fingernail Clam (Sphaeriidae)	X	X	X		X	X
Aquatic Sow Bug (Isopoda)		X		X		X
Scud (Amphipoda)			X		X	
Water Mite (Hydracarina)	X	X		X		X
Springtail (Collembola)	X	X	X	X	X	
Small Minnow Mayfly (Baetidae)	X		X		X	
Small Squaregill Mayfly (Caenidae)	X		X		X	
Damselfly (Coenagrionidae)	X	X	X	X	X	X
Dragonfly (Aeshnidae)	X		X		X	
Dragonfly (Libellulidae)	X	X	X		X	
True Bug (Hemiptera)	X	X				
Water Scavenger Beetle (Hydrophilidae)	X	X	X	X	X	X
Predaceous Diving Beetle (Dytiscidae	X		X		X	
Crawling Water Beetle (Haliplidae)	X		X		X	
Weevil (Curculionidae)		X				
Minute Moss Beetle (Hydraenidae)		X		X		
Moth (Pyralidae)	X	X	X	X	X	X
Marsh Fly (Sciomyzidae)		X		X		
Biting Midge (Ceratapagonidae)	X	X		X		
Crane Fly (Tipulidae)	X	X	X	X	X	X
Mosquito (Culicidae)	X	X	X	X	X	X
Midge (Chironomidae)	X	X	X	X	X	X
Soldier Fly (Stratiomyidae)	X	X		X		X
Shore Fly (Ephydridae)		X		X		X
Flower Fly (Syrphidae)						X

Table 4 – Taxa appearing in Hester-Dendy (HD), dip net (mesocosm seed sub-samples), activity trap (AT), and vegetation surface (VS) samples by year and location (EW – experimental wetlands, MES – mesocosms)

Sample Type	Experimental Wetlands	Mesocosms	Total
Hester-Dendy	23 (n=6)	22 (n=40)	29
Activity Trap	21 (n=12)	17 (n=12)	28
Vegetation Surface	20 (n=13)	15 (n=12)	23
Total Taxa	29	23	34

Table 5 – The number of taxa found in samples by sample type and sample location.

APPENDIX B

FIGURES

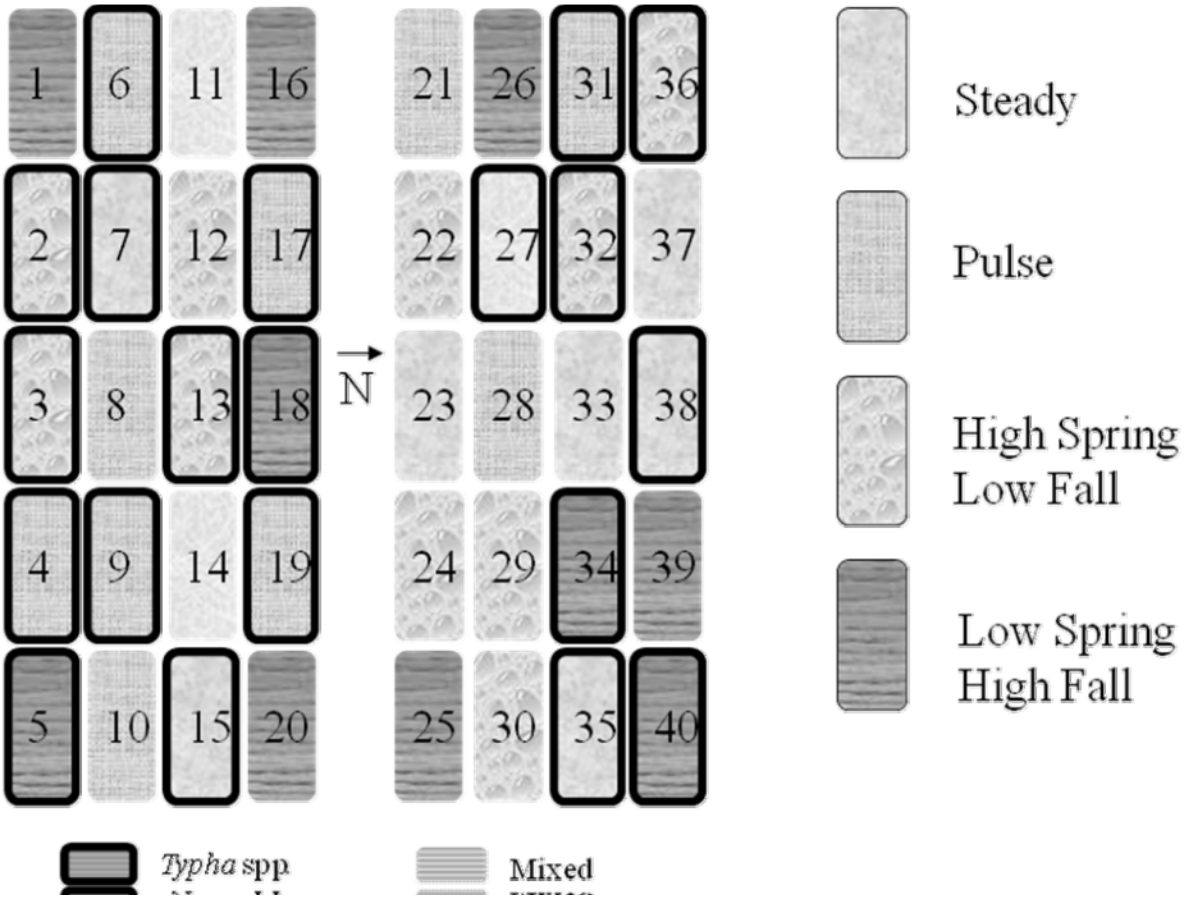


Figure 1 – The 2 (vegetation treatments) x 4 (hydrological regimes) mesocosm experimental design. Each mesocosm is approximately 1 m^2.

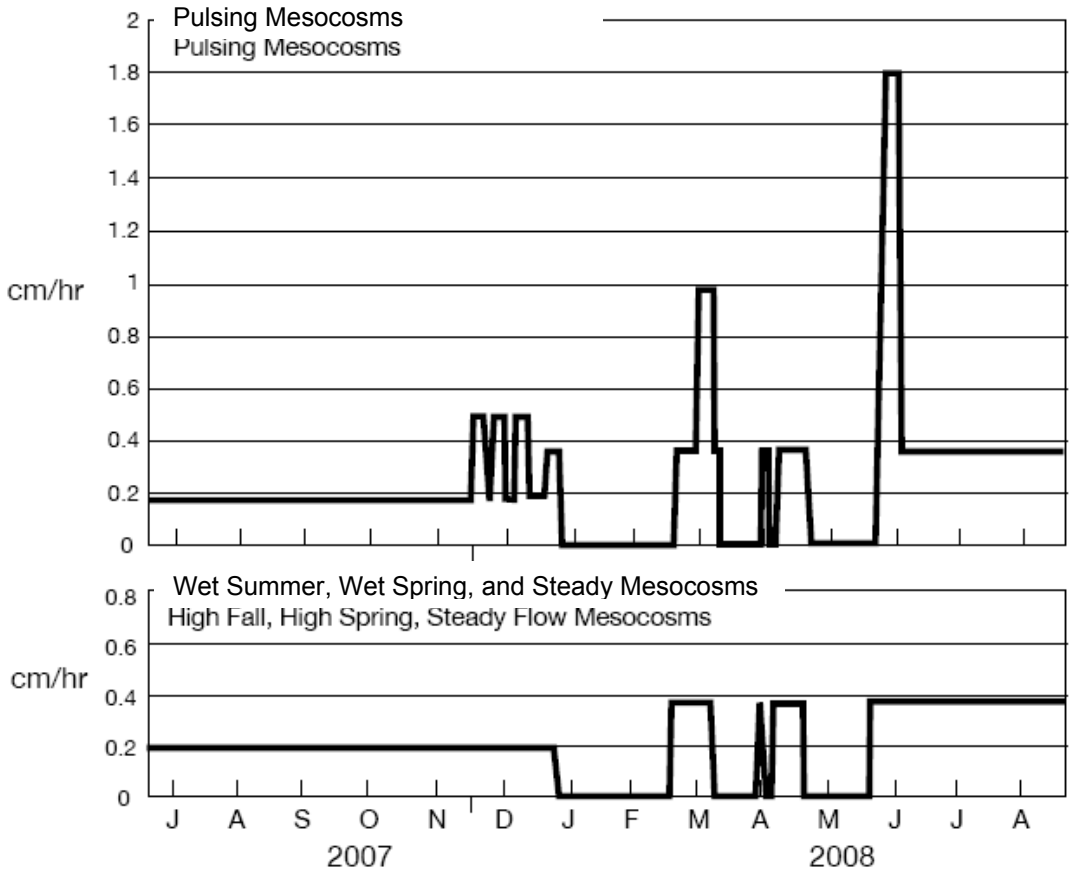


Figure 2 – The hydraulic loading rate (HLR) for the mesocosms by hydrologic regime during the study period.

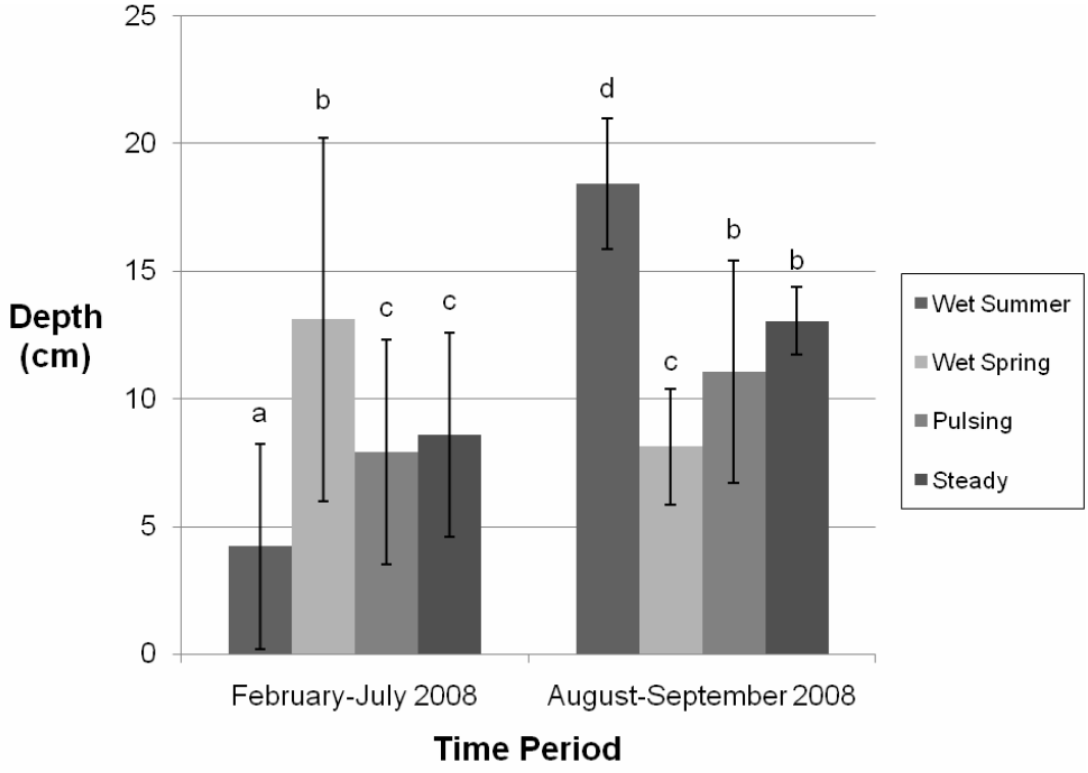


Figure 3 – Average water depth (± standard deviation) by mesocosm hydrologic regime during 2008 (different letters indicate depths that are significantly different ($p<0.05$)).

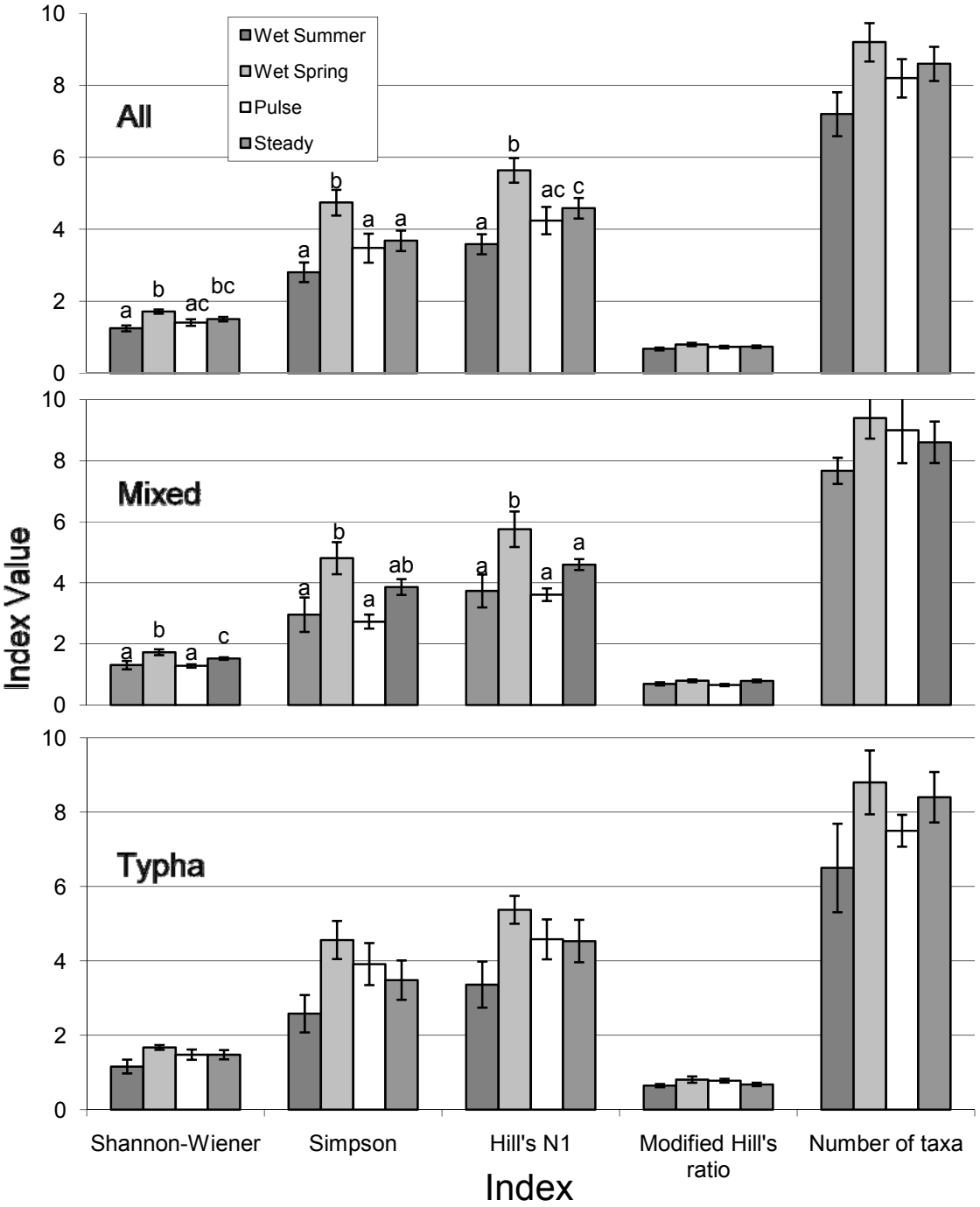


Figure 4 – Average macroinvertebrate diversity, evenness and taxa richness index values (± standard error) by treatment (vegetation type x hydrologic regime) in 2008 mesocosm Hester-Dendy samples.

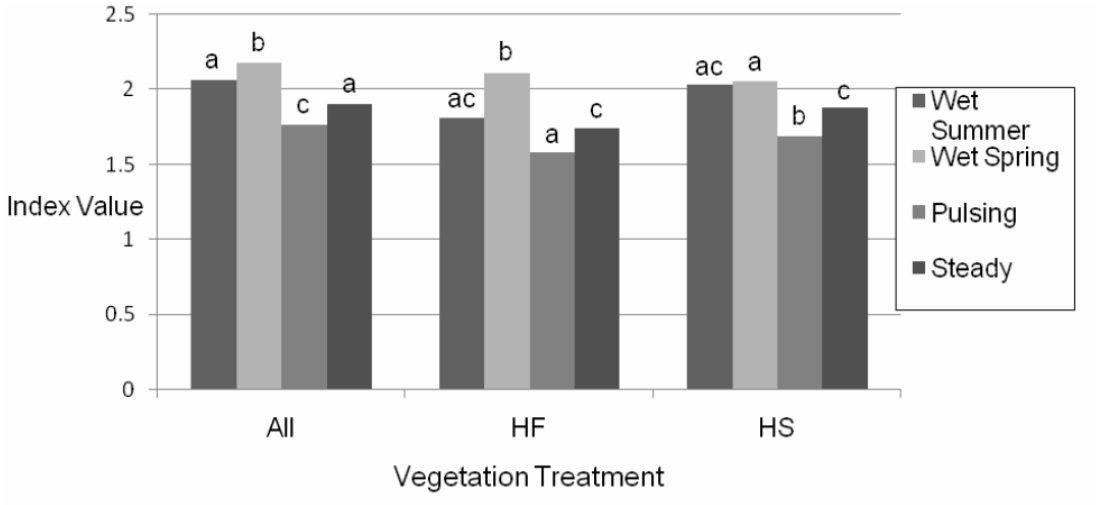


Figure 5 – Shannon-Wiener macroinvertebrate diversity indices for aggregated data for hydrologic regimes, using Hutcheson t-tests (letters indicate differences that are not significant, $p>0.05$).

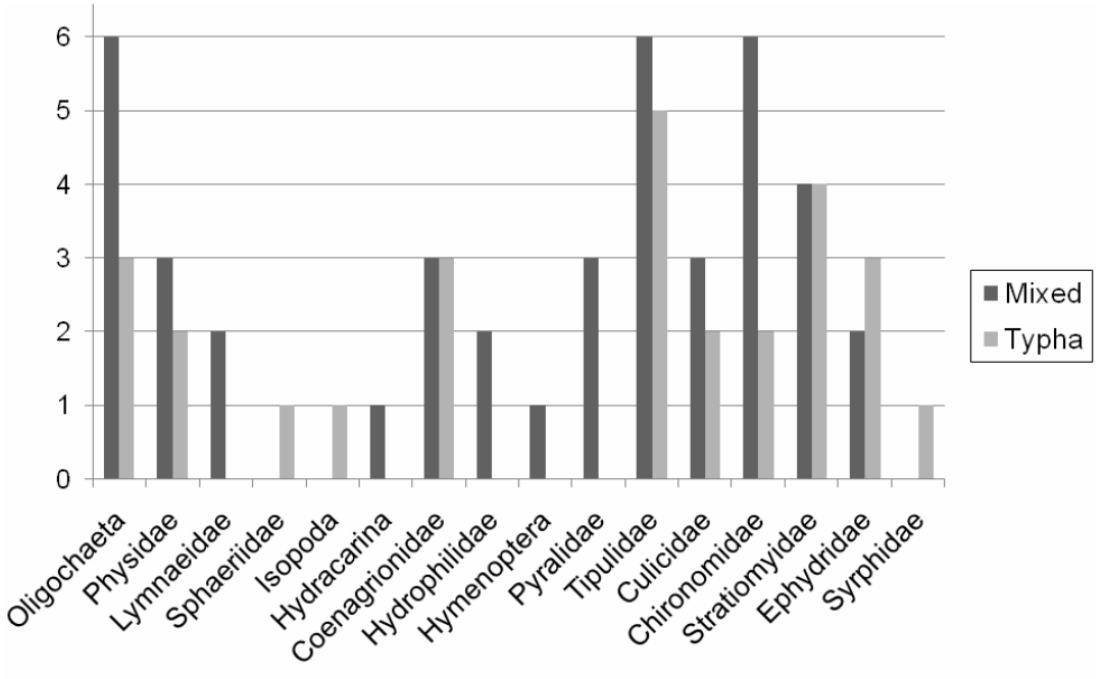


Figure 6 – Number of plant surface samples from mesocosms with a given taxon present by vegetation type.

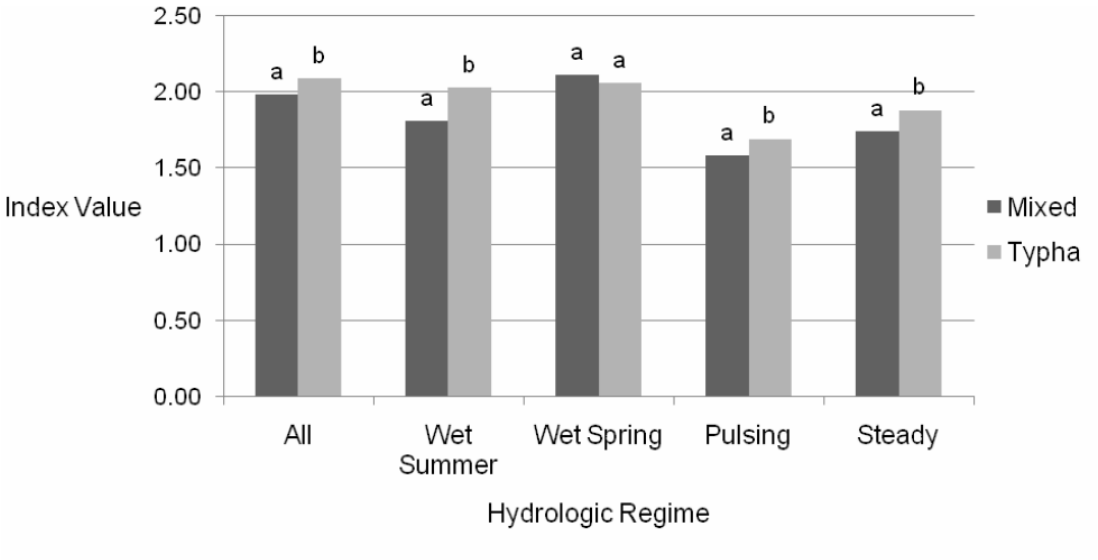
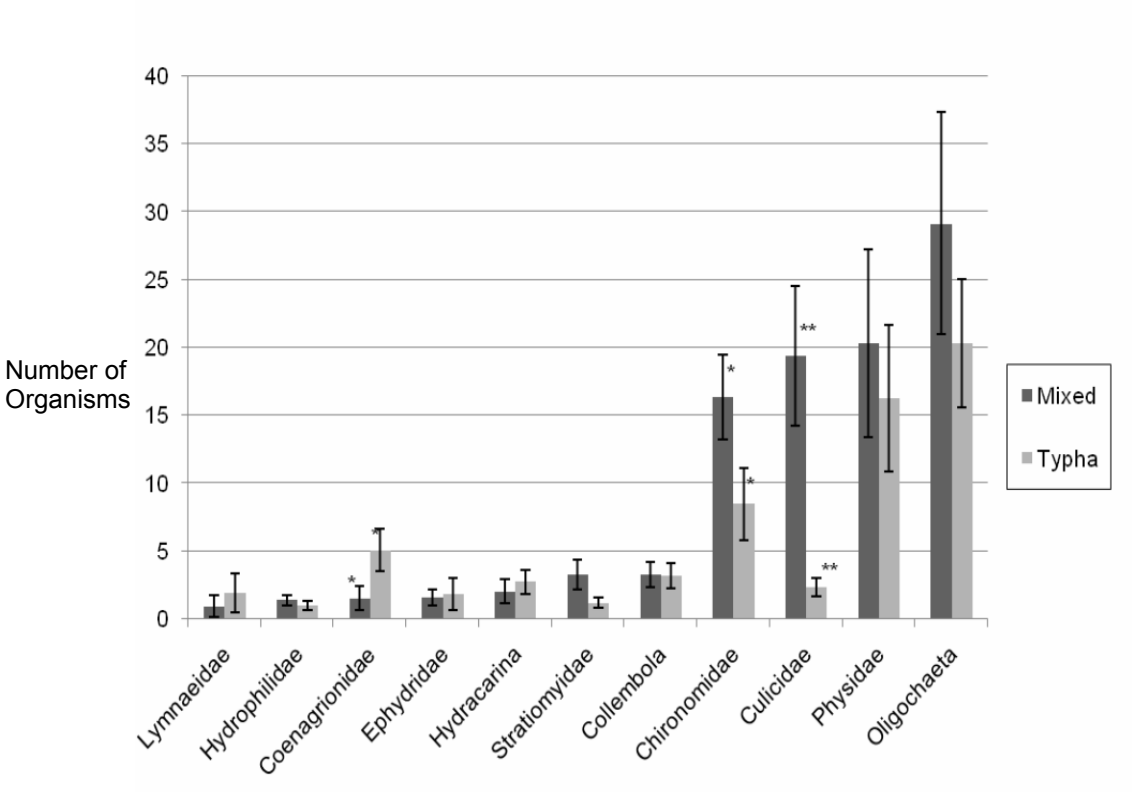


Figure 7 –Shannon-Wiener macroinvertebrate diversity indices for aggregated data for vegetation treatment types, using Hutcheson t-tests (different letters indicate differences that are significant, p>0.05).



** - Difference significant, p<0.01, * - Difference significant, p<0.05

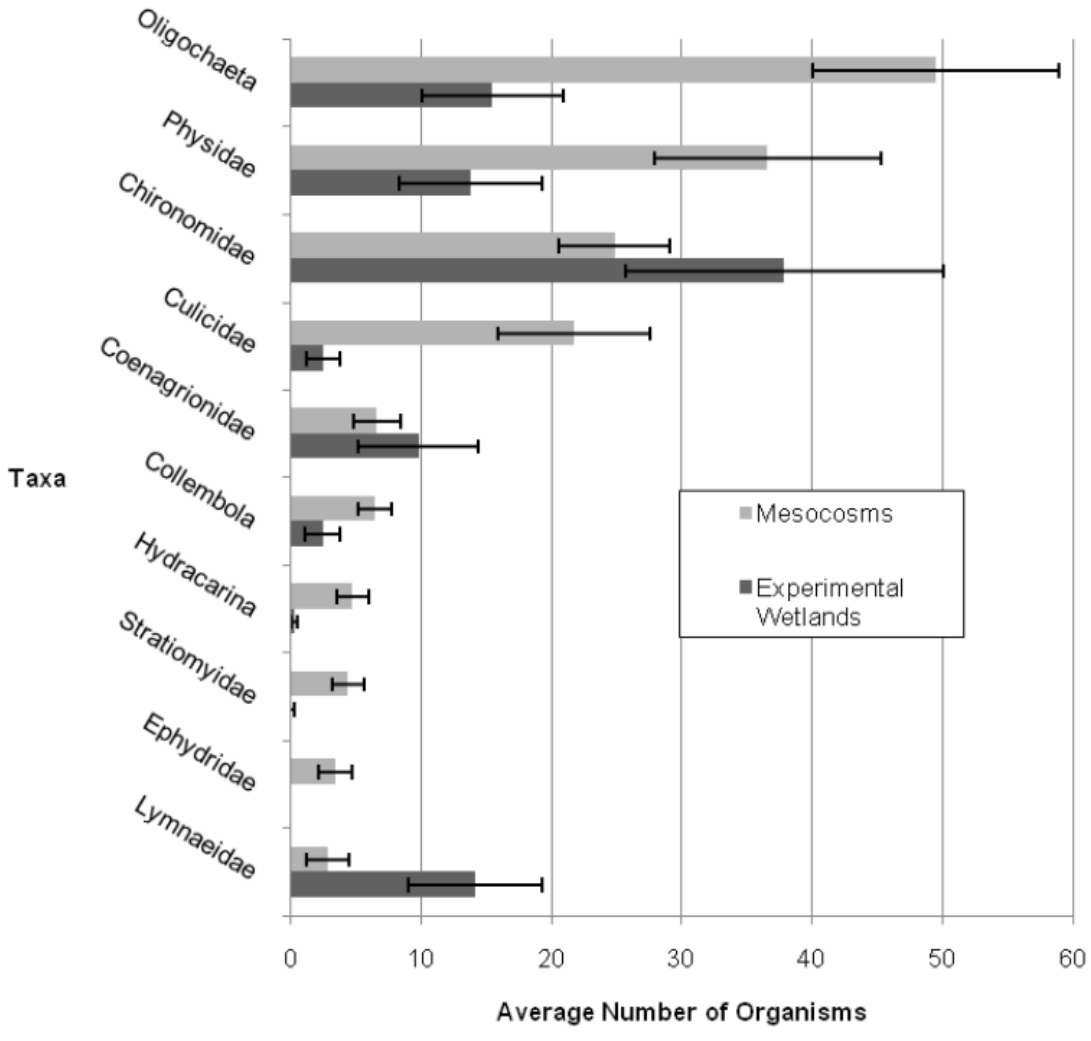
Figure 8 – Average number of organisms in each taxon for the most common taxa by vegetation treatment in mesocosms.

Taxa	Olig.	Phys.	Sphaer.	Iso.	Coen.	Hyd.	Curc.	Pyral.	Sciom.	Cerat.	Culic.
Sphaeriidae	M,S	S									
Isopoda		HF									
Collembola		T,S	S								
Coenagrionidae	HF	A,T,S	M,P	HF							
Hydrophilidae		HS		A,HF	HF						
Curculionidae	HF										
Pyralidae		A,T,S	S	M	A,T,S		HS				
Sciomyzidae		A,M,HF, HS,P	T,HF				S	HS			
Ceratapagonidae			M	A,T,HS	HF						
Culicidae	S	P			M				P		
Chironomidae	P	A(-), M(-),S(-)					A,M				HS
Stratiomyidae		P		HF	HF	A,M,HF			P	HF	
Ephydridae		A,T,S		A,M,HS	S			A,M,T, HF,P,S		HS	P

A-all mesocosms, M-mixed mesocosms, T-Typha mesososms, HF-high fall, HS-high spring, P-pulse, S-steady

Figure 9 – Statistically significant correlations ($p<0.05$) between selected taxa under different experimental conditions in the mesocosms.

a)

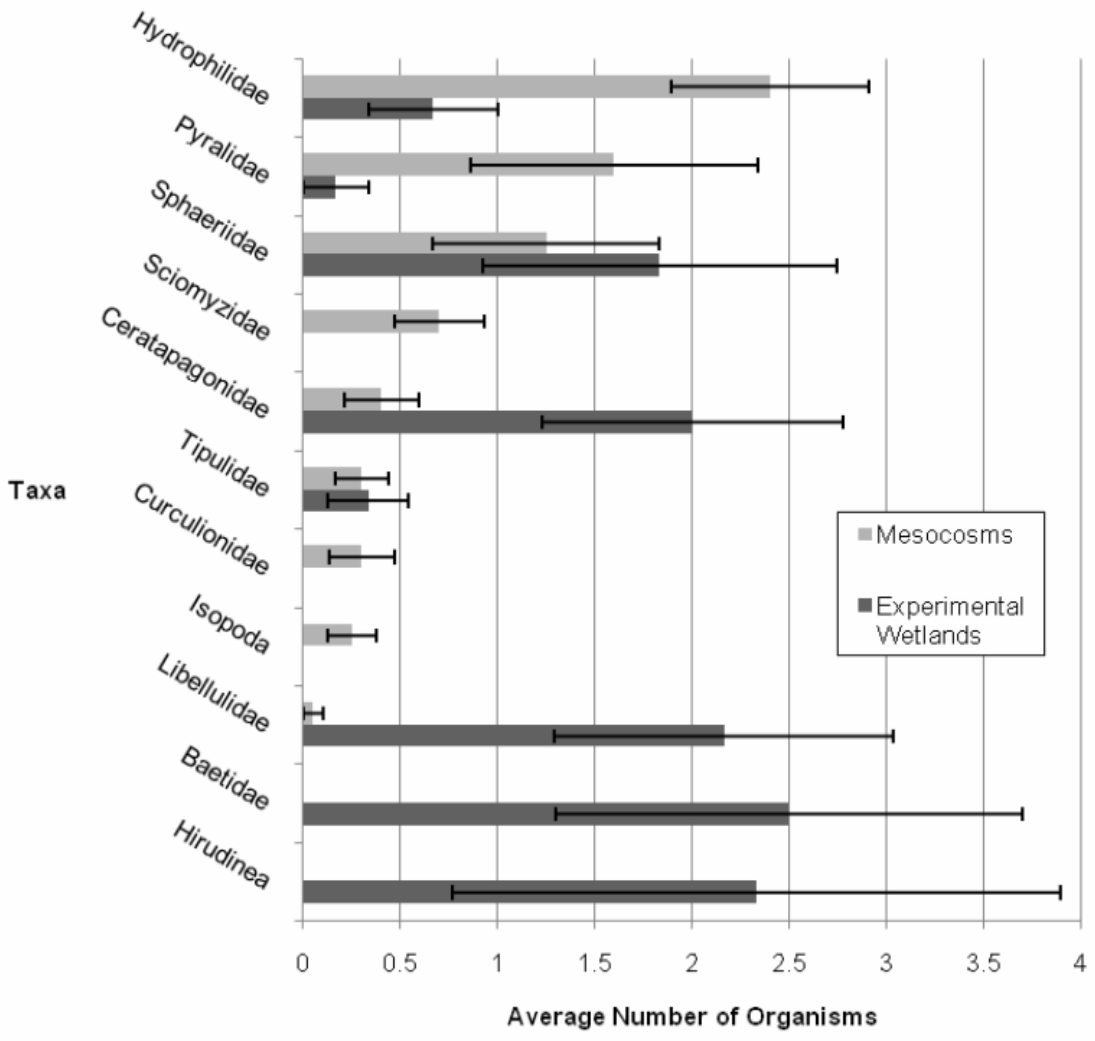


(cont.)

Figure 10 – Average number of organisms by taxa in Hester-Dendy samples from the experimental wetlands and the mesocosms in 2008 (mesocosm sample size adjusted to reflect differences in surface area between traps used in the mesocosms and those used in the experimental wetlands).
(a – high frequency taxa, b – middle frequency taxa, c – low frequency taxa).

Figure 10
(cont.)

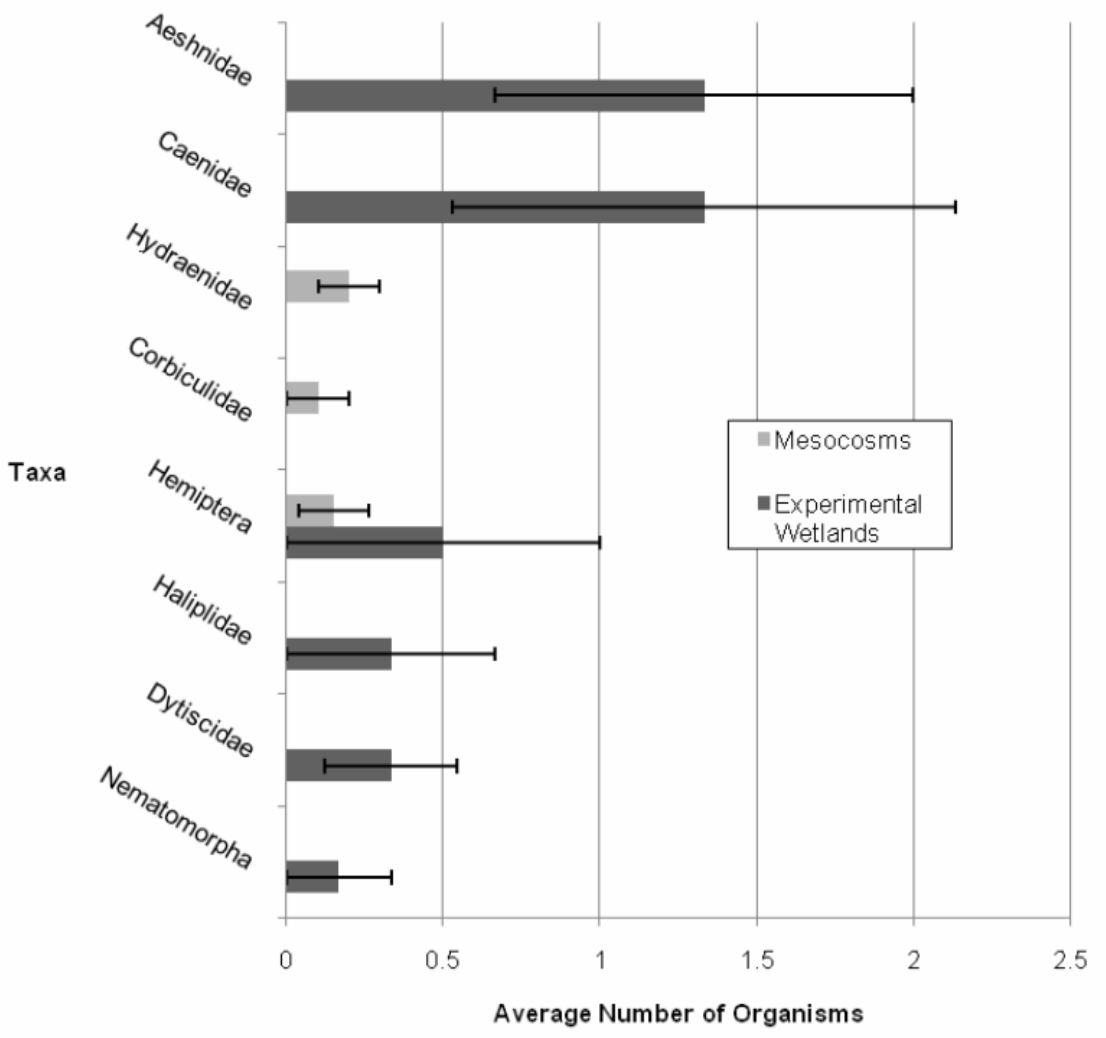
b)



(cont.)

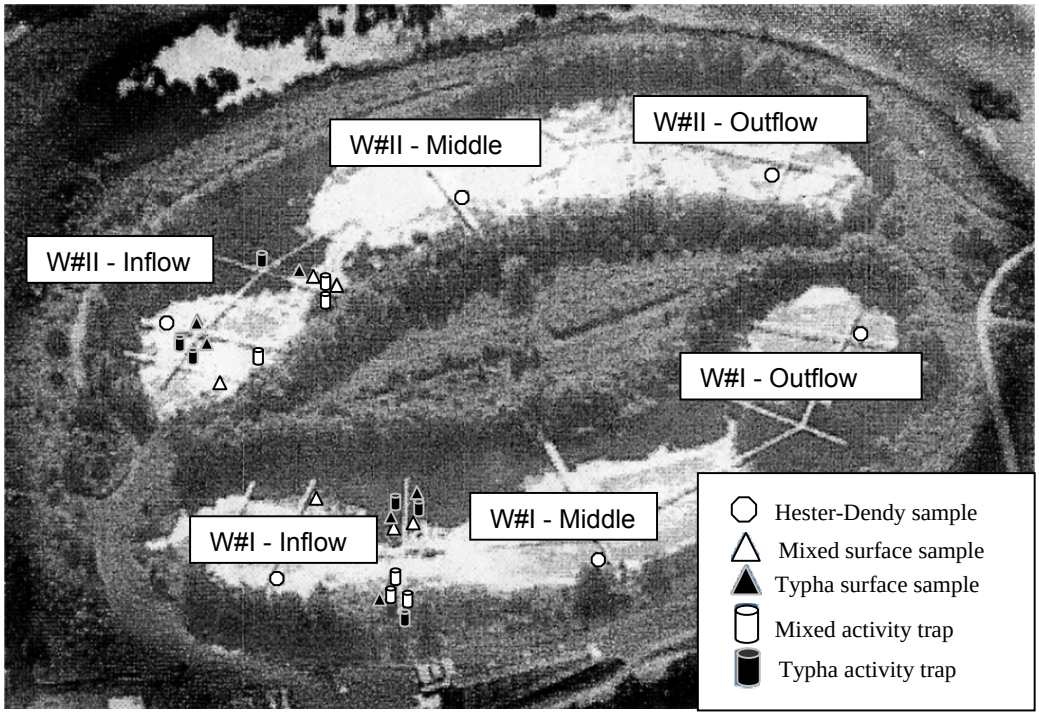
Figure 10
(cont.)

c)



APPENDIX C

EXPERIMENTAL WETLANDS DATA SUMMARY



Sampling layout for whole ecosystem wetlands

Hester-Dendy Samples August 2008						
Taxa	Wetland #I			Wetland #II		
	Inflow	Middle	Outflow	Inflow	Middle	Outflow
Hirudinea	0	0	1	10	1	2
Oligochaeta	7	10	10	39	4	23
Physidae	15	16	38	4	10	0
Lymnaeidae	5	31	21	23	5	0
Sphaeriidae	4	0	2	0	5	0
Hydracarina	0	0	1	0	1	0
Collembola	8	5	0	0	2	0
Baetidae	0	3	8	2	0	2
Caenidae	0	0	5	0	2	1
Coenagrionidae	14	3	1	10	30	1
Aeshnidae	0	0	4	2	2	0
Libellulidae	0	3	1	0	4	5
Hemiptera	0	0	0	0	0	3
Hydrophilidae	1	0	0	1	2	0
Dytiscidae	1	0	0	1	0	0
Haliplidae	0	2	0	0	0	0
Pyralidae	1	0	0	0	0	0
Ceratapagonidae	4	1	0	0	3	4
Tipulidae	1	0	0	1	0	0
Culicidae	1	1	0	0	6	7
Chironomidae	36	0	44	63	8	76
Stratiomyidae	0	0	0	0	0	1
Nematomorpha	1	0	0	0	0	0

Activity Trap Samples August 21, 2008				
	Location			
	W#I Mixed	W#II Mixed	W#I *Typha*	W#II *Typha*
Taxa	Number	Number	Number	Number
Oligochaeta	0	0	16	0
Viviparidae	0	0	1	0
Physidae	22	13	16	5
Lymnaeidae	17	6	5	15
Planorbidae	0	0	0	1
Sphaeriidae	3	2	1	0
Isopoda	0	0	2	0
Collembola	2	2	0	0
Caenidae	0	0	4	2
Coenagrionidae	2	1	0	3
Aeshnidae	2	0	0	0
Libellulidae	0	0	0	6
Hydrophilidae	2	0	3	1
Dytiscidae	1	1	0	0
Haliplidae	0	0	1	0
Curculionidae	0	0	0	1
Hydraenidae	0	0	0	1
Ceratapagonidae	0	0	0	0
Chironomidae	1	0	4	2
Stratiomyidae	1	1	1	0
Ephydridae	0	0	4	5

Vegetation Surface Samples August and September 2008				
	Location			
	W#I Mixed	W#II Mixed	W#I *Typha*	W#II *Typha*
Taxa	Number	Number	Number	Number
Oligochaeta	0	0	16	0
Physidae	13	9	13	8
Lymnaeidae	14	19	12	15
Corbiculidae	2	1	1	1
Sphaeriidae	0	0	2	0
Amphipoda	3	17	0	0
Collembola	1	0	4	2
Baetidae	1	8	3	0
Caenidae	0	2	0	0
Coenagrionidae	10	2	1	6
Aeshnidae	0	2	2	2
Libellulidae	3	0	1	0
Hydrophilidae	0	0	1	0
Dytiscidae	1	0	1	0
Haliplidae	0	0	0	1
Lepidoptera	0	3	0	0
Tipulidae	0	1	2	4
Culicidae	1	2	1	0
Chironomidae	1	0	4	5

Hester-Dendy Samples 2007						
Wetland	1	1	1	2	2	2
Sample Type	Inflow	Middle	Outflow	Inflow	Middle	Outflow
Taxa	Number	Number	Number	Number	Number	Number
Hirudinea	6	2	3	9	0	8
Oligochaeta	34	1	15	10	4	34
Physidae	0	0	8	5	35	27
Lymnaeidae	122	2	3	0	1	7
Planorbidae	0	1	0	1	3	0
Sphaeriidae	12	0	1	27	24	2
Collembola	19	5	0	1	0	0
Baetidae	0	2	0	0	0	1
Caenidae	0	0	1	0	0	0
Coenagrionidae	1	6	1	0	0	1
Hemiptera	0	3	0	0	0	0
Hydrophilidae	0	0	0	1	0	0
Dytiscidae	3	6	0	7	0	10
Curculionidae	0	0	0	0	0	1
Ceratapagonidae	4	0	0	1	0	3
Tipulidae	1	0	0	0	0	0
Chironomidae	34	7	192	29	1	62
Stratiomyidae	0	0	0	0	0	1
Ephydridae	1	0	0	0	0	0
Nematomorpha	1	0	0	0	0	0