Lower Muskegon River Habitat Restoration Project: Pre- and Post-Restoration Monitoring Results of Fishes, Macroinvertebrates, and Water Quality

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Introduction

Loss of wetlands and river connectivity are major threats to freshwater ecosystems (Grill et al. 2019; Jenny et al. 2020; Tickner et al. 2020). Efforts to restore lateral river connectivity and critical wetland habitats are part of the solution to combat the global loss of freshwater biodiversity (Tickner et al. 2020). At a local scale, pre- and post-assessment monitoring is a key component of measuring the ecological response of restoration activities (Palmer et al. 2005). Although billions of dollars are spent on ecological restoration in the USA each year, quantifying the outcomes of those project is often lacking, which can provide valuable opportunities for scientists and managers to learn from both successes and failures (Bernhardt et al. 2005; Palmer et al. 2005).

Our overall goal was to evaluate the response of fishes and macroinvertebrates to restoration efforts that reconnected the lower Muskegon River with a diked wetland near the river's confluence with Muskegon Lake. Our specific objectives were to provide pre- and post-restoration assessment of fishes, macroinvertebrates, and water quality. A brief timeline of restoration work at the site: dewatered in June-December 2020, major earth excavation was completed in October-December 2020, habitat structures were installed in December 2020-January 2021, water levels were maintained via pumping at a lower elevation (i.e., 581 feet) to establish plantings in April-September 2021, native seedlings and plantings were completed in May-June 2021, removal of berm (i.e., dike) separating the wetland from the Muskegon River in October-November 2021, and supplemental plantings of native vegetation were completed in May-September 2022. Pre-assessment monitoring was completed in August 2018, and post-assessment monitoring was completed in June 2022. In this report, we summarize the results of our pre- and post-assessment monitoring.

Methods

The restoration site is a riverine wetland associated with the lower Muskegon River near Muskegon Lake in Muskegon County, Michigan. Prior to restoration, a dike isolated the wetland from the river, mean that the lateral river connectivity severely impaired at this site prior to restoration activities. We refer to the diked wetland targeted for restoration as the Bosma

Property, which was stratified into a West Pond and East Pond for our monitoring assessment (Figure 1). The West Pond was divided into three equal sections and the East Pond was divided into two equal sections (Figure 1). At the time of site selection, each section was known to contain open-water zones and wet-meadow zones; however, the extent of each zone within each section was unclear. After a site visit in 2018, we determined that all wet-meadow zones were too shallow to fish fyke nets (i.e., water depth < 20 cm). Thus, we sampled fishes and macroinvertebrates in open-water zones and only macroinvertebrates in wet-meadow zones (Figure 1, Table 1). In the West Pond, we randomly selected open-water zones in two of the three sections and a wet-meadow zone in one out of three sections (i.e., West-B open water, West-C open water, and West-C wet meadow). In the East Pond, we randomly selected an open-water zone in one of the two sections and a wet-meadow zone in one of the two sections (i.e., East-A open water and East-B wet meadow). In 2022, we re-sampled fish and macroinvertebrates at the same sites.

Fish were sampled using modified fyke nets following the protocol of Uzarski et al. (2017). Three fyke nets were set in the open-water zone within each of the three selected sections (i.e., West-B, West-C, East-A). Fyke nets were set individually, with the lead perpendicular to the shoreline (Figures 2A-B & 3A-B), spaced at least 25 m apart, and placed in water depths between 20 cm and 100 cm. For pre-restoration sampling, fyke nets were set in the West Pond on 14 August 2018 and the East Pond on 16 August 2018. For post-restoration sampling, all fyke nets were set (i.e., both West Pond and East Pond) on 20 June 2022. Fyke nets were fished overnight with a mean soak time of 25.4 hr (range = 23.1-27.9 hr) in 2018 and 22.2 hr (range = 21.5-23.3 hr) in 2019. Fish were identified, enumerated, measured for total length, and released in the field. A few individuals of certain species (i.e., ones difficult to identify in the field) were euthanized and taken to the laboratory for identification with a dissecting microscope.

Macroinvertebrates were sampled using D-frame dip nets (D-net) with 500-µm mesh following the protocol of Uzarski et al. (2017). Macroinvertebrates were sampled near the fyke net lead at open-water zones (Figure 3C). In wet-meadow zones, we sampled macroinvertebrates in an approximately 20-m^2 area (Figure 2C), with at least 25 m between each replicate. The total number of D-net sweeps (1 m each) used to collect macroinvertebrates was recorded for each replicate. A maximum of 150 macroinvertebrates and a minimum of 50 macroinvertebrates were collected in the field for each replicate following the protocol of Uzarski et al. (2017). Briefly, once a minimum of 30 person minutes was spent picking macroinvertebrates from a replicate sample in the field, picking was continued until the nearest multiple of 50 individuals was reached. Thus, the number of macroinvertebrates picked for any replicate was affected by macroinvertebrate abundance at the site and amount of debris in the sorting tray. Once picking of a replicate was completed in the field, the number of macroinvertebrates picked in an allotted time (i.e., number of person minutes spent picking) was recorded for each replicate. Macroinvertebrate samples were preserved in 70% ethanol and taken to the laboratory for identification to the lowest reasonable taxonomic level using a dissecting microscope. The number of D-net sweeps, number of macroinvertebrates picked, and person minutes spent picking (all done in the field) provide an index of effort and a semi-quantitative measure of macroinvertebrate abundance for each replicate. For instance, a low number of net sweeps and a high number of macroinvertebrates collected in less time would be consistent with high abundance of macroinvertebrates in an area.

A suite of chemical and physical variables was recorded for each zone. Depth was measured at the mouth of the fyke net for open-water zones and the center of where macroinvertebrates were collected for wet-meadow zones. Submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV) was visually estimated for the length of the fyke-net lead between the two wings for open-water zones and in the general area where macroinvertebrates were collected for wet-meadow zones. At each zone, a YSI 6600 V2 multi-parameter data sonde (Figures 2D & 3D) was used to measure water temperature, dissolved oxygen (DO), specific conductivity, total dissolved solids, turbidity, pH, and chlorophyll-*a*.

Results

Water quality appeared to improve from pre- to post-restoration sampling with respect to DO concentration and specific conductivity. DO concentration was higher and specific conductivity was lower during the June-2022 sampling event compared with the August-2018 sampling event (Table 2). Mean DO concentration in 2018 were <1 mg/L at three of five zones, whereas all zones had mean DO concentrations >3 mg/L (with four of five zones >8 mg/L) in

2022 (Table 2). Mean specific conductivity was >650 µS/cm at all zones in 2018, whereas specific conductivity was <400 µS/cm in 2022.

The fish species composition of the fyke-net catch differed markedly between the two sampling events, although total catch did not. A total of 3,238 fish were captured during the pre- and post-restoration fyke netting with 1,577 fish captured in August 2018 (Table 3) and 1,661 fish captured in June 2022 (Table 4). The catch per unit effort was similar between years with 175 fish/fyke net in 2018 and 185 fish/fyke net in 2022, although the high catch in 2022 was due to a large number of juvenile largemouth bass captured at the West-B site (Table 4). Nevertheless, more than twice as many fish species were captured in 2022 (13 species) compared with 2018 (six fish species). Of the six fish species captured in 2018, only two species (bluegill and pumpkinseed) were recaptured in 2022 (Tables 3 & 4). In 2018, the most abundant species in the catch were pumpkinseed, bluegill, common carp, and fathead minnow, which made up nearly 90% of the catch (Table 3). In 2022, the most abundant species in the catch were largemouth bass and pumpkinseed, which accounted for nearly 96% of the catch (Table 4). Although the size distribution of fish captured during the two years was skewed toward smaller individuals (i.e., fish <10 cm TL), more large individuals (i.e., fish ≥10 cm TL) were captured in 2022 (5.1% of catch) compared with 2018 (1.2% of catch; Figure 4). Moreover, no fish larger than 45 cm TL were captured in 2018, whereas 12 individuals larger than 45 cm TL were captured in 2022.

The composition of macroinvertebrate taxa differed spatially (i.e., between zones) and temporally (i.e., between years). Macroinvertebrates from 27 families, representing 30 different genera were captured in August 2018, whereas 34 families, representing 33 genera were captured in June 2022 (Table 5). In general, less effort (particularly with respect to time spent picking macroinvertebrates in the field) was necessary to capture more macroinvertebrates in June 2022 compared with August 2018 (Table 6), suggesting that macroinvertebrates were at lower densities in the habitats we sampled in August 2018 compared with June 2022. In August 2018, Coleoptera, Culicidae (Diptera), Belostomatidae (Hemiptera), and Stratiomyidae (Diptera) were more common in wet-meadow zones but rarely encountered at open-water zones (Table 7; Figure 5A-B). Conversely, Chironomidae (Diptera), Corixidae (Hemiptera), and Caenidae (Ephemeroptera) were more common in open-water zones but less frequently encountered in wet-meadow zones in August 2018 (Table 7; Figure 5A-B). In June 2022, Coleoptera, Hemiptera, and Physidae (Gastropoda) were more common in wet-meadow zones but less frequently encountered at open-water zones (Table 8; Figure 5C-D). Conversely, Caenidae (Ephemeroptera) and Gammaridae (Amphipoda) were more common in open-water zones compared with wet-meadow zones in June 2022 (Table 8; Figure 5A-B). The biggest temporal differences (i.e., August 2018 vs June 2022) were that Oligochaeta was more common in August 2018 and Gammaridae (Amphipoda) and Baetidae (Ephemeroptera) were more common in June 2022 (Tables 6 & 7; Figure 5).

Discussion

The reconnection of the wetland at the Bosma Property along with habitat improvement activities likely results in several positive responses by fishes, macroinvertebrates, and water quality that were consistent with improved ecological health as a result of restoration activities. In terms of water quality, specific conductivity was high and dissolved oxygen concentrations were low during pre-restoration monitoring. In fact, the mean specific conductivity (across all zones; $n = 15$) for the wetland was 776 µS/cm in August 2018, which was much higher than reported for littoral habitats in Muskegon Lake (Bhagat & Ruetz 2011) and other drowned river mouth lakes along the eastern shoreline of Lake Michigan (Janetski & Ruetz 2015). High specific conductivity is often associated with anthropogenic disturbance in Great Lakes coastal wetlands (Uzarski et al. 2005). The mean specific conductivity for the wetland decreased by about 51% in June 2022 (mean specific conductivity = 377 µS/cm, $n = 15$), which was consistent with improved water quality post restoration and within the range of values observed in littoral habitat of Muskegon Lake (Bhagat & Ruetz 2011; Janetski & Ruetz 2015). Additionally, low DO concentrations were observed during daylight hours (i.e., single measurements were made when sampling biota) during August 2018 with several measurements <1 mg/L, which can affect the species of fish and macroinvertebrates that can inhabit a wetland. However, we encountered more favorable conditions during post-restoration assessment with all measurements of DO concentration >1 mg/L and most >8 mg/L, which was again consistent with improved water quality and more typical of littoral habitat in Muskegon Lake (Bhagat & Ruetz 2011; Janetski & Ruetz 2015).

Fishes appeared to respond positively to the improved water quality between sampling events. We only captured six fish species in our sampling during August 2018, which was much less than the number of species typically captured in littoral habitats of Muskegon Lake (Bhagat & Ruetz 2011) and other drowned river mouths (Janetski & Ruetz 2015) using the same sampling gear (i.e., small-mesh fyke nets). Most of the fish species captured at the Bosma Property in August 2018—such as common carp, fathead minnow, central mudminnow, and golden shiner (Table 3)—are rarely captured in littoral habitat of Muskegon Lake (Bhagat & Ruetz 2011; Janetski & Ruetz 2015) and are considered tolerant of poor environmental conditions (Becker 1983; Cooper et al. 2018). Conversely, we captured nearly twice as many fish species in June 2022 during the post-restoration assessment. More importantly, fish species tolerant of poor environmental conditions—brown bullhead, yellow bullhead, and fathead minnow (Cooper et al. 2018)—were only a small component of the catch (i.e., about 3%) in June 2022 during post-restoration assessment. Thus, most fish species captured during post-restoration assessment were considered intermediate in terms of the tolerance of poor environmental conditions (Cooper et al. 2018) and were commonly encountered in littoral habitats of Muskegon Lake (Bhagat & Ruetz 2011; Janetski & Ruetz 2015).

Macroinvertebrates also appeared to respond positively to the improved water quality, although distinguishing patterns were less clear than for fishes. In the open-water zone, the macroinvertebrate assemblage in August 2018 was dominated by tolerant taxa—Chironomidae, Corixidae, and Oligochaeta—that were indicative of poor water quality (Merritt & Cummins 1996). Conversely, some of those same taxa, namely Corixidae and Oligochaeta, were nearly absent from samples collected in the open-water zone during the post-restoration assessment in June 2022. The low numbers of Amphipoda in our sampling during August 2018 was likely explained by their intolerance to low DO concentrations (Hoback & Barnhart 1996; Irving et al. 2004), and the near absence is noteworthy because Amphipoda is generally well represented in Great Lakes coastal wetlands (Burton et al. 1999; Cooper & Uzarski 2016). In the post-restoration sampling in June 2022, Amphipoda was better represented in both open-water and wet meadow zones. Finally, Ephemeroptera taxa were more numerous in the post-restoration assessment, which is often positively associated with ecological health (e.g., Uzarski et al. 2004).

Although our results provide a valuable basis to assess the ecological success of this restoration effort, a few caveats should be considered. First, inferring the cause of differences between pre- and post-restoration assessments must be done cautiously because biotic and abiotic conditions can fluctuate over time for many reasons that may not be the result of restoration activities, although many of the responses we observed were in the hypothesized direction of improved ecological health of the wetland. Previous studies of fishes and water quality in nearby Muskegon Lake (Bhagat & Ruetz 2011; Janetski & Ruetz 2015) provided us with a stronger basis to evaluate the ecological response of this restoration effort and inform the hypothesized ecological responses to improved water quality. Second, our monitoring was restricted to a single point in time each year, which could easily miss seasonal dynamics like the production and outmigration of ecologically and economically important fishes (e.g., Cottrell et al. 2021). If this were the case, then a more extensive assessment may have shown additional ecological benefits of the restoration effort that we did not observe.

In conclusion, we found evidence that restoring lateral river connectivity and enhancing habitat improved the ecological health of a riverine wetland based on the responses of fishes, macroinvertebrates, and water quality. At least at the local scale, our assessment suggests this restoration effort was ecologically successful.

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Table 1. Locations (latitude and longitude) for each fish and macroinvertebrate sampling site at the Bosma Property; coordinates are the mean of the three replicates at each site. Fish were sampled in open-water (OW) zones; macroinvertebrates were sampled in open-water and wet-meadow (WM) zones. Submerged aquatic vegetation (SAV) and emergent aquatic vegetation (EAV) were visually estimated at each sampling location. Mean ± 1 standard error (*n* = 3) of water depth, SAV, and EAV at sampling sites. Site locations are depicted in Figure 1.

Year	Site	Zone	Taxa Sampled	Lat (°)	Long (°)	Depth (cm)	SAV (%)	EAV (%)
2018	West-B	OW	Fish, Macroinvertebrates	43.26969	-86.23155	84±2	0±0	0±0
2018	West-C	OW	Fish, Macroinvertebrates	43.26991	-86.22967	79±1	0±0	0±0
2018	East-A	OW	Fish, Macroinvertebrates	43.27122	-86.22714	89±6	0±0	0±0
2018	East-B	WM	Macroinvertebrates	43.27225	-86.22588	17±1	0±0	82±2
2018	West-C	WM	Macroinvertebrates	43.27054	-86.22975	23±2	0±0	63±2
2022	West-B	OW	Fish, Macroinvertebrates	43.27000	-86.23161	80±13	5±3	0±0
2022	West-C	OW	Fish, Macroinvertebrates	43.27058	-86.22952	89±3	3±3	3±2
2022	East-A	OW	Fish, Macroinvertebrates	43.47149	-86.22727	68±12	3±2	4±1
2022	East-B	WM	Macroinvertebrates	43.27227	-86.22551	27±2	0±0	50±6
2022	West-C	WM	Macroinvertebrates	43.27153	-86.22905	13±1	0±0	35±9

Table 2. Mean ± 1 standard error (*n* = 3) of water quality variables at fish and macroinvertebrate sampling sites at the Bosma Property. Measurements were made with a YSI sonde. Fish were sampled in open-water (OW) zones; macroinvertebrates were sampled in open-water and wet-meadow (WM) zones. Measurements for macroinvertebrates were concurrent with fish fyke net measurements for open-water zones.

Site	Date of Measurement	Zone	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Specific Conductivity (µS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Chlorophyll *a* (ug/L)
West-B	8/15/2018	OW	26.20±0.26	3.84±0.97	47.97±12.45	802±1	0.52±0.000	8.0±0.8	7.44±0.04	106.6±11.4
West-C	8/15/2018	OW	27.72±0.73	4.42±2.22	56.60±28.78	818±6	0.53±0.004	9.3±1.0	7.27±0.21	93.6±4.6
East-A	8/17/2018	OW	24.54±0.11	0.45±0.09	5.53±1.09	753±3	0.49±0.001	11.3±0.2	7.07±0.06	74.7±4.8
East-B	8/22/2018	WM	17.51±0.52	0.64±0.13	6.80±1.40	699±30	0.45±0.020	26.7±9.3	6.42±0.07	98.3±3.2
West-C	8/22/2018	WM	20.21±0.82	0.60±0.06	6.70±0.72	806±31	0.52±0.020	15.7±0.9	6.43±0.04	74.2±11.5
West-B	6/20/2022	OW	22.29±0.27	9.29±0.36	107.00±4.74	370±0	0.24±0.000	3±0.6	8.17±0.05	7.5±0.3
West-C	6/20/2022	OW	22.76±0.24	8.69±0.21	101.07±2.87	367±0	0.24±0.000	5.1±0.5	8.16±0.04	7.2±1.0
East-A	6/20/2022	OW	23.46±0.22	9.12±0.18	107.43±3.26	369±0	0.24±0.000	23.4±6.1	8.19±0.04	12.5±1.4
East-B	6/22/2022	WM	27.91±0.14	8.74±1.86	111.87±24.02	380±4	0.25±0.003	3.6±1.2	8.16±0.34	11.1±0.1
West-C	6/22/2022	WM	25.12±1.52	3.35±0.13	40.93±2.37	397±9	0.26±0.006	1.8±0.7	7.31±0.08	23.4±3.2

Note: If the SE = 0, then the value was < 0.5 µS/cm for specific conductivity and < 0.0005 g/L for total dissolved solids.

Table 3. Number and mean total length (TL; range reported parenthetically) of fish captured by fyke netting (*n* = 3 nets per site) at the Bosma Property on 15 and 17 August 2018. Fish were only sampled in open-water zones.

		West-B		West-C		East-A		
Common name	Scientific name	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)	Grand Total
common carp	*Cyprinus carpio*	247	6.3 (2.5-42.0)	46	4.1 (2.1-7.8)	0	--	293
pumpkinseed	*Lepomis gibbosus*	536	4.9 (3.1-14.8)	24	4.7 (3.7-8.6)	0	--	560
bluegill	*Lepomis macrochirus*	311	3.8 (2.2-8.6)	59	3.7 (2.4-5.0)	0	--	370
golden shiner	*Notemigonus crysoleucas*	50	8.0 (4.8-10.3)	8	5.8 (4.5-9.1)	1	8.9	59
fathead minnow	*Pimephales promelas*	174	6.0 (3.5-7.4)	15	5.3 (4.0-7.0)	0	--	189
central mudminnow	*Umbra limi*	9	8.2 (6.8-9.7)	5	5.7 (5.0-7.0)	92	6.1 (3.8-11.2)	106
	Total	**1327**		**157**		**93**		**1577**

Table 4. Number and mean total length (TL; range reported parenthetically) of fish captured by fyke netting (*n* = 3 nets per site) at the Bosma Property on 21 June 2022. Fish were only sampled in open-water zones.

		West-B		West-C		East-A		
Common name	Scientific name	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)	Grand Total
bluegill	*Lepomis macrochirus*	0	--	21	15.7 (5.4-20)	5	11.1 (5.4-19.4)	26
bowfin	*Amia calva*	1	58.2	5	65.2 (62.9-68.5)	4	52.3 (49.6-53.4)	10
brook silverside	*Labidesthes sicculus*	1	8.9	2	8.1 (7.7-8.4)	0	--	3
brown bullhead	*Ameiurus nebulosus*	0	--	2	27.3 (26-28.5)	0	--	2
emerald shiner	*Notropis atherinoides*	0	--	0	--	2	5.7 (5.1-6.3)	2
fathead minnow	*Pimephales promelas*	1	6.1	1	6.6	2	5.8 (4.8-6.7)	4
largemouth bass	*Micropterus salmoides*	1376	2.4 (2.0-3.1)	3	2.2 (2.1-2.3)	8	2.9 (2.5-3.5)	1387
northern pike	*Esox lucius*	0	--	1	46	0	--	1
pumpkinseed	*Lepomis gibbosus*	32	7 (4.1-14.7)	42	12.4 (4.1-19.2)	133	5.7 (4.4-10.1)	207
rock bass	*Ambloplites rupestris*	0	--	0	--	1	14.0	1
silver redhorse	*Moxostoma anisurum*	2	40.5 (33.7-47.2)	0	--	0	--	2
yellow bullhead	*Amieurus natalis*	1	38.4	0	--	0	--	1
yellow perch	*Perca flavescens*	5	11.4 (3.2-21.4)	3	8.2 (2.3-19.3)	7	9.8 (2.7-12.5)	15
	Total	**1419**		**80**		**162**		**1661**

Table 5. Lists of macroinvertebrate taxa captured at the Bosma Property during August 2018 and June 2022. An * indicates that those individuals were not identified beyond either class/sub-class/order or family. An “x” denotes presence in a sampling year.

Class/Sub-Class/Order	Family	Genus	2018	2022
Acari	*	*	x	x
Amphipoda	Crangonyctidae	Crangonyx	x	
Amphipoda	Gammaridae	*Gammarus*		x
Amphipoda	Hyalellidae	*Hyalella*	x	x
Arhynchobdellida	Erpobdellidae	*	x	
Coleoptera	Dytiscidae	*	x	x
Coleoptera	Haliplidae	*Haliplus*	x	
Coleoptera	Haliplidae	*Peltodytes*	x	x
Coleoptera	Hydrophilidae	*Berosus*		x
Coleoptera	Hydrophilidae	*Enochrus*	x	x
Coleoptera	Hydrophilidae	*Hydrochus*	x	
Coleoptera	Hydrophilidae	*Tropisternus*	x	x
Coleoptera	Lampyridae	*	x	
Coleoptera	Noteridae	*Hydrocanthus*	x	x
Coleoptera	Noteridae	*Suphisellus*	x	
Coleoptera	Scirtidae	*Cyphon*	x	
Coleoptera	Scirtidae	*Scirtes*	x	
Collembola	*	*		x
Diptera	Ceratopogonidae	*Bezzia/Palpomyia*	x	
Diptera	Ceratopogonidae	*		x
Diptera	Chaoboridae	*Chaoborus*	x	
Diptera	Chironomidae (Pseudochironomini/Chironomini)	*	x	x
Diptera	Chironomidae (Orthocladiinae)	*		x
Diptera	Chironomidae (Tanypodinae)	*	x	x
Diptera	Chironomidae (Tanytarsini)	*	x	x
Diptera	Chironomidae	*		x
Diptera	Culicidae	*Mansonia/Coquillettidia*	x	
Diptera	Culicidae	*		x
Diptera	Stratiomyidae	*Odontomyia*	x	
Diptera	Stratiomyidae	*Odontomyia/Hedriodiscus*	x	x
Diptera	Tipulidae	*	x	x
Ephemeroptera	Baetidae	*Callibaetis*	x	x
Ephemeroptera	Baetidae	*Centroptilum/Procloeon*		x
Ephemeroptera	Baetidae	*Pseudocloeon*		x
Ephemeroptera	Caenidae	*Caenis*	x	x
Ephemeroptera	Ephemeridae	*Hexagenia*		x
Ephemeroptera	Heptageniidae	*Maccaffertium*		x
Ephemeroptera	Heptageniidae	*		x
Ephemeroptera	Siphlonuridae	*Siphlonurus*		x
Gastropoda	Lymnaeidae	*Lymnaea*		x
Gastropoda	Physidae	*Physa*	x	x
Gastropoda	Planorbidae	*Gyraulus*	x	x
Gastropoda	Planorbidae	*Helisoma*		x
Gastropoda	Planorbidae	*		x
Gastropoda	Succineidae	*Succinea*	x	
Hemiptera	Belostomatidae	*Belostoma*	x	
Hemiptera	Belostomatidae	*		x
Hemiptera	Corixidae	*Hesperocorixa*	x	x
Hemiptera	Corixidae	*Sigara*		x
Hemiptera	Corixidae	*Trichocorixa*	x	x
Hemiptera	Corixidae	*		x
Hemiptera	Gerridae	*		x
Hemiptera	Mesovelidae	*Mesovelia*		x
Hemiptera	Naucoridae	*		x
Hemiptera	Nepidae	*Ranatra*		x
Hemiptera	Notonectidae	*		x
Hemiptera	Pleidae	*Neoplea*	x	x
Isopoda	Asellidae	*Caecidotea*	x	x
Megaloptera	Corydalidae	*Chauliodes*		x
Odonata	Aeshnidae	*Anax*		x
Odonata	Aeshnidae	*		x
Odonata	Coenagrionidae	*Enallagma*		x
Odonata	Coenagrionidae	*Ischnura*	x	
Odonata	Coenagrionidae	*		x
Odonata	Corduliidae	*Epitheca*	x	
Odonata	Libellulidae	*Erythemis*	x	x
Odonata	Libellulidae	*Pachydiplax*	x	
Odonata	Libellulidae	*Sympetrum*		x
Oligochaeta	*	*	x	x
Plecoptera	Perlidae	*Perlesta*		x
Trichoptera	Leptoceridae	*Nectopsyche*		x
		Count	39	54

Note: Subfamily or tribe is listed in parentheses for Chironomidae.

Table 6. Mean ± 1 standard error (*n* = 3) for variables related to field collection of macroinvertebrates at the Bosma Property. Macroinvertebrates were sampled in open-water (OW) and wet-meadow (WM) zones.

Site	Date of Collection	Zone	Number of 1-m Net Sweeps	Person-Minutes Spent Picking (min)	Number of Macroinvertebrates Picked
West-B	8/16/2018	OW	13.0±0.0	42.8±7.1	83.3±16.7
West-C	8/14/2018	OW	15.3±1.5	98.9±31.2	50.0±0.0
East-A	8/15/2018	OW	12.0±0.0	39.6±4.5	66.7±16.7
East-B	8/22/2018	WM	23.0±1.5	54.1±1.4	83.3±16.7
West-C	8/22/2018	WM	21.0±1.0	54.6±9.1	50.0±0.0
West-B	6/20/2022	OW	21.7±1.2	43.9±17.7	116.7±33.3
West-C	6/20/2022	OW	30.7±6.3	30.6±1.3	116.7±16.7
East-A	6/20/2022	OW	28.3±2.4	43.5±4.7	116.7±16.7
East-B	6/22/2022	WM	17.3±2.0	40.7±5.2	133.3±16.7
West-C	6/22/2022	WM	18.3±0.9	40.1±4.3	133.3±16.7

Table 7. Taxa composition of macroinvertebrates captured at the Bosma Property in August 2018. An * indicates that those individuals were not identified beyond Class/Sub-Class/Order. Site locations are given in Figure 1. OW is the open-water zone, and WM is wet-meadow zone.

Class/Sub-Class/Order	Family	East-A OW	East-B WM	West-B OW	West-C OW	West-C WM	Grand Total
Acari	*	3		7	2		12
Amphipoda	Crangonyctidae					2	2
Amphipoda	Hyalellidae	3		1		2	6
Arhynchobdellida	Erpobdellidae		2			1	3
Coleoptera	Dytiscidae		13			7	20
Coleoptera	Haliplidae		2				2
Coleoptera	Hydrophilidae		34		1	9	44
Coleoptera	Lampyridae		1			1	2
Coleoptera	Noteridae		4			4	8
Coleoptera	Scirtidae		40			26	66
Diptera	Ceratopogonidae	39		3	5		47
Diptera	Chaoboridae	1					1
Diptera	Chironomidae	53	13	78	33	5	182
Diptera	Culicidae		20			29	49
Diptera	Stratiomyidae		4			7	11
Diptera	Tipulidae		2				2
Ephemeroptera	Baetidae	3		1	1		5
Ephemeroptera	Caenidae	6	1	59	23		89
Gastropoda	Physidae	22	26		1	2	51
Gastropoda	Planorbidae	2	1		1		4
Gastropoda	Succineidae		1				1
Hemiptera	Belostomatidae		11			11	22
Hemiptera	Corixidae	11		78	31		120
Hemiptera	Pleidae	33	73		2	17	125
Isopoda	Asellidae	1		1	3	7	12
Odonata	Coenagrionidae	1	7	9		1	18
Odonata	Corduliidae			1			1
Odonata	Libellulidae		2				2
Oligochaeta	*	27	13	12	48	24	124
	Total	205	270	250	151	155	1031

Table 8. Taxa composition of macroinvertebrates captured at the Bosma Property in June 2022. An * indicates that those individuals were not identified beyond Class/Sub-Class/Order. Site locations are given in Figure 1. OW is the open-water zone, and WM is wet-meadow zone.

Class/Sub-Class/Order	Family	East-A OW	East-B WM	West-B OW	West-C OW	West-C WM	Grand Total
Acari	*	5	4	2	2		13
Amphipoda	Gammaridae	44		39	8		91
Amphipoda	Hyalellidae	12	28	6	5	1	52
Coleoptera	Dytiscidae		32			48	80
Coleoptera	Haliplidae		5				5
Coleoptera	Hydrophilidae		8			41	49
Coleoptera	Noteridae		1			3	4
Collembola	*					4	4
Diptera	Ceratopogonidae		23			20	43
Diptera	Chironomidae	184	79	91	166	87	607
Diptera	Culicidae		1				1
Diptera	Stratiomyidae					1	1
Diptera	Tipulidae		1			4	5
Ephemeroptera	Baetidae	34	42	155	85	78	394
Ephemeroptera	Caenidae	59	5	34	103		201
Ephemeroptera	Ephemeridae	17		1	1		19
Ephemeroptera	Heptageniidae	3					3
Ephemeroptera	Siphlonuridae			1		2	3
Gastropoda	Lymnaeidae	1	3			2	6
Gastropoda	Physidae	6	137	4		92	239
Gastropoda	Planorbidae	3	9			6	18
Hemiptera	Belostomatidae		4			9	13
Hemiptera	Corixidae		8	7		20	35
Hemiptera	Gerridae		1				1
Hemiptera	Mesovelidae					1	1
Hemiptera	Naucoridae		3				3
Hemiptera	Nepidae		1			3	4
Hemiptera	Notonectidae		13			9	22
Hemiptera	Pleidae		6			4	10
Isopoda	Asellidae			2			2
Megaloptera	Corydalidae		1				1
Odonata	Aeshnidae	1	17			13	31
Odonata	Coenagrionidae	2	7	2	3	2	16
Odonata	Libellulidae		6				6
Oligochaeta	*	2	1	9	1	2	15
Plecoptera	Perlidae	1					1
Trichoptera	Leptoceridae	1					1
	Total	375	446	353	374	452	2000

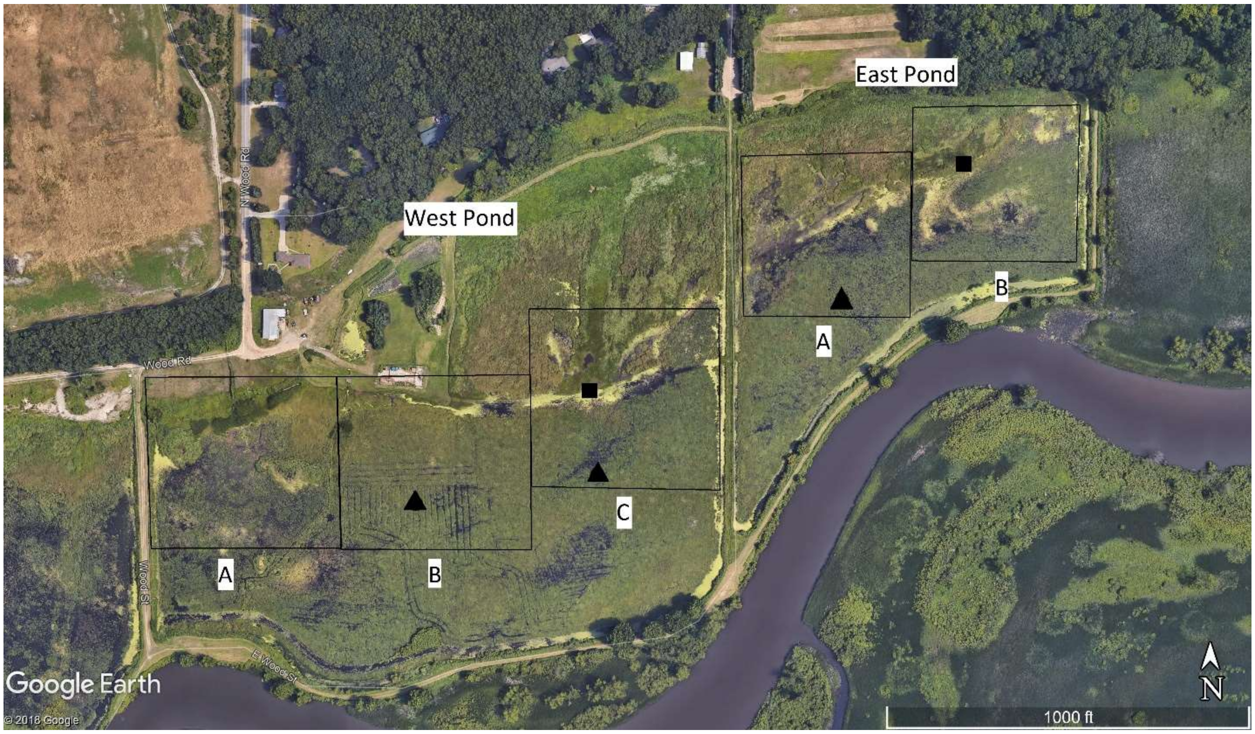

Figure 1. Map of Bosma Property (Muskegon County, Michigan). Fish and macroinvertebrate sampling was conducted in the East Pond and West Pond. Black triangles represent sampling locations of open-water zones, and black squares represent sampling locations of wet-meadow zones. This image shows the Bosma Property prior to restoration.

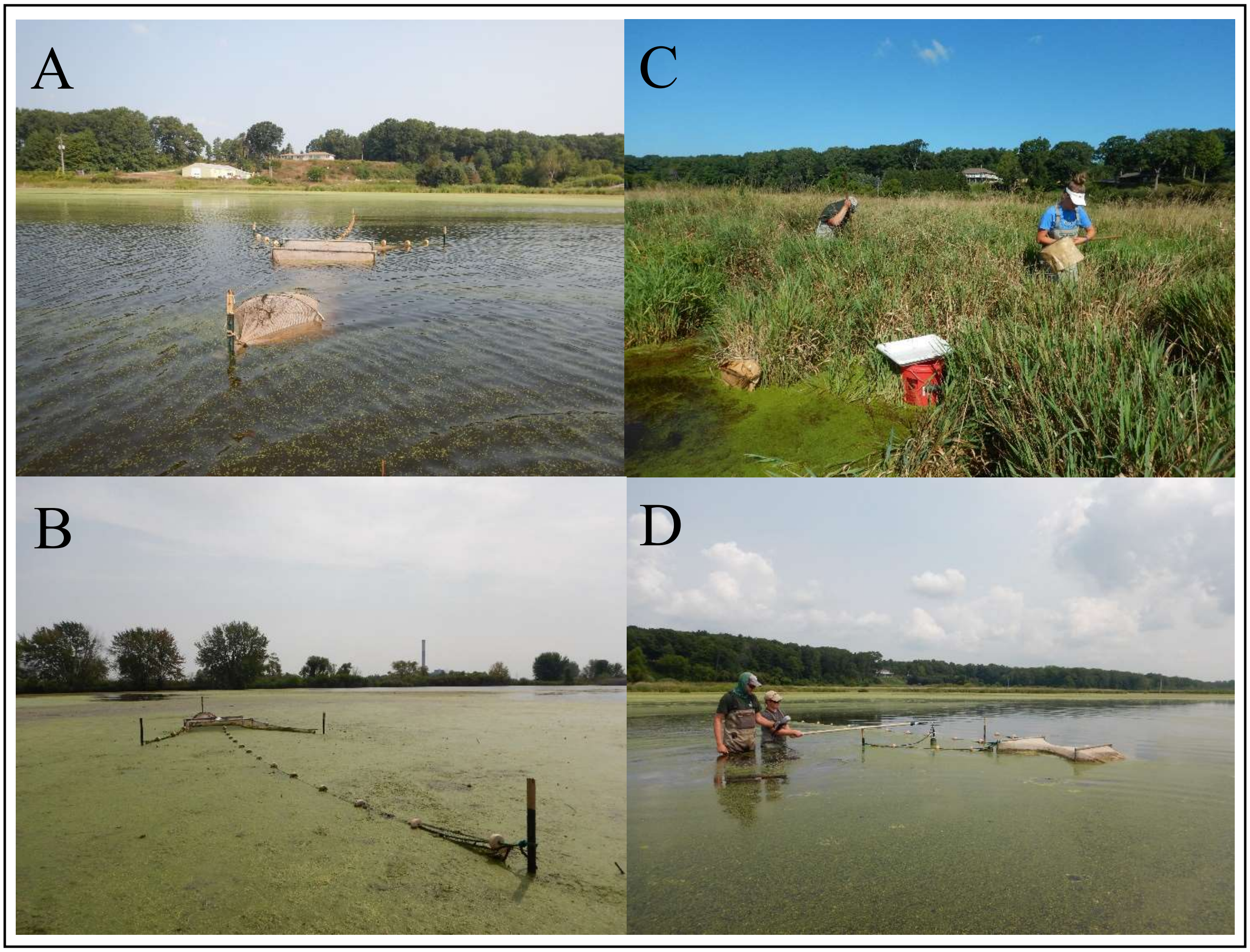

Figure 2. Photos taken while sampling the Bosma Property in August 2018. (**A**) A single fyke net set in an open-water zone in the West Pond. (**B**) The mouth and lead of a fyke net. (**C**) Macroinvertebrates collected using D-nets in a wet-meadow zone. (**D**) Water chemistry variables measured at the mouth of a fyke net mouth using a YSI sonde.

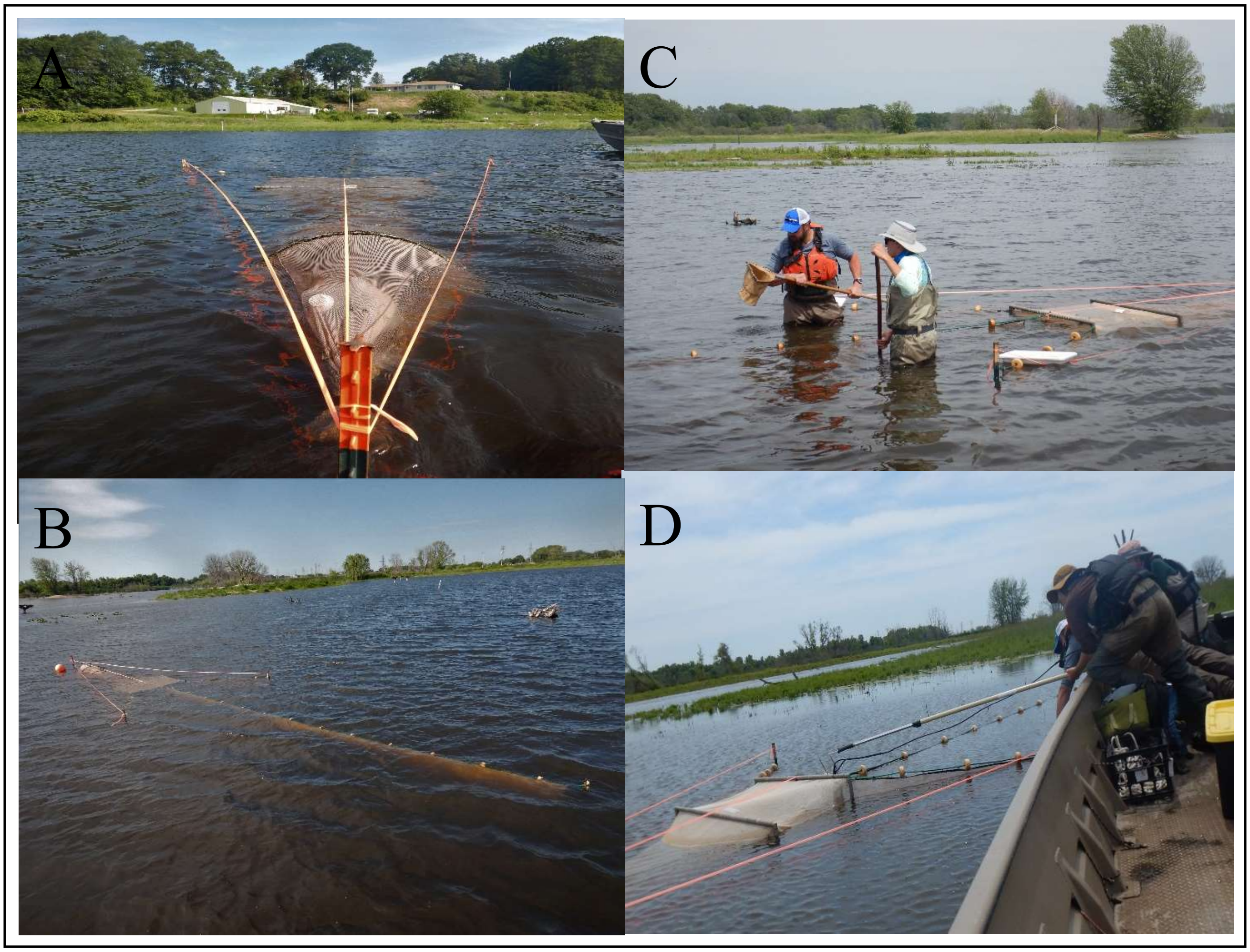

Figure 3. Photos taken while sampling the Bosma Property in June 2022. (**A**) A single fyke net set in an open-water zone in the West Pond. (**B**) The mouth and lead of a fyke net; reconnection of wetland to the Muskegon River can be seen top left. (**C**) Macroinvertebrates being collected using D-nets at an open-water zone. (**D**) Water chemistry variables measured at the mouth of a fyke net using a YSI sonde from a boat.

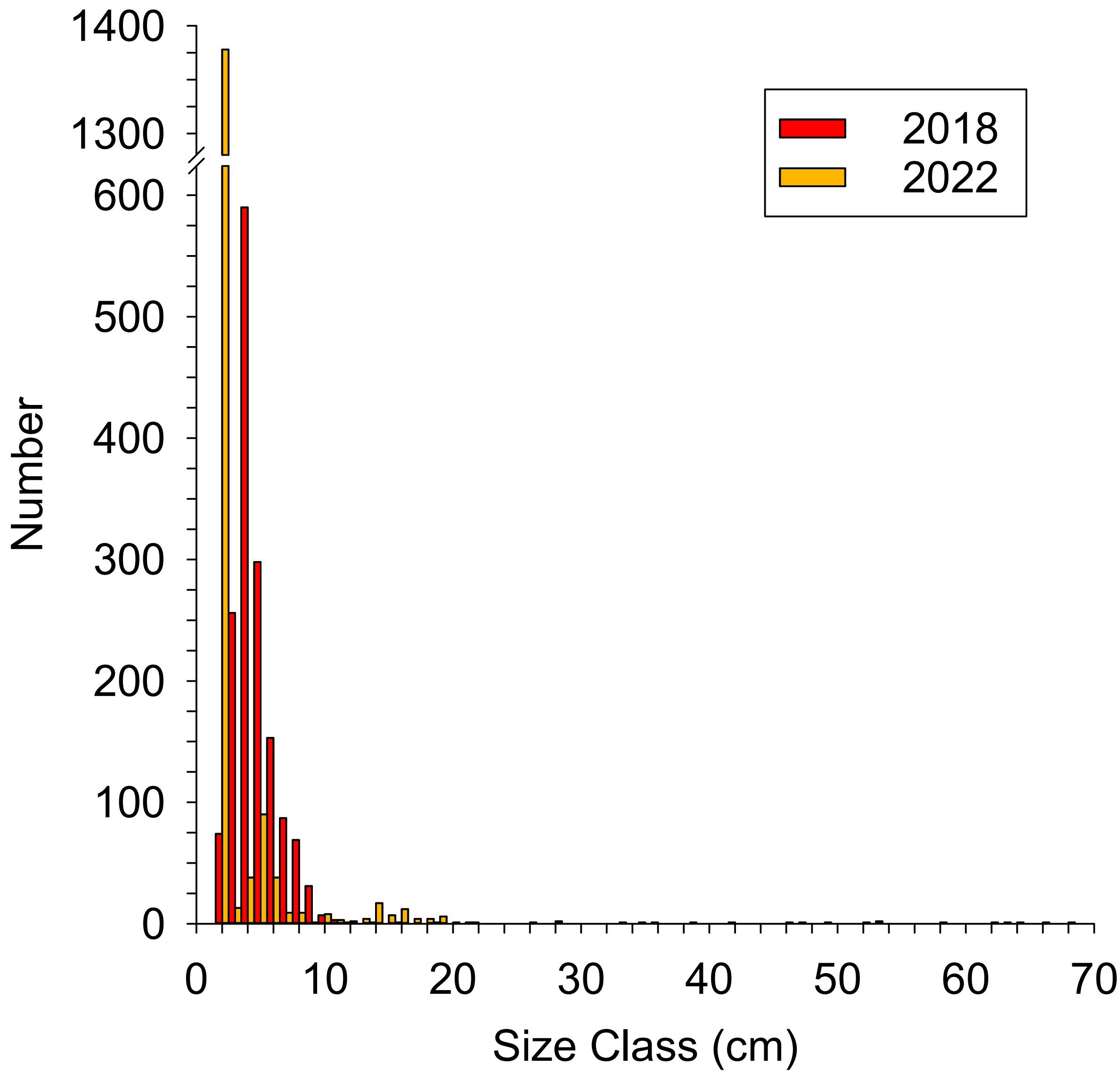

Figure 4. Size distribution for fish captured at the Bosma Property by fyke netting (*n* = 9 nets per year) during August 2018 and June 2022. Values on the *x* axis represent the start of each 1-cm size class (e.g., the 4-cm size class represents fish with a total length [TL] ranging from 4.0 cm to 4.9 cm). The largest fish captured was 42.0 cm TL in 2018 and 68.5 cm TL in 2022. Additionally, the large number of fish in the 2-cm size class captured during 2022 (i.e., 1,378 individuals) were largemouth bass (Table 4).

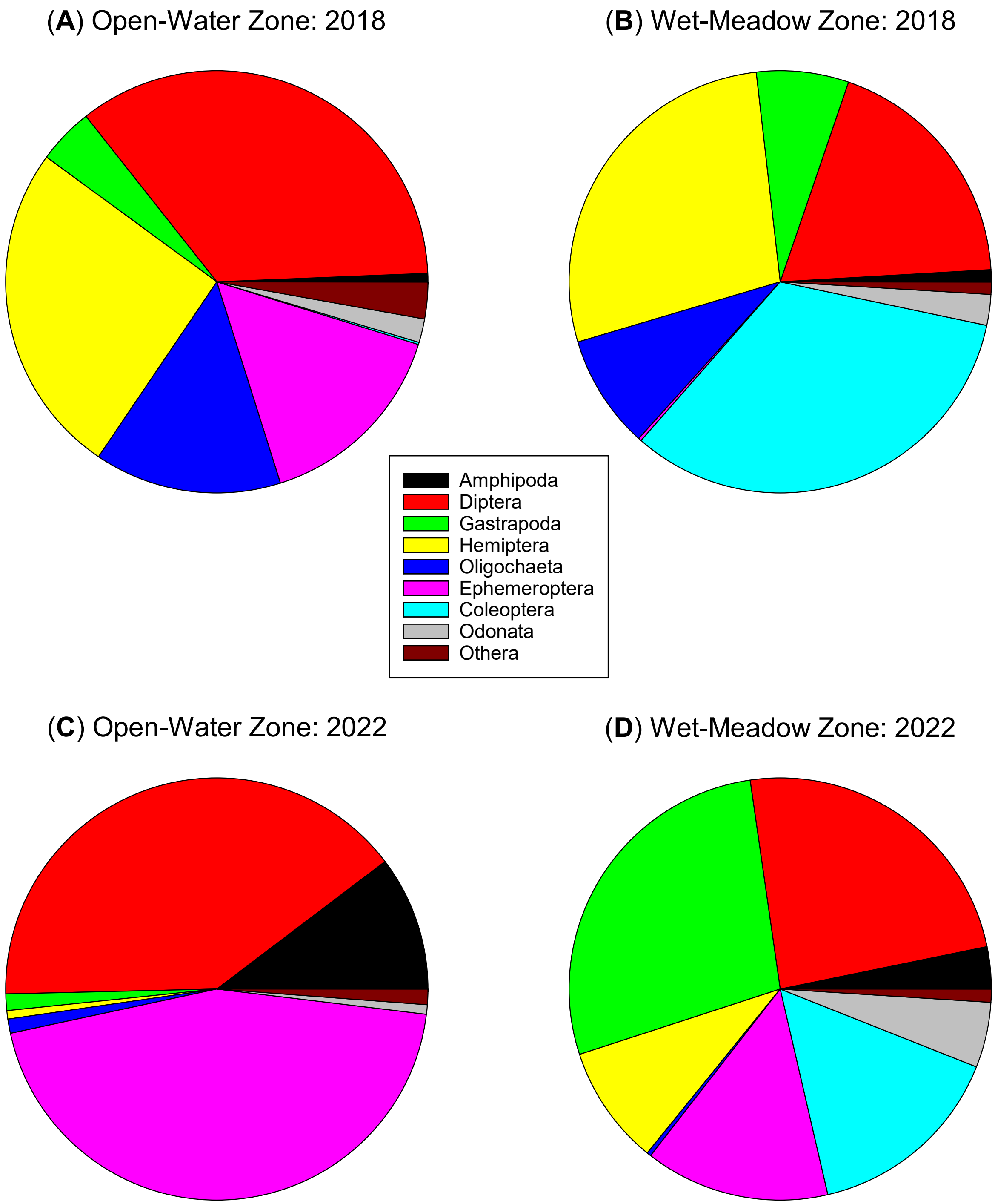

Figure 5. Macroinvertebrate taxa captured at the Bosma Property by D-frame dip nets during August 2018 and June 2022 (*n* = 9 for open-water zone replicates per year and *n* = 6 for wet-meadow zone replicates per year).