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Return of Floodplain Connectivity and Concurrent Macroinvertebrate Community Response Following Wetland Restoration in Western Kentucky

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Return of Floodplain Connectivity and Concurrent Macroinvertebrate Community Response Following Wetland Restoration in Western Kentucky

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Return of Floodplain Connectivity and Concurrent Macroinvertebrate Community Response Following Wetland Restoration in Western Kentucky

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Abstract

Wetlands improve the quality of our nation's streams, rivers, and lakes, and they support a diverse assemblage of plant and animal species. The U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) is responsible for administering the Wetland Reserve Program (WRP), a multi-billion-dollar effort to restore wetlands throughout the nation. Each year, WRP enrolls thousands of acres of private farmland into conservation easements with the goal of improving water quality and creating wildlife habitat. Hydrological modification structures, such as levee breaks, ditch plugs, or shallow water areas are constructed on easements to create wetlands by improving water retention and returning floodplain connectivity to adjacent rivers. The main objectives of my study were to assess the efficacy of these hydrological modifications and to quantify macroinvertebrate diversity, abundance, and secondary production on easements enrolled in WRP. My study sites included restoration easements of various ages as well as mature bottomland forests, which represent pre-disturbance "reference" wetlands, and low-quality, drained wetlands. A combination of pressure transducers, LiDAR, and drone imagery was used to determine wetland extent and hydroperiod on each easement. Macroinvertebrates were collected monthly from each wetland with stovepipe cores and dip-net sweeps. The results of my study indicate that hydrological modification structures allow easement wetlands to capture and retain floodwaters throughout the year. Insects accounted for 12.6% of the total abundance in degraded wetlands and increased to 26.5% in WRP easements and to 65.5% in reference wetlands. There was no statistical difference in annual production (g DM/m^2), abundance, or biomass, diversity between wetland types. However, we found a wide range of annual production (850 to 7,746 mg DM/m^2) and relative abundance of emergent taxa (<20% to >80%) among individual wetlands. Non-insect taxa were important to total biomass, and total Mollusk biomass decreased from 63% in degraded wetlands to 2.3% in reference wetlands. The frequency, intensity, and duration of inundation at each site were the primary variables influencing invertebrate community structure. Because new easements are permanently enrolled, there is tremendous potential to quantify the physical and biological changes for years or decades following enrollment. Understanding how these easements respond to restoration will provide opportunities for adaptive management, which can play a critical role in the protection, restoration, and creation of imperiled wetland ecosystems.

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Introduction

Wetlands are some of the most important and productive ecosystems on the planet. They provide a wide variety of renewable ecosystem services, which are valued at nearly US $33 trillion per year (Zedler 2000). Wetlands maintain and improve the quality of our nation's freshwater resources by filtering excess pollutants and sediments from surface runoff and transforming nutrients (Hunter et al. 2008; Meyer and Whiles 2008; Stewart and Downing 2008). More specifically, wetlands can reduce excessive and problematic nutrient loads from agricultural lands, including those that contribute to the algal blooms and hypoxia of the Gulf of Mexico’s dead zone (Mitsch et al. 2001; Cheng et al. 2020). Wetlands and floodplains can alleviate the devastating effects of flooding, which is the most frequent and fatal disaster in many regions of the United States (Watson et al. 2016). Furthermore, wetland habitat supports and produces a diverse assemblage of plant and animal species, including many that are dependent on wetlands for critical life stages (Mitch and Gosselink 2015).

Although wetlands are extremely valuable to the health and maintenance of ecosystems throughout the United States, they were often destroyed and reclaimed for other purposes, primarily agriculture (Benson et al. 2018). A report by the U.S. Department of Agriculture’s Natural Resources Conservation Service (USDA-NRCS) estimates that half a million wetland acres were drained annually in the United States from the mid-1950s to the mid-1970s (Sucik and Marks 2010). As a result, the continental U. S. lost 53% of its natural wetlands (Zedler and Kercher 2005; Guidugli-Cook et al. 2017). This large-scale land conversion, while increasing agricultural productivity, has eliminated valuable wetland function (MacDonald et al. 1979; Skaggs et al. 1994; Zedler 2000).

The recent recognition of ecological services provided by wetlands has stimulated efforts to restore wetlands to their pre-disturbance conditions (Zedler 2000; Uuema et al. 2018). The main goals of these restorations often include wildlife conservation (Stewart and Downing 2008), water quality improvement (Mitsch et al. 2001; Stewart and Downing 2008), nutrient removal (Groffman and Hanson 1997; Cheng et al. 2020)), and regional biodiversity improvement (Zedler 2000). These restorations are conducted on a variety of wetlands, like swamps (Dierberg and Brezonik 1985), fens (Koerselman et al. 1989), marshes (Comin et al. 1997), floodplains (Mitsch et al. 2001), and riparian forests (Peterjohn and Correll 1984).

The conservation and restoration of wetlands are now bolstered by a myriad of federal laws including the Clean Water Act of 1972 and the Food Security Act of 1985. To compensate for past and present wetland loss, federal mandates include "swampbuster" provisions and "no-net loss" policies, which deny federal subsidies to farm and business owners for draining wetlands (Mitsch and Gosselink 2015). Furthermore, the Food Security Act of 1985 appointed the USDA-NRCS as the primary federal wetland advisory agency responsible for developing conservation practices and their associated technical standards and specifications (NRCS 2014).

As of 1990, USDA-NRCS has also been responsible for administering the Wetland Reserve Program (WRP). The primary goal of the WRP is to "achieve the greatest wetland function and values, along with optimum wildlife habitat, on every acre enrolled in the program" (NRCS 2014). In the Midwest, the WRP aims to reduce sediments and nutrients and improve the quality of water entering the Mississippi River. To accomplish this, the USDA-NRCS provides landowners with financial incentives and technical support to retire farmland in perpetuity from agricultural production and to restore the previous hydrology or to conserve or maintain existing wetlands (Benson et al. 2018; Brasher et al. 2007; Tapp and Webb 2015). While federal conservation efforts have been made on public land, projects are primarily focused on private land, which is where the greatest wetland losses have occurred (Zedler 2003). Since 1989, the USDA has spent nearly US$4.2 billion on wetland restoration (Cheng et al. 2020) and enrolled 2.35 million acres into WRP nationwide (NSAC 2010).

The WRP is the primary conservation and restoration program within the Mississippi Alluvial Valley (MAV), an area of the United States that has undergone dramatic wetland loss. The alluvial valley of the Mississippi River originates at the confluences of the Ohio and Mississippi Rivers near Cairo, Illinois, USA. The valley extends approximately 1000 km south toward the Gulf of Mexico. Prior to European colonization, the MAV was dominated by bottomland hardwood forests (BLH) and wetlands adjacent and hydrologically connected to the Mississippi River and its major tributaries (King and Keeland 1999; Faulkner et al. 2011). BLH are floodplain forests which are periodically inundated by a variety of upland sources and backwater flooding from adjacent or nearby rivers and streams (Hunter et al. 2008). These wetlands are important for water quality improvement and flood control within the MAV (King and Keeland 1999). The structure and function of these forests is primarily determined by the frequency, duration, and timing of flooding (King and Keeland 1999). Overbank flooding from nearby rivers has made BLH one of the most productive forests on earth (King and Keeland 1999). These floodplain wetlands contained mast-producing oaks and hickories and protein-rich aquatic invertebrates, which made the BLH an important stop for migrating and wintering waterfowl (Fredrickson and Heitmeyer 1988; Brasher et al. 2007; Hubert and Krull 1973).

Large-scale hydrological modifications within the MAV, including levees, river channelization, and artificial drainage, have reduced the frequency and extent of flooding, altered the flood-pulse cycle, and reduced the sediment and nutrient loading in these floodplain ecosystems (Frederickson 1979; Hunter et al. 2008; Faulkner et al. 2011). Furthermore, the extensive flood-protection modifications have minimized overbank flooding and eliminated most of these riverine wetlands (Faulkner et al. 2011). Today, only 25% of the original bottomland hardwood forest in the MAV remains (Rudis 1995, MacDonald et al. 1979), and small forested wetland tracts are scattered throughout a large, agricultural matrix (Twedt and Loesch 1999). The land-use conversion and degradation within the MAV has been so extensive that the historic floodplains are now considered an endangered ecosystem (Noss et al. 1995).

The destruction of bottomland forests and riverine wetlands within the MAV has led to the implementation of a variety of public and private conservation practices designed to restore ecosystem services. As a result, approximately 45,000 ha of bottomland hardwoods have been reforested (Faulkner et al. 2011). Reforestation techniques often involve the planting of flood-tolerant hardwood species, such as *Quercus* sp. and *Carya* sp. (Faulkner et al. 2011). The WRP has been responsible for the enrollment and restoration of nearly 215,000 ha of wetlands in the MAV (NRCS 2010). Oftentimes, USDA-NRCS purchases marginal farmland in riparian corridors prone to flooding by streams and rivers. Because hydrologic connectivity is an integral and indispensable aspect of riverine wetland function (Hodges 1997), restoration efforts on these WRP easements include the construction or demolition of levees, the plugging of drainage ditches, and the addition of shallow water depressions.

While the restoration goal or wetland type may vary, the measure of success is often the same: return of pre-disturbance function. Although wetland restorations are widely attempted, recovery of ecosystem structure and function remain uncertain (Benson et al. 2018; Brasher et al. 2007; Meyer and Whiles 2008; Moreno-Mateas 2012). Oftentimes, restoration projects will not include the necessary monitoring to evaluate success (Burnhardt et al. 2007; Follastad-Shah

2007; Palmer et al. 2014) because few resources are allocated or available for a thorough evaluation (Bash and Ryan 2002). Monitoring projects may also lack sufficient scale (Maresch et al. 2008), duration (Zedler 2000), or replication (Wallace and Webster 1996). Restoration projects often fail to mimic complex wetland hydrologic conditions, and they may be in poor locations relative to human-altered landscapes (Mitsch and Wilson 1996; Tarr et al. 2005). Notions of recovery or success may be misinterpreted because of confounding variables and limited knowledge of individual wetland function or target wetland conditions (Mitsch and Wilson 1996; Burnhardt et al. 2007; Palmer et al. 2014). While results from some project-level assessments generally indicate that restoration is successful, extrapolating results to other types of restoration projects may be misleading (National Research Council 2001). Furthermore, the science behind the creation and restoration of wetlands is a relatively novel field, which continues to add new principles and techniques (Mitsch and Gosselink 2015).

Although there is still little consensus as to which ecological or environmental metrics define a successfully restored wetland (Marchetti et al. 2010), the examination of the local aquatic macroinvertebrate community is generally considered an effective method of assessment. Aquatic macroinvertebrates are excellent indicators of water quality (Hilsenhoff 1987; Wallace and Webster 1996; Campbell et al. 2002; EPA 2002; Meyer et al. 2011), and they are numerous and widely distributed (Hering et al. 2003). Macroinvertebrates are vital to freshwater ecosystem processes; they influence the rate of nutrient cycling and the decomposition of organic matter (Marchetti et al. 2010; Meyer et al. 2011). Macroinvertebrates have a central position in wetland food webs and are subject to both bottom-up and top-down forces (Marchetti et al. 2010). They provide an important food source for a variety of riparian consumers including fish, amphibians, bats, songbirds, and migrating waterfowl (Mitsch and Gosselink 2015).

Macroinvertebrate taxa often have different environmental requirements that produce unique community assemblages (Stewart and Downing 2008). These communities often reflect local ecological conditions, such as primary production, plant community characteristics, and the ability of a wetland to support vertebrates or remove pollutants (Wissinger 1999). The return of wetland function is reflected by the taxonomic composition of the resident aquatic macroinvertebrate community, especially if that community closely resembles the abundance and diversity of those found in natural wetland systems (Stewart and Downing 2008).

Because restoration ecology, especially wetland restoration, is a relatively new field, there exists a great need for refinement of restoration techniques (Mitsch and Wilson 1996) and the associated ecological monitoring to measure success (Lake 2001). Furthermore, some wetlands restored through WRP are in the early stages of restoration while others have been enrolled since the early 2000s. Easement wetlands encompass a wide variety of physical and biological characteristics along with hydrological restoration practices. Monitoring these characteristics over time following enrollment provides an opportunity for the direct evaluation of restoration practices and outcomes. Therefore, my main objectives for this study were to assess wetland restoration on land enrolled in WRP by 1) determining if hydrological restorations could return and sustain floodplain connectivity and 2) quantifying and comparing aquatic macroinvertebrate biomass, abundance, production, richness, and functional structure to minimally disturbed, reference wetlands and to low-quality wetlands on agricultural fields still in row crop production.

Study Area

Kentucky

A small portion of western Kentucky lies at the very northern extent of the MAV. Kentucky, like many other states, has experienced massive declines in total wetland area. Although merely 6% of Kentucky's historic land cover consisted of wetlands prior to colonization, more than 80% had been destroyed by the 1990's (Dahl 1990). In Kentucky, wetlands follow a particular west to east pattern, with more and larger wetlands occurring at the western portion of the state (USGS 1990). Larger wetlands reside in the floodplains of the Mississippi, Ohio River, and other large streams. These riverine wetlands are hydrologically connected and regularly flooded by their neighboring streams and creeks, and they stay wetter for much longer than others throughout the state (Abernathy et al. 2010). However, most of Kentucky wetlands are small, between 1.21 and 4 ha (Guidugli-Cook et al. 2017). There have been few studies examining the location and condition of Kentucky's wetlands. A study by Guidugli-Cook et al. (2017) concluded that most wetlands throughout Kentucky are considered of moderate quality, with limited wetland function. Like the rest of the country, most of Kentucky's wetlands (75%) reside on privately owned land (EPA 2001).

At the far western end of Kentucky lies the Bayou de Chien (BDC) watershed (HU 08010201), which was identified by the Mississippi River Basin Initiative as a major contributor of sediment and nutrient runoff to the Gulf of Mexico. It is located at the northern tip of the MAV and encompasses three large tributaries of the Mississippi River –Mayfield Creek, Obion Creek, and the Bayou de Chien. The watershed has a total surface area of 251,400 ha. According to the National Land Cover Database, as of 2016, the BDC is categorized as 66 % row-crop agriculture and pastureland, 20% forested and grassland, and 5% urban development. Most of the watershed has been converted from bottomland hardwood forest to row crop agriculture and pasture, with modifications including the construction of drainage ditches and levees along the largest rivers. Forested wetland areas are generally restricted to land adjacent to creeks, streams, rivers, and agricultural drainage ditches. From 2001 to 2015, USDA-NRCS enrolled 2245 ha of marginal farmland in the Bayou de Chien–Mayfield watershed in western Kentucky.

WRP Easements

I focused sampling efforts on 9 restored wetlands on WRP easements within the BDC watershed (Fig 1). The USDA-NRCS provided information about each easement, including restoration blueprints, age since enrollment, and age since restoration, which aided my site selection. The easements I selected ranged in age from 0 to 12 years since hydrological restoration. Methods to restore easement wetlands included a levee break (LB), a shallow excavated depression (hereby referred to as shallow water area or SWA), a drainage ditch plug (DP), or tree planting (TP). In some cases, a combination of restoration methods was implemented on the easement wetlands. These easements range in size from 4.48 ha to 101.73 ha. The easement wetlands are classified as riparian wetlands; their main source of water is overbank flow from nearby rivers. Each easement was planted with water-tolerant hardwood saplings, to promote reforestation of BLH. However, the vegetative community on each wetland can be categorized as either persistent emergent (n=8) or forested (n=1). Some easements are actively managed with food plots and mowing (*personal observation*). A more detailed breakdown of each easement can be found in Appendix A.

Reference-standard wetlands

I selected two reference wetlands to compare with the easements. These reference wetlands resemble the most undisturbed or least-altered, accessible wetlands in far western

Kentucky. The first wetland is in the Obion Creek Wildlife Management Area-Travis Slough Tract. The Travis Slough Tract is a 133 ha WMA extending from southern Carlisle County into Hickman County. A portion of the WMA is adjacent to Obion Creek, a 77 km spring-fed creek that flows into the Bayou de Chien at the confluence of the Mississippi River. The creek's floodplain represents one of the largest remaining tracts of BLH within the state and is filled with cypress, tupelo, water-tolerant oaks, box elder, silver maple, and river birch (KEEC 2022).

The second reference-standard wetland I selected is a portion of the remnant channel of Mayfield Creek. A large portion of Mayfield Creek was rerouted and straightened to aid in drainage, leaving a low to no-flow, highly sinuous remnant channel behind. A deep layer of fine, silt mud has accumulated at the bottom of the remnant channel. The sides of the channel are flanked by large bald cypress, and for most of the growing season, the channel is covered with yellow pond lily (*Nuphar lutea*).

Low-quality Wetlands

To understand how restored WRP easements wetlands transition from cropland, I compared them to low-quality, degraded wetlands. The low-quality wetlands I selected are on or directly adjacent to agricultural land, and they remain undrained. Although they are highly disturbed, these low-quality wetlands have hydrophytic plant, fish, and invertebrate communities. One low-quality wetland site was located directly within a farmed soybean field, while the other was a drainage ditch between two actively farmed corn fields.

1. Examination of WRP easement wetland hydrology and restoration techniques

1.1 Background Information

The devastating and far-reaching effects of hydrological modification on wetlands within the U.S. cannot be overstated. Hydrology is the most important variable and the primary driving force responsible for wetland existence, form, biological composition, and function (Junk et al. 1989; Bedford 1996; Richter 1996; Cheng 2020). Hydropattern, or the frequency, duration, intensity, and timing of flood events, affects wetland primary productivity (Murdock et al. 2011), sediment retention, microbially-driven nutrient transformations (Hunter et al. 2008), decomposition (Kellison and Young 1997), vegetative heterogeneity and complexity (Meyer et al. 2015), and invertebrate community composition (Batzer and Wissinger 1996; Zimmer et al. 2000; Whiles and Goldowitz 2005). Wetlands are maintained through the interaction of the hydrologic cycle with the landscape; local climate, for instance, influences the accumulation and retention of water, while local topography determines wetland location (Bedford 1996). Streams and rivers are the primary source of water for riverine wetlands, and they deliver essential minerals and nutrients to their floodplains (Hunter 2008).

Hydrological modification practices associated with agriculture include the channelization of streams and rivers, the construction of levees to disconnect rivers from their floodplains, and the addition of ditches to prevent water from collecting on crops. Therefore, the return of floodplain connectivity and the retention of floodwaters is an indispensable component of bottomland hardwood wetland creation and restoration (Kaller et al. 2015). Various techniques are applied to wetland creation or hydrological restoration on easements enrolled in the WRP. These techniques include the addition of a shallow water area (SWA), the construction or demolition of levees, and the plugging of drainage ditches (Fig. 1.1). Although one, some, or all these techniques are utilized on every easement enrolled in the program, there is little knowledge about their efficacy. Therefore, I attempted to quantify the hydrology and extent of each WRP easement wetland and to examine the success of each restoration type. The hydrological data collected from each easement wetland may guide future restoration efforts and further our understanding of wetland restoration.

1.2 Objectives

The objectives of my study were: (1) to evaluate hydropattern of each WRP easement wetland, (2) to determine the extent and intensity of flooding on each WRP easement, (3) to delineate wetland extent by calculating wetted surface area, and (4) to examine the efficacy of each type of hydrological restoration.

1.3 Methods

Hydrology

I recorded water level fluctuations in each wetland using water level loggers (HOBO® U20-001-04, Onset Computer Corporation). One logger was placed at each site in the deepest accessible location in the water column. The loggers were programmed to record depth (m) and water temperature (℃) every 15 minutes. Water levels were recorded in each wetland for approximately one year, beginning in the fall of 2018 and ending in the fall of 2019. I used the information from the data loggers to calculate hydropattern for each wetland, as well as water depth and temperature. To determine the intensity of flooding, I calculated flashiness, or the average change in water level over a 24-hour period. The minimum depth measurement was subtracted from the maximum depth measurement for each day. This difference was averaged for the entire sampling period for each site. Higher flashiness values indicate abrupt changes in water level, or more intense flood events.

Wetted Surface Area

I created a "bathtub" model to assess wetland extent (i.e., the average proportion of the easement's surface area that was inundated with water) for each enrolled easement. LiDAR point cloud data for the study area was acquired from kygeonet.maps.arcgis.com and converted to a 1-meter DEM using the Spatial Analyst tool in ArcGIS 10.7. The DEM was converted to a 32-bit integer raster from a floating-point elevation raster. Each raster pixel has an integer value that indicates elevation (masl). In the raster's attribute table, all pixels with an integer value below the elevation of the water level logger plus the site's average water depth were selected. Each wetland's average water depth was calculated by taking the average depth of all the dates when invertebrates were on that easement. The number of selected pixels was multiplied by 0.828 (pixel size in m^2) to calculate wetted surface area. For two sites, the available point cloud data was not current enough for the model to be applicable. In this instance, I delineated wetland extent using recent, high-resolution infrared photographs collected by the National Agriculture Imagery Program. Model accuracy was determined by frequent site visits from 2018 to 2020 and high-resolution drone imagery collected monthly from 2019 to 2020.

1.4 Results

The hydrological modifications allowed most (n = 8) easement wetlands I sampled to receive and retain floodwaters from nearby streams or rivers; GUTH, whose SWA was 550 m uphill of Obion Creek, did not receive floodwaters from the creek during flood events. Flood pulses are indicated on the hydrograph by short, periodic increases in water depth (Fig 1.2). The hydrological characteristics of the easement wetlands differed greatly (Table 1.1). On average, easement wetlands were inundated for 337 (± 31.2) days of the year. Six of the easement wetlands had intermittent hydroperiods. GDMN had a 62-day drought, the longest of any easement wetland. SAOF had the most nonconsecutive dry days (91), with four separate drying events.

The wetland at COFY had the highest maximum depth (6.08 m) and the highest average depth (0.91 m). Wetland area among easements was highly variable. The average wetted surface area was 17.5 (± 24.36) ha. Of the easements sampled, when water levels were at their average depth, 49.53 (± 31.9) percent of the total surface area of the easement was inundated. A Pearson's correlation test revealed that wetland elevation and maximum water depth are negatively correlated ($r(7) = -0.72$; $p < 0.028$); as the wetland's elevation (masl) increases, the maximum water depth of that wetland decreases.

1.5 Discussion

Hydrological modifications on WRP easements were able to return floodplain connectivity and create functioning riverine wetlands. However, the level to which each easement wetland can retain floodwaters or provide suitable wildlife habitat is determined by three nested, concurrent factors including: (1) the easement's location within the BDC watershed, (2) the wetland's location within the easement, and (3) the type of hydrological modification creating each wetland.

Overbank flooding is important for the creation and maintenance of BLH wetlands within the MAV (Reinecke et al. 1988; Heitmeyer 2006). However, backflow from the Mississippi River combined with rapidly rising water levels in nearby tributaries can lead to excessive ponding on nearby easements (i.e., COFY and GDMN). The wetlands on GDMN and COFY, which are located near the confluence of the Obion Creek and Bayou de Chien, are only two meters higher in elevation than the Mississippi River; thus, during flood events, water greatly exceeded the boundary of the easements' shallow water areas and the capability of the water control structures to regulate water levels (Fig 1.3). On the other hand, easements farther upstream and a mere two or three meters higher in elevation along the Bayou du Chien received overbank and backwater floodwaters at a moderate frequency and magnitude. Satellite imagery captured shortly after heavy rainfall events highlights the extent of this backwater flooding of the larger tributaries of the Mississippi River (Fig. 1.4).

The individual catchment for each WRP easement is small; the high density of drainage ditches and canals located on adjacent farm fields greatly reduces overland flow onto the easement. Therefore, the location of the created wetland on the easement is especially important. For instance, GUTH has a newly constructed SWA that is far-removed from a nearby stream, and therefore, it only receives water from precipitation and overland flooding rather than riverine inputs. Although it retains water year-round, the SWA creates a wetland that is a very small percentage (1.3%) of the easement's total surface area.

The results of this study represent a snapshot in time of the local hydrological conditions at the easement wetlands. Throughout the duration of my study, western Kentucky received particularly high amounts of rainfall. Therefore, estimates of flood intensity and duration may be exaggerated. In fact, GDMN and COFY were dry in the summer of 2018 before the depth loggers were deployed, and they have since dried up in summers after the study ended (*personal observation*).

Shallow Water Areas

Shallow water areas are great restoration tools because they sequester sediments and nutrients from adjacent streams, and they provide quality structure for a variety of wetland plants and animals. In the BDC watershed, SWAs would be most beneficial on easements located farther upstream from the Mississippi River. At higher elevations, easement wetlands can avoid excessive and prolonged water levels, but they would occasionally receive waters from nearby streams and backwater flooding from the Mississippi River. Placement of SWAs on easements should be carefully considered. SWAs should be adjacent to or downhill of nearby creeks and rivers, so they can catch excess sediments and nutrients during flooding events. The berm surrounding these SWAs should be at a lower elevation than the maximum water level during flood events, so that the SWAs do not exclude but trap floodwaters. Furthermore, SWAs should encompass a variety of depths. Deep areas should be constructed for the persistence of fish during long periods of drought. However, a high percentage of total area should remain less than 0.65 cm for use by dabbling ducks (Tapp and Webb 2015).

Ditch plugs

Easement wetlands created via ditch plugs received and stored floodwaters for most of the year. Shallow water and dense, diverse aquatic plant communities were noticeable shared characteristics among the ditch plug wetlands. While ditch plugs may be the most cost-effective restoration practice, the floodwater retention capabilities of wetlands created with this technique is limited. The extensive beaver levee and dam network on ALEN greatly increased the wetted surface area of the easement. However, when the dams and beavers were removed, water returned to the boundary of the remnant drainage ditch and greatly diminished wetland extent (Fig 1.5). Like ALEN, water on the HWST easement primarily remained within the confines of the remnant drainage ditch (Fig 1.6), with a small, very shallow pool forming near the southern end of the easement (*personal observation*). The ditch plug/borrow pit method employed on HOPK seems to be the most economical and effective hydrological restoration technique because it acts as a combination of both ditch plug and shallow water area (Fig 1.7). The remnant drainage ditches on HOPK were shallow and heavily vegetated. The deeper borrow pits, on the other hand, acted as refugia for fish and amphibians during droughts (*personal observation*). On average, more than half of the surface area of HOPK was inundated with water at any one time.

Levee Break

HEST was the only easement wetland that received water directly from a levee break. During flood events, massive amounts of water and sediment poured through the break and scoured or covered any existing macrophyte or invertebrate communities (*personal observation*). While levee breaks allow massive amounts of sediment to be removed and stored from adjacent creeks, the constant delivery and pileup of sediment may be detrimental to adjacent biotic communities. However, a gradient of succession expanding out from the levee break may form throughout the easement given a longer time scale.

Conclusion

It is estimated that millions of metric tons of nitrogen and phosphorus can be removed from the Gulf of Mexico every year if only 2% of the total surface area of the Mississippi River Basin is converted or restored to functioning wetlands (Mitsch et al. 2001). While seemingly a small percentage, reaching this goal would require current national conservation and restoration efforts to increase dramatically. Therefore, the selection of private lands, the placement of wetlands, and the methods of hydrological restoration need to be strategic. WRP easements and their associated wetlands should be proximal, and preferably adjacent to rivers and streams, with priority given to areas where agricultural drainage is highest.

If the primary goal of the WRP is to increase sediment and chemical sequestration, then easement restorations should focus on increasing wetland extent by facilitating the lateral expansion and retention of water. These constructed wetlands should include topography, such as ridges and divots, which can trap sediment and create a variety of microhabitats for flora and fauna (Hunter et al. 2008). More than likely, a combination of different hydrological restoration methods working in conjunction with one another may be required on each easement to achieve the previously mentioned objectives. For instance, a levee break may increase the frequency of flooding onto the easement by decreasing the required height for stream water to breach the levee, while a lower elevation shallow water area can retain that water and sediment.

The intended functions of WRP easement wetlands are to reduce sediments and nutrients entering the Mississippi River and to provide optimum wildlife habitat. Yet, it is unclear if these “dual-purpose” wetlands can adequately fulfill both objectives, or if the goals are counterintuitive or counterproductive goals. For instance, wetlands that retain maximum sediment loads may do so at the expense of the wetland’s macrophyte and benthic community (Gleason and Euliss Jr. 1998). Furthermore, environmental variables associated with nutrient retention may be less favorable to local biota because high nutrient loads can negatively affect diversity (Hansson et al. 2005). However, there is little evidence to suggest that WRP easement wetlands could not successfully improve water quality and support diverse biotic communities. Therefore, it is important to assess not only the physical characteristics of these newly created wetlands, but the chemical and biological responses as well.

2. Macroinvertebrate community dynamics in WRP easement wetlands

2.1 Background Information

Macroinvertebrates are an integral component of wetland ecosystems. They play a role in nutrient cycling by decomposition of organic matter (Wissinger 1999), and they act as energy conduits between primary production and secondary consumers (Zimmer et al. 2000). For instance, the emergence of adult insects provides an important resource subsidy for a variety of riparian consumers, including birds, bats, amphibians, and spiders (Zimmer et al. 2000; Baxter et al. 2005). Invertebrates are an important source of protein for migrating waterfowl and can influence the habitat selection of shorebirds (Meyer et al. 2015). Furthermore, invertebrates are excellent bioindicators of water quality, and they are often used as a proxy for monitoring wetland health and function (Hilsenhoff 1987; Wallace and Webster 1996; Baxter et al. 2004).

Macroinvertebrate communities can provide an indirect measure of wetland restoration success because community composition is closely linked to hydrology and other local abiotic variables (Meyer and Whiles 2008). Macroinvertebrates can recolonize quickly following restoration in some wetlands (Brown et al. 1997), and the presence or absence of certain taxa may be indicative of water quality and wetland health (Osborn 2005). Wetland restorations are usually considered successful with the return of pre-disturbance function or conditions (Kentula 2000; Zimmer et al. 2000), which can be assessed by comparing the restoration's invertebrate community to local natural or reference wetlands (Mitsch and Wilson 1996; Marchetti et al. 2010). Oftentimes, these reference-standard wetlands represent the least-altered or most desired conditions in the local area, not necessarily natural conditions (Lepori et al. 2005).

Because macroinvertebrates are integral to the health of wetland ecosystems, it is important to consider how these communities respond to restoration. My study aimed to assess the quantity, quality, and availability of aquatic macroinvertebrates in WRP easement wetlands following restoration. I compared these invertebrate communities to those found in local reference-standard wetlands, which I considered to be an example of ideal restoration target conditions. I also compared easement communities to those found in degraded wetlands, which often imitate conditions prior to restoration. I considered the wetland restoration successful if the easement wetland had an invertebrate community that converged on reference wetland assemblages. Evaluating one component of these WRP restorations, such as macroinvertebrates, can provide us with valuable information on the condition and function of newly created wetlands.

2.2 Objectives

My main objectives for this study were: (1) to quantify the abundance, biomass, and annual production of macroinvertebrate communities in WRP easement wetlands, (2) to evaluate the composition of macroinvertebrate communities in WRP easement wetlands, and (3) to compare WRP invertebrate communities to local reference-standard and low-quality, degraded wetland communities.

2.3 Methods

Invertebrate collection

I collected invertebrate samples by driving a stovepipe coring device (18 cm diameter, 60 cm depth, 254 cm^2 sampling area) into the substrate at each wetland. I collected three cores from haphazard locations in each site every ~ 30 days when water was present from 2018-2020. Because of differences in hydropattern, the number and timing of sampling dates varied greatly among sites (Table 2.1). The corer was inserted 20 cm into the benthic substrate. All sediments and vegetation down to ~ 10 cm below the sediment surface were removed by hand into a bucket. The sediment/water mixture was elutriated in a 20-L bucket and rinsed through a 250 μm sieve. Collected macroinvertebrates and benthic material were preserved in a 6-10% Formalin solution and returned to the laboratory for processing. Along with the cores, I used a 744 cm^2 D-frame net with 500 μm mesh to get a multi-habitat assessment of the invertebrate community at each wetland. Like the benthic cores, wetlands were sampled at each site every ~ 30 days when water was present from 2018-2020. Twenty jabs (~0.5 m^2/jab) of the net were selected haphazardly from existing habitats (open water, submerged vegetation, detritus, emergent vegetation, woody debris) and combined to represent a single composite sample. Again, because of differences in hydropattern, the number and timing of dip net sampling dates varied greatly among sites (Table 2.2).

Invertebrate Sample Processing

I washed each benthic core sample through a nested 1000 μm (US Sieve Mesh Size #18) and 250μm (US Sieve Mesh Size #60) sieves to divide them into coarse (>1mm) and fine (<1mm,>250um) fractions, respectively. I separated invertebrates from debris using a dissecting microscope. All invertebrates in the coarse fraction were removed. Fine fractions were subsampled (1:2 to 1:32 of total volume) prior to processing (Whiting et al. 2011) with a Folsom wheel sample splitter (Vemco ®).

Dip-net samples were washed through a 500 μm (US Sieve Mesh Size #35) sieve to remove silt and other non-organics. Washed sample materials were placed in a pan with 12 equal-size grids. Using a random number generator, a grid was selected, and all invertebrates were removed using a dissecting scope. If the grid yielded less than 200 invertebrates, another grid was selected, and the process was repeated until the total number of animals exceeded 200. All invertebrates from the cores and dip net samples were counted, measured (total millimeters body length), and identified to the lowest practical taxonomic level using a variety of keys (Pennak 1978; Merritt and Cummins 2008; Wiggins 1996). I identified most taxa to genus, while other taxa, such as oligochaetes and some crustaceans (i.e., zooplankton) were identified to class (Meyer and Whiles 2008). The functional feeding group (FFG) of each taxon was recorded (Merritt and Cummins 2008). Individuals in the classes Ostracoda and Branchiopoda and subclass Copepoda were classified in the functional group "Zooplankton." The life history of each invertebrate taxon was also noted. If an invertebrate had a terrestrial adult stage, then it was considered "emergent".

Invertebrate Abundance, Biomass, and Production

The abundances of the fine subsamples were extrapolated to estimate total fine sample invertebrate abundance. The abundance numbers from the fine fraction were added to the abundance numbers from the course fraction to obtain an overall abundance estimate for each benthic core and standardized to a m^2 estimate. The abundance values of the three cores were averaged to obtain an abundance estimate for the month for each site. Biomass for each benthic core was calculated using length-mass regressions from a several sources (Benke et al. 1999; Rogers et al. 1977; Méthot et al. 2012; Smock 1980). Biomass estimates were calculated for each month at each site using the same method as abundance. I estimated production (g/m^2) using the cohort method with P/B ratios from a variety of studies (Herman et al. 1983; Anastácio and Marques 1995; Barahona et al. 2005; Scholl et al. 2016). Total annual production was estimated for each site. All values used in my analysis and presented here are based only on sampling periods when water was present. When a wetland was dry, I did not collect any cores and that date was not included in the calculations.

Statistical and data analysis

I compared differences in invertebrate community abundances, biomass, and production among wetland types using one-way analysis of variance (ANOVA), and I compared individual means using Tukey's multiple comparison procedure (a=0.05). Statistical analyses of species composition and diversity were performed on presence–absence data (Thiere et al. 2009). All statistical analyses were performed using R statistical software. I used nonmetric multidimensional scaling (NMDS) (Minchin 1987) to compare macroinvertebrate community composition among wetland type (vegan package, version 2.5-6; Oksanen et al. 2019, R Core Team 2020). Samples were transformed using Hellinger method to meet requirements of normality and heteroscadicity. I used analysis of similarity (ANOSIM; Clarke and Green 1988) with Bray-Curtis dissimilarities method to detect differences in macroinvertebrate assemblages among wetland types. The relationship between individual invertebrate taxa and site clustering was evaluated using the envfit function, which correlates different variables onto the ordination axes. I compared differences in relative abundance of invertebrate taxa and functional groups among wetland types using one-way analysis of variance (ANOVA), and I compared individual means using Tukey's multiple comparison procedure (a=0.05).

2.4 Results

Benthic Cores (FFG, Abundance, Biomass, Production)

Average invertebrate abundance ranged from 29,092 individuals/ m^2 in the reference wetlands to 93,001 individuals/m^2 in the low-quality wetlands ($F=0.997$; $df = 2,10$; $P > 0.40$; Table 2.3). Zooplankton (primarily ostracods) were the dominant invertebrate group collected at each wetland type. The high density of zooplankton greatly exaggerated the average density of macroinvertebrates. However, the same statistical analyses were run without zooplankton, and similar statistical results were obtained. Because zooplankton are an integral component of wetland food webs (Dodson and Lillie 2001), numbers and results with zooplankton included will continue to be reported. Invertebrate biomass showed the same pattern as abundance; reference wetlands had the lowest average biomass (6,804 mg/m^2), low-quality wetlands had the highest average biomass (14,236 mg/m^2), and the average biomass for wetland easements fell within that range (7,564 mg/m^2). Invertebrate biomass was not statistically different among the different wetland types (F=0.49; df 2,10; P>0.62). Although zooplankton were the most abundant invertebrate group at each wetland type, they contributed less than 1 % to each wetland type's overall biomass (Table 2.3)

After zooplankton, collector-gatherers were the most abundant FFG at all sites (Table 2.3). Predators were significantly more abundant in the reference wetlands than in the low-quality or easement wetlands (F=5.95; df=2,10; P<0.019). Collector-gatherers accounted for the highest relative biomass in all wetland types. Scrapers accounted for the second highest total biomass in the low-quality and easement wetlands, while predators had the second highest relative biomass in the reference wetlands (Table 2.3). Shredders and herbivore-piercers accounted for very little of the total abundance or total biomass in all wetland types. There was no significant difference in the amount of emergent invertebrate biomass among wetland types (F=1.3; df=2,10; P>0.312).

There was no statistical difference in annual production (mg DM/m^2) between wetland types (F=0.088; df = 2,10; P>0.91; Fig 2.1). The relative monthly production of emergent invertebrates fluctuated greatly between monthly sampling events at each WRP easement wetland (Fig 2.2), and there was considerable overlap in annual production estimates between the nine WRP easement wetlands and the two other wetland types (Fig 2.1). HWST had the highest annual production of any wetland with 7,746 mg DM/m², while SAOF had the lowest production at 850 mg DM/m². Like the density and biomass estimates, the WRP easement wetlands showed great variation in monthly production values (Fig 2.2).

Dip-net Sampling (Relative abundance and community ordination)

There was no significant difference in taxa richness ($F = 3.33$; df 2, 10; $P = 0.08$) or Shannon diversity among all three wetland types ($F = 0.32$; df 2,10; $P = 0.73$; Table 2.6). Dip net sampling was able to capture more mobile taxa. Crayfish, which had been absent from the benthic cores, made up approximately 26% and 21% of the invertebrates collected in the low-quality and easement wetlands, respectively. The relative abundance of fingernail clams (Sphaeriidae) was significantly higher in the reference wetlands than the other wetland types ($F = 4.44$; df 2,10; $P = 0.04$; Table 2.6).

There was great overlap of invertebrate species richness and evenness between sites for each sampling date (Fig. 2.3). Therefore, ANOSIM failed to show significant differences in community composition between wetland types ($R = 0.076$, $p = 0.07$). The two-dimensional NMDS of average macroinvertebrate community ordination shows two WRP easement wetlands, ALEN and HWST, separating from the low-quality wetlands and clustering with the reference wetlands (Fig 2.4); certain invertebrate taxa were correlated with this vector divergence including oligochaetes ($r = 0.61$, $p = 0.008$), chironomids ($r = 0.68$, $p = 0.002$), non-biting midges ((*Bezzia* sp. ($r = 0.60$, $p = 0.013$) and *Serromyia* sp. ($r = 0.62$, $p = 0.006$)), Libellulids ((*Erythemis* sp. ($r = 0.75$, $p = 0.002$), *Pachydiplax* sp. ($r=0.47$, $p = 0.05$)), family Aeshnidae ($r = 0.55$, $p = 0.019$), family Coenagrionidae ($r = 0.44$, $p = 0.042$), the amphipod *Hyallela* sp. ($r = 0.71$, $p = 0.002$), and the mayfly *Caenis* sp. ($r = 0.54$, $p = 0.017$) (Fig 2.5). The low-quality wetlands were separated by a high density of copepods and cladocerans (Fig 2.5).

2.5 Discussion

There are very few studies evaluating invertebrate communities in Kentucky wetlands (KDW 2020) and in bottomland forests within throughout the MAV (Batzer and Wissinger 1996; Heitmeyer et al. 2010). My study is the first intensive, year-round investigation of aquatic macroinvertebrate communities in restored WRP easement wetlands in Kentucky. The data collected in this study indicate that WRP easement wetlands can have diverse and abundant invertebrate communities like those found in local reference-standard wetlands. Furthermore, the average invertebrate biomass in WRP easements examined in this study were like those found in naturally flooded forests in the MAV (Wehrle et al. 1995, Foth et al. 2014, Foth et al. 2018), persistent emergent wetlands (Whiles and Goldowitz 2005, Meyer and Whiles 2008, McClain et al. 2018), floodplain wetlands along the Mississippi River (Flinn et al. 2005), and actively managed WRP wetlands in Arkansas and Missouri (Tapp and Webb 2015). The results of my study shed a positive light on wetland restoration and the status of WRP easements in western Kentucky, and they are an important step toward determining the success of current restoration practices in the region and could be applicable to other situations within the MAV.

The nine WRP easement wetlands I sampled varied considerably in age, restoration type, hydropattern, and location within the BDC watershed, all of which could have influenced local invertebrate communities. The high variability within and among the wetlands sampled made estimates of recovery unpredictable and muddled. My data, therefore, indicate equally diverse and abundant invertebrate communities in low-quality, WRP easement, and reference-standard wetlands. However, despite the similarities in species richness, Shannon diversity, abundance, and biomass, biologically important taxonomic differences and trends are evident among the wetland types.

The relative abundance of major invertebrate classes (Annelida, Crustacea, Insecta, Molluska) either increased or decreased from low-quality to reference wetlands, with WRP easement wetlands falling somewhere on a gradient between the two. For instance, insects accounted for 12.6 % of the total abundance in the low-quality wetlands and increased to 26.5% in the WRP easement wetlands and to 65.5% in the reference wetlands (Table 2.4). Molluscan biomass also showed a discernible trend among the wetland types; total molluscan biomass decreased from 63.0 % in the low-quality wetlands to 2.3 % in the reference wetlands (Table 2.5). However, the relative biomass of the fingernail clam (Sphaeriidae) increased from 1.6% in the low-quality wetlands to 65.3 % in the reference wetlands (Table 2.5). Several of the functional feeding groups including collector-gatherers, predators, shredders, and zooplankton, as well as the relative abundance of emergent taxa, also followed these patterns.

Perhaps most surprising was the significant difference in the abundance of predators between the reference wetlands and the other two wetland types. Ceratopogonidae (primarily genus *Serromyia*) made up a large proportion of the predators found in reference wetlands, possibly due to the high levels of organic matter and nutrients available at these sites (Erram et al. 2019). Odonates (primarily Libellulidae and Coenagrionidae) were also particularly abundant predators in the reference wetlands. The high abundance of these gill-breathing, clingers and sprawlers can indicate good water quality and healthy vegetative community (Osborn 2005). The relative abundance of family Sphaeriidae varied significantly between the reference wetlands and other wetland types, despite the higher relative abundance of mollusks in the low-quality and easement wetlands. Fingernail clams prefer silt-loam benthos as opposed to rocky substrates (Lauer and McComish 2001), and one of the reference wetlands (SARC) had benthos consisting primarily of fine sediments. Significant populations of these filter-feeding collectors are indicative of sufficient particular organic matter and ecological integrity (Cummins and Merritt 2001).

Because invertebrates are such integral components of wetland food webs, it's important to examine the wetland community's ability to support a rich and diverse assemblage of riparian consumers. Emergent taxa accounted for only 1.9% of the total biomass in the low-quality wetlands and increased to 22.3% in the reference wetlands (Table 2.3). The relative abundance of emergent taxa also increased from 13.1% in low-quality wetlands to 45.8% in the reference wetlands; the average relative abundance of emergent taxa in WRP easement wetlands fell in between the low-quality and reference wetlands, with 23.0% of all taxa collected having a terrestrial adult stage (Table 2.6). Some easement wetlands, like GUTH and ALEN, produced a large percentage of emergent taxa, while others, like COFY and HEST, produced mostly non-emergent individuals. GUTH, a wetland dominated by non-biting midges, had the highest production of emergent taxa with roughly 84% of all invertebrate production belonging to taxa with a terrestrial adult stage. On the other hand, HEST had the lowest production of emergent taxa with only 19%. Although invertebrate production varied greatly among the WRP easement wetlands, there was year-round food availability for both aquatic and terrestrial consumers (Fig. 2.2).

Based on community richness and evenness, only two of the easement wetlands (ALEN and HWST) had invertebrate assemblages that resemble those found in the reference-standard wetlands (Fig 2.4). Both easement wetlands had permanent hydroperiods and diverse and dense vegetative communities, much like the reference sites. The high relative abundance of certain invertebrate taxa (family Ceratopogonidae, Hyallelidae, Libellulidae, Coenagrionidae, order Oligochaeta) and the low relative abundance of zooplankton (primarily Cladocerans and

Copepods) influenced the congregation of ALEN and HWST and the reference wetlands (Fig 2.5). SWAN and SAOF appeared most like the low-quality wetlands, while COFY, HOPK, HEST, GDMN, and GUTH fell on a gradient between the low-quality and reference wetlands (Fig 2.4). However, there was considerable variation in the community composition of each wetland from month to month. Furthermore, there was significant overlap between each wetland type, indicating a degree of nestedness within the wetland invertebrate communities (Zimmer et al. 2000, Gleason and Rooney 2017).

Restoration age is often considered a driving force behind species accumulation (Simenstad and Thom 1996; Thiere et al. 2009; Marchetti et al. 2010). Macroinvertebrates can quickly colonize new wetlands (Balcombe et al. 2005; Batzer et al. 2006; Stewart and Downing 2008, Meyer and Whiles 2008), and invertebrate diversity can approach and converge on reference levels within a few years (Barnes 1983; Fairchild et al. 1999; Dodson and Lillie 2001; Stanczak and Keiper 2004; Lepori et al. 2005; Marchetti et al. 2010). Twenty-two taxa were collected from the GUTH wetland 3 months after creation and 55 taxa were collected from HWST only 2 years post-restoration. However, other studies reveal a much grimmer reality, showing that restoration efforts fail to ever restore biological structure and function even after a century (Moreno-Mateas 2012). Either recovery is slow, or these novel ecosystems have moved towards alternate states, which will differ from reference conditions (i.e., there is no "climax" community) (Hilderbrand et al. 2005; Moreno-Mateas 2012).

Wetlands are dynamic ecosystems with communities that can vary greatly from year to year (Zimmer et al. 2000), and it is important to remember that sampling efforts represent a "snapshot" of the local invertebrate community. A variety of factors, including vegetation, the presence or absence of predators, wetland hydrology or flooding (Zimmer et al. 2000; Tarr et al.

2005; Gallardo et al. 2008; Meyer et al. 2015; Leps et al. 2016), along with other idiosyncrasies and randomness, may work in combination to influence the assemblages found in certain areas at certain times. Therefore, assessing recovery levels a few years after project completion may limit our understanding of restoration success (Leps et al. 2016); some suggest that 15-20 years should be the minimum time allotted (Mitsch and Wilson 1996), while others claim that 3-8 years is enough to assess biological recovery (Lepori et al. 2005). Monitoring efforts employed a few years post-restoration may only indicate the trajectory of restored communities and not the ultimate gained wetland function (Mitsch and Wilson 1996). Furthermore, these newly created wetlands may never recover lost biodiversity or ecological function (Marchetti et al. 2010, Moreno-Mateas et al. 2012), which would make any attempt at proving success a failure (Leps et al. 2016).

The results of my study, however, indicate that the Wetland Reserve Program can promote the conservation of regional biodiversity and limit wetland loss due to agricultural land use. Only a few years following extreme degradation, created and restored wetlands can support healthy aquatic invertebrate communities. Because it is extremely difficult to determine which specific environmental variable is the most influential in any one wetland at any one time, management and restoration practices should be diverse and widespread. By creating and promoting diverse wetlands throughout the watershed, we can maximize the abundance, biomass, production, and diversity of invertebrates at a regional scale.

Conclusion

Since WRP's inception, USDA-NRCS has enrolled over 2,000 ha of private land and restored or created dozens of wetlands within the Bayou de Chien watershed. These conservation easements are often located adjacent to tributaries of the Mississippi River, and they are subject to a wide array of hydrological conditions. Over the two-year duration of my study, I assessed the ability of each hydrological restoration technique to reestablish floodplain connectivity, to retain water on the easement, and to create functioning wetlands. Furthermore, I examined the local aquatic macroinvertebrate communities on several easement wetlands and compared them to local degraded and reference-standard wetlands. Although the nine easement wetlands in my study represent a small fraction of the total number of enrolled easements in western KY and the MAV, the information I provide here may be an important step in assessing the effectiveness of wetland restoration and creation through WRP.

The return of pre-disturbance condition is a lofty goal, and restoration efforts may never be able to maximize biodiversity and wetland function (i.e., chemical and sediment sequestration) on the same wetland (Zedler 2000). However, there is no doubt that the physical, chemical, and biological components of wetlands on restored WRP easements show great improvement from their former cropland systems (Besasie and Buckley 2012; Zhang et al. 2012; Marton et al. 2014; Walls et al. 2014). Thus, the small-scale rehabilitation of private lands through the Wetland Reserve Program can play a crucial role in the protection of critical wetland habitats and the improvement of water quality across the landscape.

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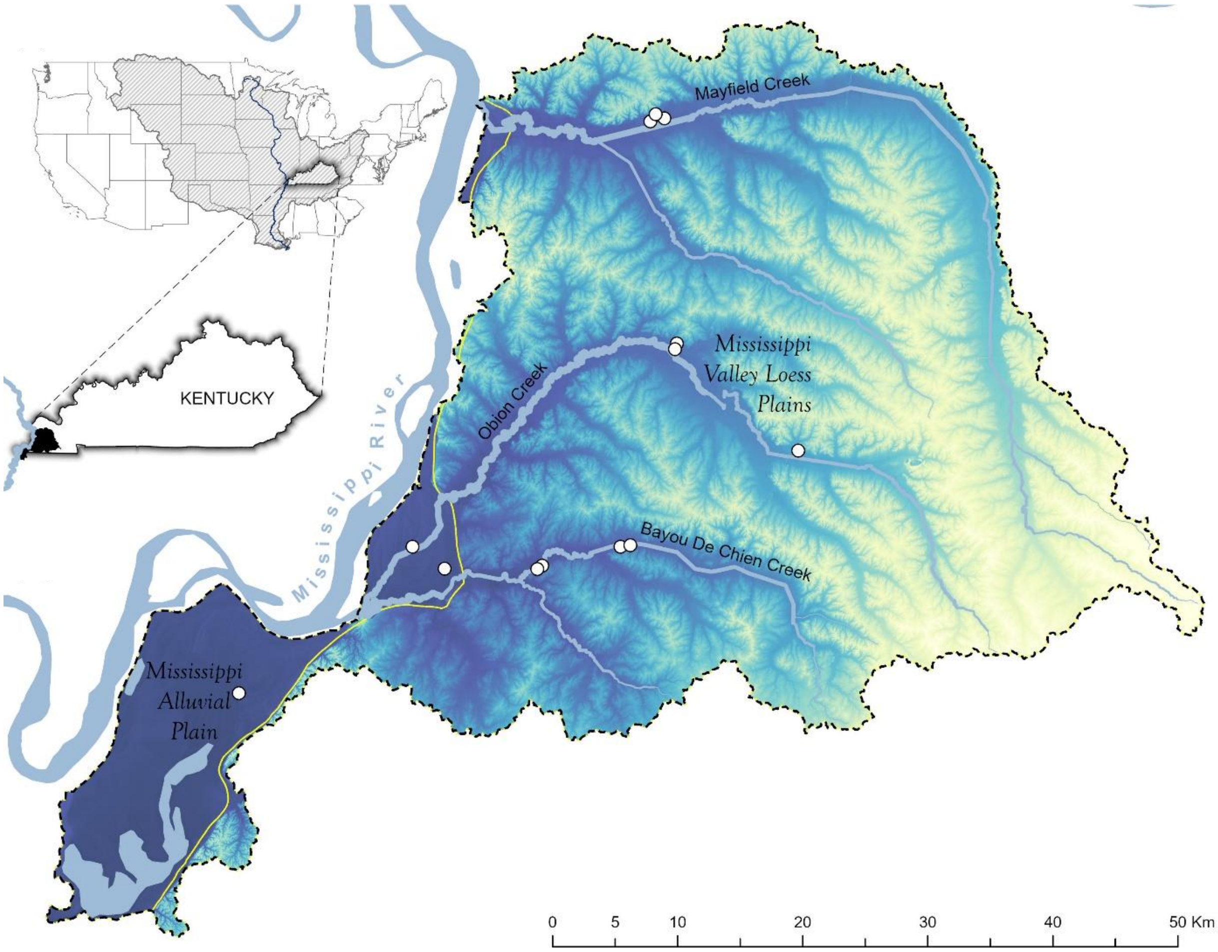

Figure 1 Digital elevation model of the study area located within the Mississippi River Alluvial Valley. Study sites include 9 WRP easement wetlands, 2 low-quality wetlands, and 2 reference-standard wetlands.

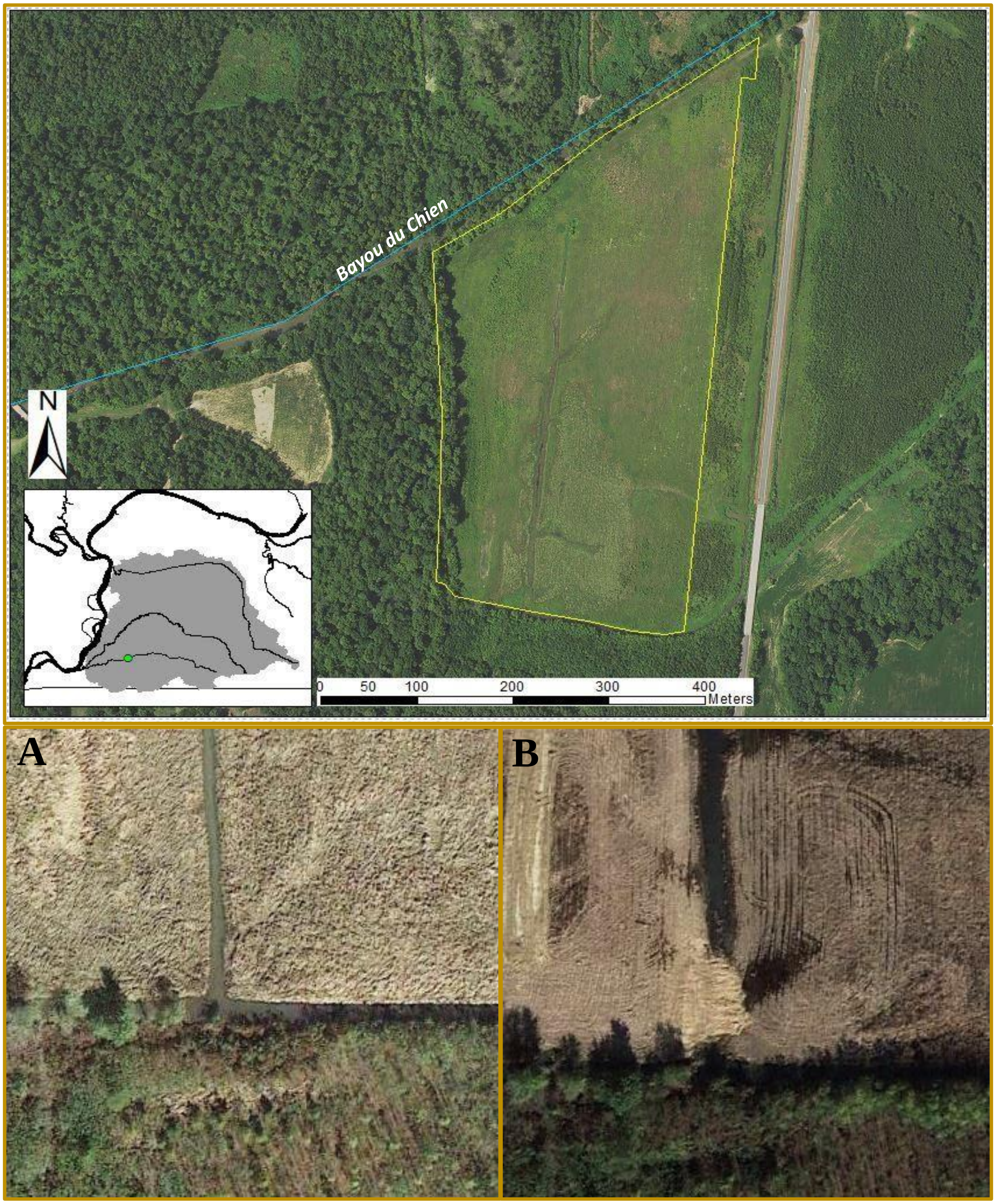

Figure 1.1 A drainage ditch plug is one of the hydrological restoration tools used by USDA-NRCS on WRP easements. Satellite images of HWST shows the drainage ditch before (A) and after (B) the ditch plug was installed.

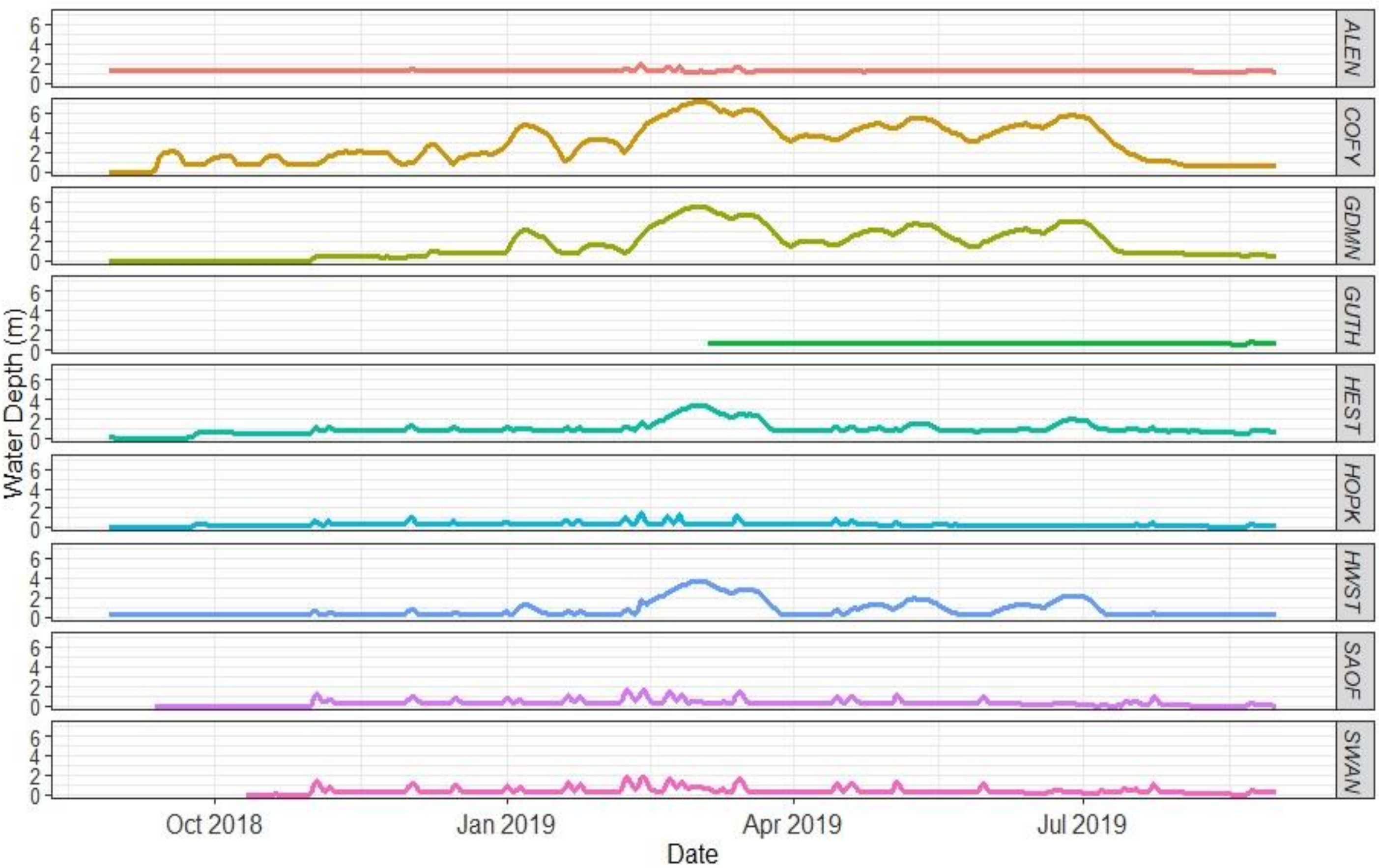

Figure 1.2 Hydrographs of the 9 WRP easement wetlands throughout the duration of the study. Water depth was measured with pressure loggers placed within each wetland.

Table 1.1 Physical and hydrological characteristics of the 9 WRP easement wetlands sampled from fall 2018 to fall 2019*. Site age is the number of years since hydrological restoration. Maximum depth and average depth are measurements collected from water level loggers (HOBOs). Hydroperiod is the amount of time the easement was inundated during the sampling period. LiDAR was used to procure the elevation (meters above sea level) of each HOBO. Average wetted surface area is the area of the easement that is inundated when water levels are at their average depth. Inundation refers to wetland extent when the easement is inundated at average water depth. Flashiness shows a change in water level over a 24 h period; the measurement was calculated by taking the minimum water depth and subtracting it from the maximum water depth of each day and then averaging that number over the entire sampling period for each site. Wetlands were considered dry if the water depth above the HOBO was <0.1 m.

	WRP Easement Wetlands								
Characteristics	ALEN	COFY	GDMN	GUTH	HEST	HWST	HOPK	SWAN	SAOF
Age in 2019 (y)	5	12	4	1	6	2	4	2	2
Easement Size (ha)	27.33	101.73	46.62	56.97	15.91	14.26	27.3	4.48	11.8
Restoration Type	DP	SWA	SWA	SWA	LB	DP	DP	SWA	TP
Avg. Water Temp °C	16.9	15.3	15.2	21.8	16.4	16.1	20.4	15.7	13.1
Max Water Temp °C	31.4	36.1	36.4	31.5	37.1	36.9	39.6	37.8	35.3
HOBO Elev.(masl)	97.78	89.39	90.9	116.54	93.69	92.04	98.09	97.78	98.38
Max Water Depth (m)	1.11	6.08	5.56	0.92	3.0	3.65	1.58	1.99	1.75
Avg. Water Depth (m)	0.35	0.91	0.62	0.7	0.69	0.39	0.32	0.29	0.3
Days Dry	0	15	62	0	18	0	29	33	91
Drying Events	0	1	1	0	1	0	2	2	4
Flashiness	0.034	0.15	0.09	0.02	0.08	0.08	0.07	0.15	0.11
Avg. wetted area (ha)	20.5	77.8	27.4	0.7**	7.7**	1.4	9.8	1.1	11.3
Inundation (%)	75	76.4	58.7	1.3	48.2	9.6	56.2	24.8	95.6

*Logger not deployed in GUTH until 5 Mar 2019

** Wetland extent was delineated using high-resolution aerial imagery (2018 USDA National Agriculture Imagery Program)

Figure 1.3 Backflow from the Mississippi River combined with overbank flooding from Obion Creek created an extreme ponding event on GDMN. The easement wetland, located two miles from the Mississippi River, was inundated with at least four meters of water for a month.

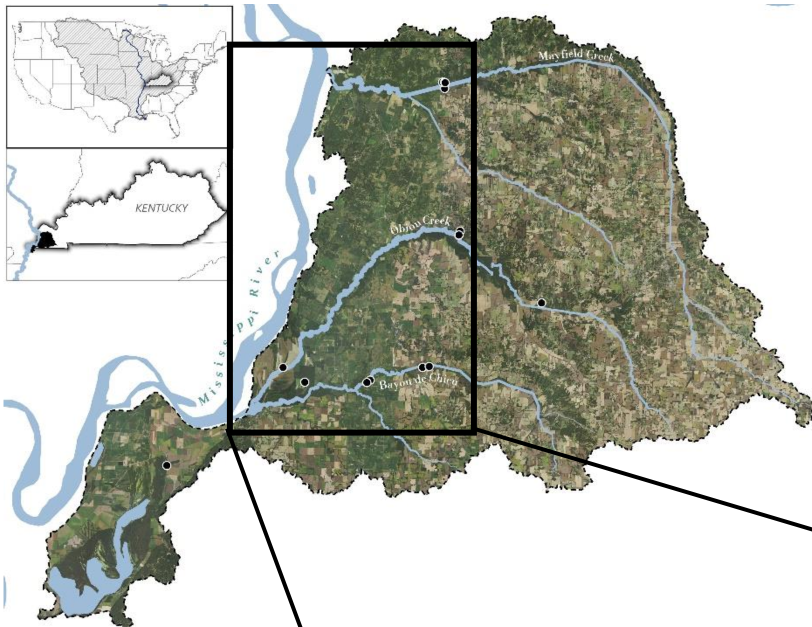

Figure 1.4 A combination of shortwave infrared, near infrared and blue bands (band combination 11,8,2) from the Sentinel-2 satellite shows the extent of flooding in the BDC watershed along the Mississippi River floodplain. Satellite images were captured on March 6, 2021. Backwater flooding from the Mississippi River following the recent rain event stopped at approximately 95.0 masl along Mayfield Creek and 91.0 masl along Obion Creek and the Bayou de Chien.

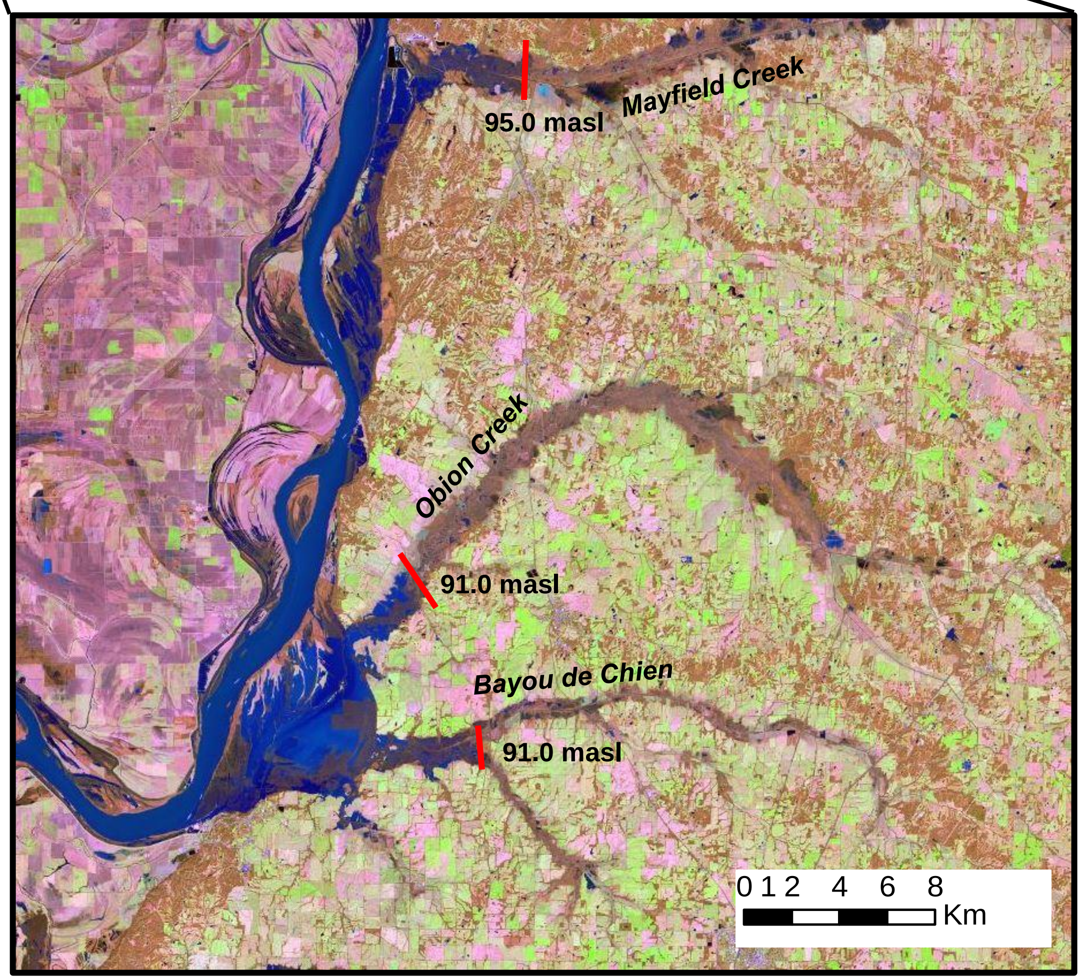

Figure 1.5 An extensive beaver dam and levee system at ALEN greatly increased the extent of the easement's wetland (top). Efforts to remove the dams and to exterminate the beavers began at the beginning of 2020. Afterwards, water stayed within the confines of the remnant drainage ditch (bottom).

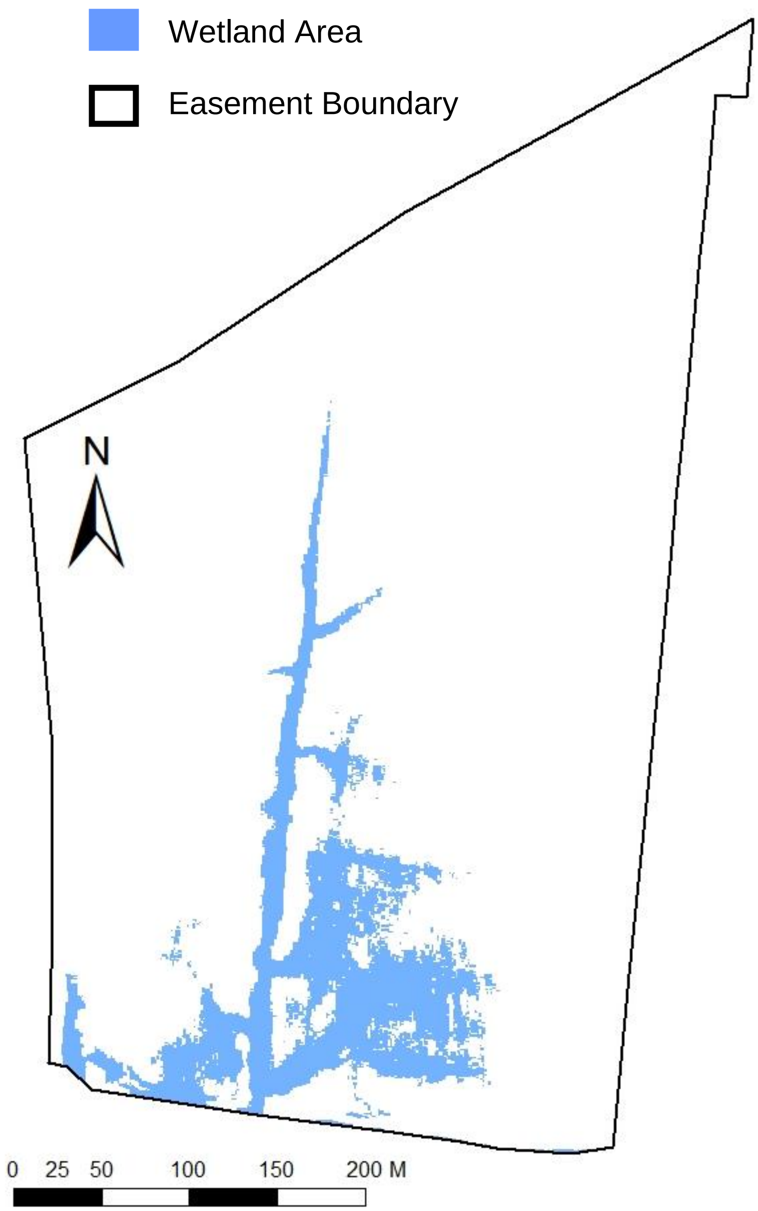

Figure 1.6 When water levels were at an average depth, approximately 10% of the surface area of the HWST easement was inundated with water.

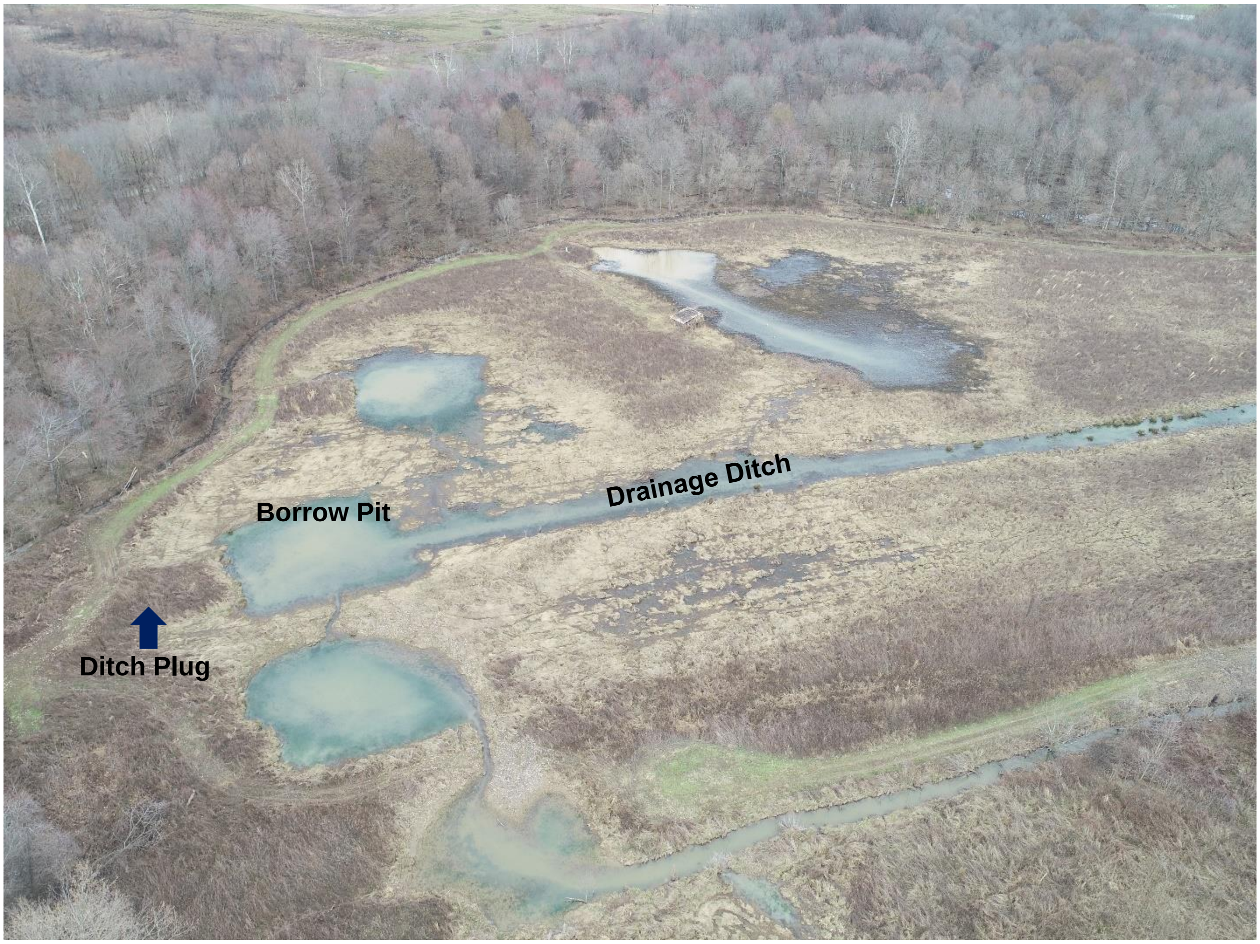

Figure 1.7 Drone imagery shows the ditch plug and borrow pit method used to hydrologically restore the wetland on HOPK. This restoration method kept approximately 56% of the easement's surface area inundated when water levels were at an average depth.

Table 2.1 Year and month when benthic cores were collected at each site and the total number of cores collected for each site (i.e., January = 1, February = 2). Age is the number of years since hydrological restoration until sampling began.

				Year		
Site	Type	Age	2018	2019	2020	Total Cores
ALEN	Easement	5	6, 8, 9, 10, 11	1, 3, 4, 5		27
COFY	Easement	12	7, 9, 10, 12	8		15
GDMN	Easement	4	5, 6, 7, 11	7		15
GUTH	Easement	1		3, 4, 5, 6	2	15
HEST	Easement	6	8, 9, 10, 11	1, 3, 5		21
HOPK	Easement	4	8, 9, 10, 11	1, 3, 4, 5		24
HWST	Easement	2	8, 9, 10, 11	1, 3, 5		21
SAOF	Easement	2	11	1, 3, 4, 5		15
SWAN	Easement	2	11	1, 3, 4, 5		15
BCYP	Low-Quality	NA	5, 7, 10, 11	2, 3, 4, 5		24
OWMA	Low-Quality	NA	9, 10, 11	1, 3, 4, 5		21
OBOT	Reference	NA	9, 10, 11	1, 3, 4, 5		21
SARC	Reference	NA	9, 10, 11	1, 3, 4, 5		21

Table 2.2 Year and month when dip net samples were collected at each site and the total number of dip net samples collected at each site (i.e., January = 1, February = 2). Age is the number of years since hydrological restoration until sampling began.

				Year		
Site	Type	Age	2018	2019	2020	Total Samples
ALEN	Easement	5	5,6, 8, 9, 10, 11	1, 3, 4, 5		10
COFY	Easement	12	7, 9, 10, 12	8		5
GDMN	Easement	4	5, 6, 7, 11	7		5
GUTH	Easement	1		3, 4, 5, 6	2	5
HEST	Easement	6	6, 7, 8, 9, 10, 11	1, 3, 5		9
HOPK	Easement	4	4, 6, 7, 8, 9, 10, 11	1, 3, 4, 5		11
HWST	Easement	2	5, 6, 7, 8, 9, 10, 11	1, 3, 5		10
SAOF	Easement	2	4, 6, 11	1, 3, 4, 5		7
SWAN	Easement	2	6, 11	1, 3, 4, 5		6
BCYP	Low-Quality	NA	5, 7, 10, 11	2, 3, 4, 5		8
OWMA	Low-Quality	NA	4, 5, 6, 8, 9, 10,11	1, 3, 4, 5		11
OBOT	Reference	NA	5, 6, 7, 8, 9, 10,11	1, 3, 4, 5		11
SARC	Reference	NA	6, 7, 8, 9, 10, 11	1, 3, 4, 5		10

Table 2.3 Average abundance and biomass of macroinvertebrate functional feeding groups (FFG) among wetland types. Values are means (±1SEM). Percentages are the contributions of each FFG to total abundance and total biomass. If a taxon has a terrestrial adult stage, then it is considered emergent. Numbers followed by a and b denote significant differences between wetland type (P<0.05).

Variable	Low-Quality (n=2)		WRP Easement (n=9)		Reference (n=2)	
Abundance (No./m²)	**93,001.0 (33,902)**	**%**	**58,857.1 (15,839.6)**	**%**	**29,092.4 (9,867.6)**	**%**
Collector-filterer	79.2 (39.2)	<1	100.7 (33.9)	<1	259.1 (200.0)	<1
Collector-gatherer	10,509.1 (4,859.1)	11.3	13,261.1 (3,487.1)	22.5	9,792.4 (1173.3)	33.7
Herbivore-piercer	84.5 (81.2)	<1	3.0 (2.2)	<1	45.7 (45.71)	<1
Predator	281.8 (13.2)[b]	<1	1,106.7 (367.0)[b]	1.9	3,677.1 (938.1)[a]	12.6
Scraper	631.9 (454.8)	<1	514.5 (231.5)	<1	54.3 (37.1)	<1
Shredder	148.5 (133.5)	<1	40.6 (19.8)	<1	7.6 (1.9)	<1
Zooplankton	81,266.3 (38,458.7)	87.4	43,830.5 (13,879.1)	74.5	15,256.2 (9,867.6)	52.4
Biomass (mg/m²)	**14,236.4 (9,855.4)**		**7,564.7 (2,899.0)**		**6,804.2 (1,794.3)**	
Collector-filterer	45.8 (5.1)	<1	109.6 (68.1)	1.5	76.4 (58.3)	1.1
Collector-gatherer	10,949.0 (7,740.2)	77.0	6,298.0 (2,835.9)	83.3	5,701.0 (1,227.6)	83.8
Predator	155.2 (135.4)	1.1	361.4 (169.7)	4.8	968.3 (597.3)	14.2
Scraper	2,900.0 (2,277.1)	20.4	697.1 (218.4)	9.2	40.2 (17.0)	<1
Shredder	97.0 (69.8)	<1	50.0 (13.9)	<1	2.4 (0.7)	1.0
Zooplankton	89.7 (38.1)	<1	48.7 (13.9)	<1	15.9 (10.1)	<1
Life History (mg/m²)						
Emergent	263.3 (122.5)	1.9	778.7 (268.9)	10.3	1,513.9 (653.6)	22.3
Non-Emergent	13,973.0 (9,739.0)	98.1	6,786.0 (2,856.8)	89.7	5,289.5 (1141.3)	77.7

Table 2.4 Average abundance (No./m²: ± 1 SD) and percent contribution of macroinvertebrate taxa in each wetland type collected via benthic cores. Percent contribution of major groups is the percent of total macroinvertebrate abundance; percent contribution of individual taxa within groups is percent contribution to that group. Min. and max. are the lowest and highest abundance (No./m²) measures within the WRP easement wetlands.

	Low-Quality (n = 2)		WRP Easements (n = 9)				Reference (n = 2)	
Taxon	No/ m²	%	No./m²	%	Min.	Max.	No./m²	%
Annelida	**9,197.4 (6,525.2)**	**78.6**	**9,574.8 (7,508.4)**	**63.7**			**4,106.7 (2,300.5)**	**29.7**
Hirudinea	1.8 (0.2)	<1	21.6 (40.9)	<1	0.0	123.8	51.4 (56.6)	1.3
Oligochaeta	9,195.6 (6,525.1)	99.0	9,553.2 (7,487.9)	99.0	1,680.0	2,6259.0	4,055.2 (2,243.9)	98.7
Crustacea	**192.5 (161.5)**	**1.5**	**238.5 (363.4)**	**1.6**			**173.3 (121.1)**	**1.3**
Amphipoda	42.5 (15.3)	22.1	205.4 (361.1)	86.1	2.7	1118.1	156.2 (121.1)	90.1
Isopoda	129.0 (173.1)	67.0	28.7 (58.4)	12.0	0.0	168.0	3.8 (5.4)	2.2
Malacostraca	21.0 (26.9)	10.9	3.2 (2.9)	1.3	0.0	7.6	13.3 (5.4)	7.7
Insecta	**1,476.2 (352.9)**	**12.6**	**3,983.2 (3,941.7)**	**26.5**			**9,058.1 (1,943.5)**	**65.5**
Coleoptera	25.2 (11.4)	1.7	69.3 (90.5)	1.7	2.7	259.0	47.6 (5.4)	<1
Collembola	17.1 (5.4)	1.2	15.6 (14.2)	<1	0.0	45.7	10.5 (14.8)	<1
Diptera	1,287.1 (226.9)	87.2	3,523.1 (3,551.4)	88.5	544.0	11,548.6	8,661.9 (1,695.7)	95.6
Ephemeroptera	1.0 (1.3)	<1	58.2 (103.8)	1.5	0.0	323.3	73.3 (84.9)	<1
Hemiptera	124.8 (101.0)	8.5	178.2 (231.9)	4.5	18.7	629.3	121.9 (16.2)	1.3
Megaloptera	0.0	0	0.0	0.0	0.0	0.0	29.5 (17.5)	<1
Odonata	21.0 (29.6)	1.4	137.4 (355.9)	3.5	0.0	1,083.8	113.3 (138.7)	1.3
Molluska	**707.5 (698.9)**	**6.0**	**570.2 (707.3)**	**3.8**			**313.3 (230.3)**	**2.3**
Planorbidae	103.5 (124.8)	14.6	172.3 (317.7)	30.2	0.0	979.0	10.5 (4.0)	3.3
Physidae	528.5 (518.4)	74.7	319.0 (418.6)	55.9	64.0	1158.1	46.7 (52.5)	14.9
Sphaeriidae	75.6 (55.7)	10.7	78.8 (90.7)	13.8	0.0	276.7	256.2 (278.8)	81.8
Hydrachnidia	**5.6 (5.6)**	**<1**	**223.1 (370.5)**	**<1**	0.0	1160.0	**62.9 (45.8)**	**<1**
Hydrazoa	**3.3 (4.7)**	**<1**	**20.3 (21.8)**	**<1**	0.0	58.7	**0.0**	**0.0**
Nematoda	**122.1 (102.0)**	**<1**	**388.4 (454.7)**	**<1**	26.7	1102.9	**117.1 (90.2)**	**<1**
Tricladida	**1.7 (2.4)**	**<1**	**14.8 (41.7)**	**<1**	0.0	125.9	**3.8 (5.4)**	**<1**

Table 2.5 Average biomass (mg/m²: ± 1 SD) and percent contribution of macroinvertebrate taxa in each wetland type collected via benthic cores. Percent contribution of major groups is the percent of total macroinvertebrate abundance; percent contribution of individual taxa within groups is percent contribution to that group. Min. and max. are the lowest and highest biomass (mg/m²) measures within the WRP easement wetlands.

	Low-Quality (n = 2)		WRP Easements (n = 9)				Reference (n = 2)	
Taxon	mg/ m²	%	mg/m²	%	min.	max.	mg/m²	%
Annelida	**1,113.4 (761.9)**	**8.2**	**1,494.7 (1,730.0)**	**20.4**			**601.0 (333.2)**	**12.1**
Hirudinea	0.0	0.0	4.7 (11.0)	<1	0.0	33.7	2.4 (0.3)	<1
Oligochaeta	1,113.3 (761.9)	100.0	1,490.0 (1,728.6)	99.0	75.2	5450.8	598.6 (332.3)	99.0
Crustacea	**8,925.3 (10,335.8)**	**65.4**	**150.0 (185.2)**	**2.0**			**2,655.7 (1,654.2)**	**53.6**
Amphipoda	19.4 (17.4)	<1	67.2 (113.3)	44.8	0.3	336.4	33.0 (4.2)	1.2
Isopoda	80.5 (113.6)	<1	23.5 (41.5)	15.7	0.0	117.3	<1	<1
Malacostraca	8,825.5 (10,431.9)	99.0	59.3 (172.6)	39.6	0.0	519.4	2,622.1 (1,641.8)	98.7
Insecta	**509.7 (186.5)**	**3.8**	**897.2 (798.7)**	**12.2**			**1,580.3 (948.7)**	**37.0**
Coleoptera	216.7 (47.5)	42.5	85.2 (90.3)	9.5	0.2	236.0	21.3 (3.8)	1.4
Collembola	<1	<1	<1	<1	0.0	3.6	<1	<1
Diptera	246.5 (197)	48.4	581.9 (509.4)	64.9	118.6	1366.9	1,141.8 (576.9)	72.3
Ephemeroptera	0.9 (1.2)	<1	22.5 (26.4)	2.5	0.0	66.8	54.2 (65.9)	3.4
Hemiptera	26.3 (31.8)	5.2	12.7 (18.0)	5.1	0.8	184.0	44.1 (29.5)	2.9
Megaloptera	0.0	0	0.0	0.0	0.0	0.0	52.4 (22.4)	3.3
Odonata	4.6 (6.4)	3.2	157.8 (363.5)	17.6	0.0	1112.8	265.6 (257.9)	16.8
Molluska	**2,945.7 (3,227.8)**	**21.8**	**728.6 (683.3)**	**9.9**			**115.9 (57.5)**	**2.3**
Planorbidae	2159.1 (2,388.0)	73.3	194.3 (206.7)	26.7	36.3	1509.9	5.5 (0.0)	4.8
Physidae	740.9 (832.3)	25.2	488.0 (511.4)	67.0	17.8	321.7	34.7 (24.0)	29.9
Sphaeriidae	45.7 (7.3)	1.6	46.3 (50.0)	6.4	3.7	153.7	75.7 (81.5)	65.3
Hydrachnidia	**<1**	**<1**	**<1**	**<1**	0.0	1.7	**<1**	**<1**
Hydrazoa	**<1**	**<1**	**<1**	**<1**	0.0	2.4	**0.0**	**0.0**
Nematoda	**4.5 (4.4)**	**<1**	**8.3 (8.1)**	**<1**	0.5	22.9	**3.3 (3.1)**	**<1**
Tricladida	**<1**	**<1**	**5.7 (16.0)**	**<1**	0.0	48.4	**<1**	**<1**

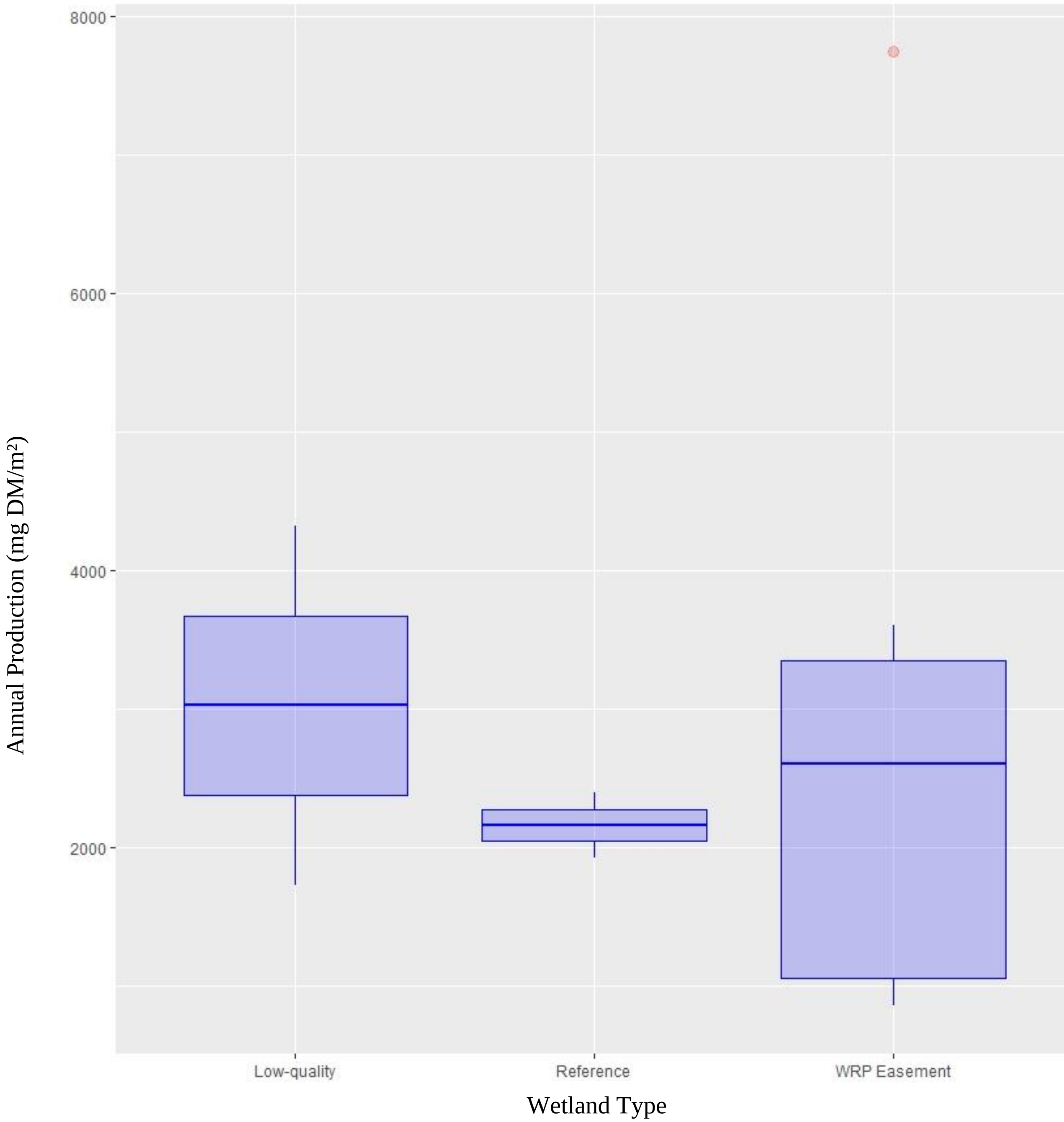

Figure 2.1 Annual production of macroinvertebrates in each wetland type. Samples were collected via benthic cores. One-way ANOVA revealed no significant difference among wetland type ($P>0.05$).

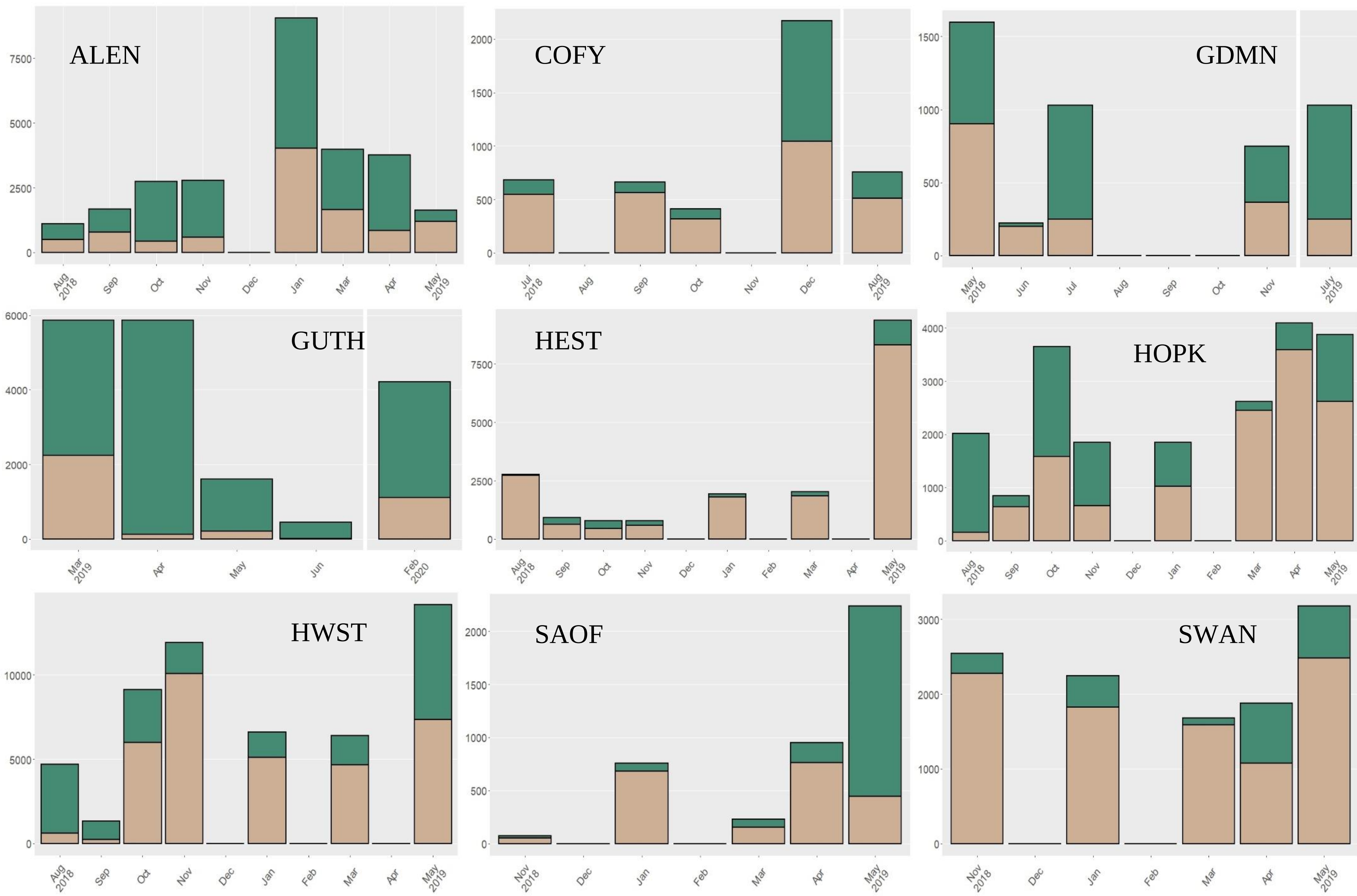

Figure 2.2 Monthly production (mg DM/m²) of emergent and non-emergent macroinvertebrate taxa at each WRP easement wetland.

Table 2.6 Average relative abundance (%) of macroinvertebrate taxa collected in dip net samples at wetland type. Values are means (± 1 SD). Percent contribution of major groups is the percent of total macroinvertebrate abundance; percent contribution of individual taxa within groups is percent contribution to that group. Min. and max. are the lowest and highest relative abundance measures within the WRP easement wetlands. Numbers followed by a and b denote significant differences between wetland type (P<0.05).

Taxon	Low-Quality (n=2)	WRP Easement (n=9)			Reference (n=2)
			Min.	**Max.**	
Annelida	**15.4 (14.1)**	**27.6 (14.0)**	**7.0**	**35.8**	**23.2 (3.9)**
Hirudinea	1.1 (<1)	<1 (2.0)	0.0	6.1	1.3 (1.4)
Oligochaeta	98.9 (<1)	99.2 (2.0)	93.9	100.0	98.7 (1.4)
Crustacea	**7.8 (3.9)**	**10.6 (13.6)**	**7.0**	**77.4**	**11.3 (4.0)**
Amphipoda	68.3 (15.7)	56.1 (39.7)	0	98.8	93.8 (4.2)
Isopoda	6.0 (8.5)	22.8 (24.4)	0	66.7	<1
Malacostraca	25.8 (24.2)	21.2 (24.4)	0	59.1	5.7 (3.5)
Insecta	**16.7 (1.2)**	**41.2 (16.9)**	**7.4**	**64.4**	**48.6 (10.4)**
Coleoptera	11.8 (2.0)	5.3 (5.5)	<1	18.1	1.4 (0.3)
Collembola	<1	<1	0.0	2.0	<1
Diptera	58.9 (2.3)	66.9 (24.1)	23.9	91.1	85.5 (3.9)
Ephemeroptera	8.1 (11.1)	8.5 (17.7)	<1	55.6	2.6 (1.7)
Hemiptera	10.2 (6.3)	14.3 (19.4)	2.0	65.1	3.7 (0.7)
Megaloptera	0.0	0.0	0	0	1.7 (0.4)
Odonata	10.7 (9.7)	4.6 (6.8)	0	20.7	4.8 (2.5)
Molluska	**12.7 (6.9)**	**19.1 (8.6)**	**4.0**	**22.7**	**6.8 (6.0)**
Planorbidae	23.6 (17.4)	26.0 (19.6)	0.0	61.5	11.7 (2.2)
Physidae	60.6 (39.8)	62.0 (24.0)	25.3	100.0	24.3 (14.0)
Sphaeriidae	15.8 (22.4)	11.2 (13.0)^{b}	0.0	40.0	63.9 (11.6)^{a}
Taxa Richness	**45 (2.8)**	**34.6 (10.2)**	**19**	**52**	**52 (7.1)**
Shannon Diversity	**2.3 (0.14)**	**2.1 (0.32)**	**1.47**	**2.36**	**2.2 (0.03)**
Emergent Taxa	**13.1(1.6)**	**23.0(11.5)**	**6.0**	**40.8**	**45.8(10.1)**

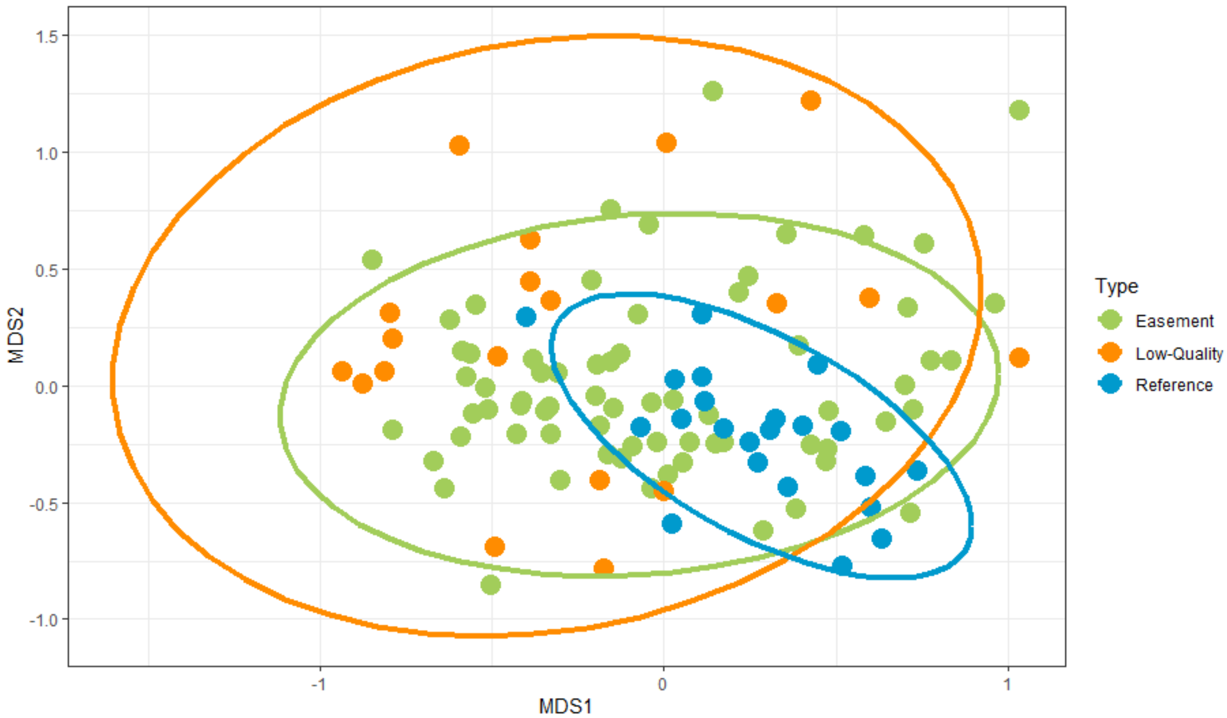

Figure 2.3 Ordinations of macroinvertebrate community structure using species richness and evenness. Samples were taken from 9 WRP easement wetlands, 2 low-quality wetlands, and 2 reference-standard wetlands. Points represent individual sampling events. Ellipses are predictions of where new points will fall. P<0.05

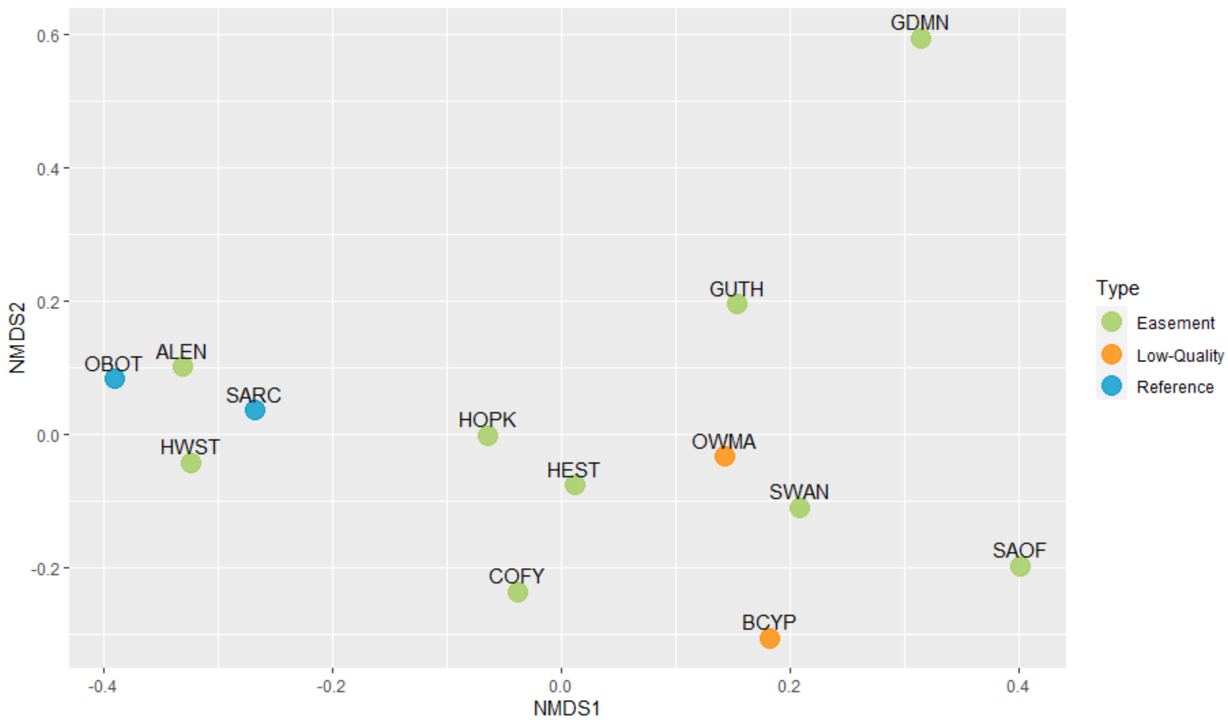

Figure 2.4 Ordinations of macroinvertebrate community structure using species richness and evenness. Samples were taken from 9 WRP easement wetlands, 2 low-quality wetlands, and 2 reference-standard wetlands. Points represent the average community structure for each site over the entire sampling period.

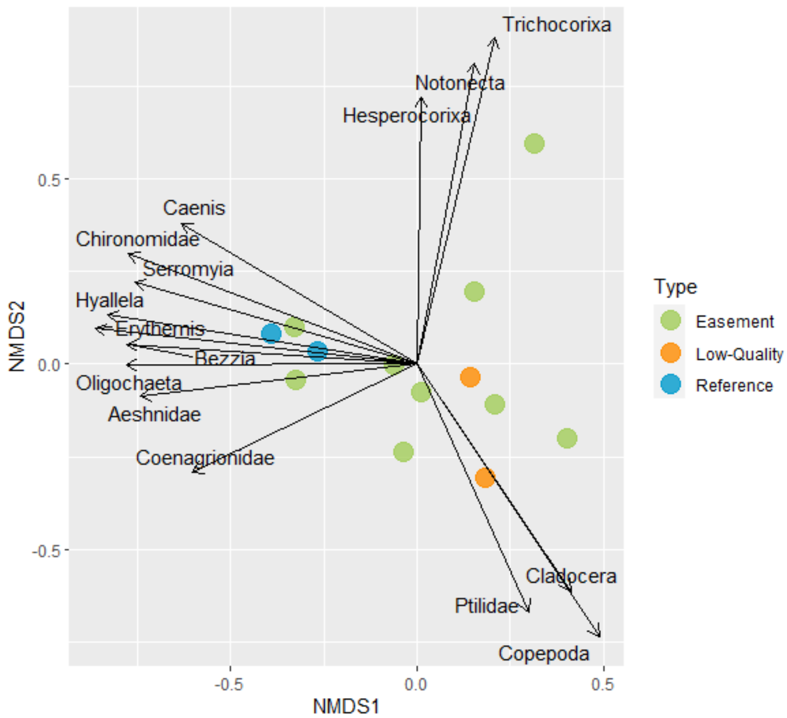

Figure 2.5 Ordinations of macroinvertebrate community structure using species richness and evenness. Samples were taken from 9 WRP easement wetlands, 2 low-quality wetlands, and 2 reference-standard wetlands. Points represent the average community assemblage for each site over the entire sampling period. Vector length is proportional to the correlation of the individual invertebrate species to the sites.

Appendix

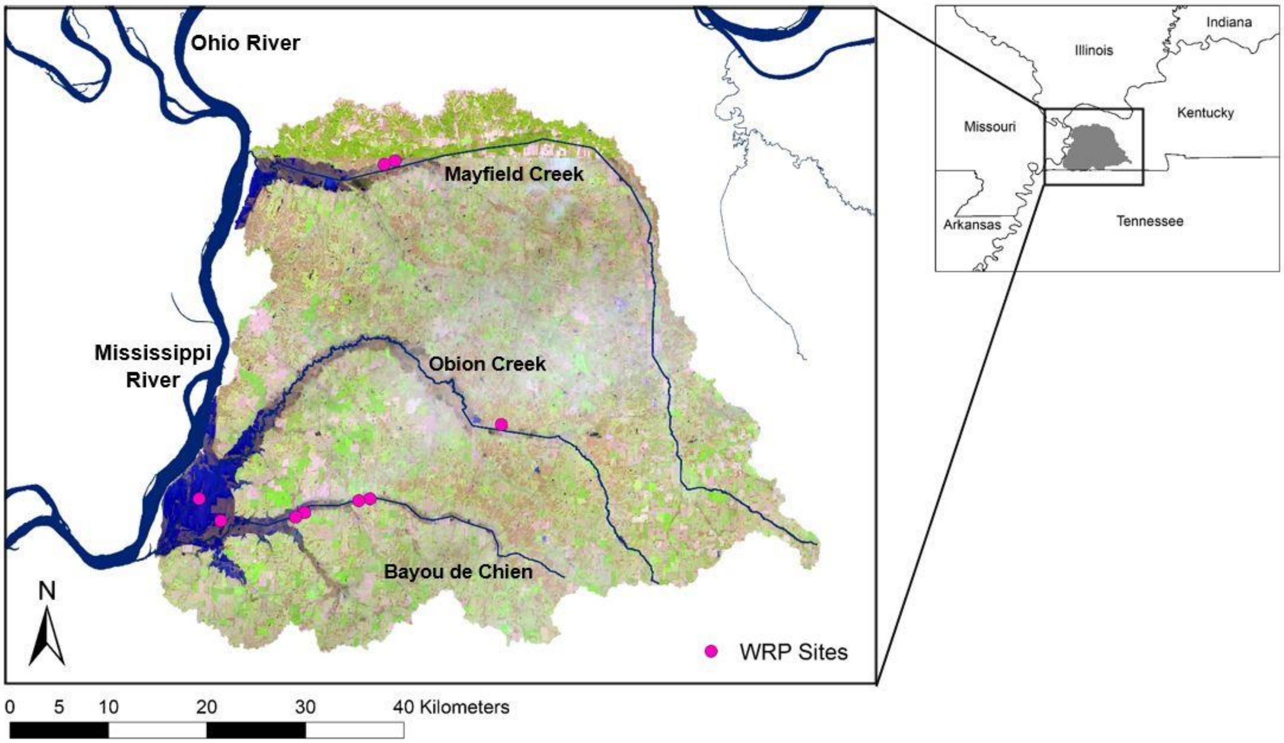

Figure A.1 Invertebrate sampling occurred on nine WRP easement wetlands located within the Bayou du Chien watershed (HUC 08010201) in western Kentucky from May 2018 to June 2018.

Allen (ALEN)

ALEN is a 27.3 ha easement located in Hickman County, KY (Fig. A.2). The easement was enrolled in WRP in 2012, but it had been enrolled in CRP for many years prior. ALEN is adjacent to the Bayou de Chien, but it disconnected from the creek by a levee that spans the northern edge of the easement wetland (Fig. A.3). Throughout ALEN are remnant drainage ditches that were plugged in 2014 as part of a restoration effort by NRCS. The site is surrounded primarily by row crop agriculture; however, a parcel of land directly east is also enrolled in WRP. Allen has a diverse plant community with several varieties of facultative and obligate wetland plant species. Invertebrate dip-net sampling took place monthly from May 2018-May 2019, while benthic cores were taken monthly from August 2018-May 2019.

Figure A.2. Photo of Allen captured from the main beaver dam on October 30, 2018.

A total of 36 families and at least 46 genera of aquatic macroinvertebrates were collected via dip net sampling throughout the study (Table A.1). The class Insecta comprised 47.6 percent of all taxa collected with the dip net (Table A.1).

ALEN had the most diverse assemblage of Hemipterans and Odonates out of all the easement wetlands sampled. While zooplankton dominated invertebrate abundance, collector-gatherers contributed almost 74% to total biomass (Table A.2). Furthermore, approximately 40% of all biomasses belonged to invertebrates with an emergent terrestrial stage, the second highest of all the easement wetlands. Unlike other easement wetlands, gastropods composed a very small percentage of the invertebrate community (Table A.1). ALEN was one of two easement wetlands which most closely resembled the reference-standard wetlands sampled in this study.

Extensive beaver activity in ALEN kept water levels relatively low and stable throughout the year. As a result, a large proportion of the easement surface area was inundated with water (Table A.3). The diverse assemblage of both emergent and submersed aquatic vegetation resulted in a healthy macroinvertebrate community. Beaver dams were removed in early 2020, resulting in a dramatic decrease in the surface area of the wetland. Although outside the scope of this study, it will be interesting to see the consequences of this management decision.

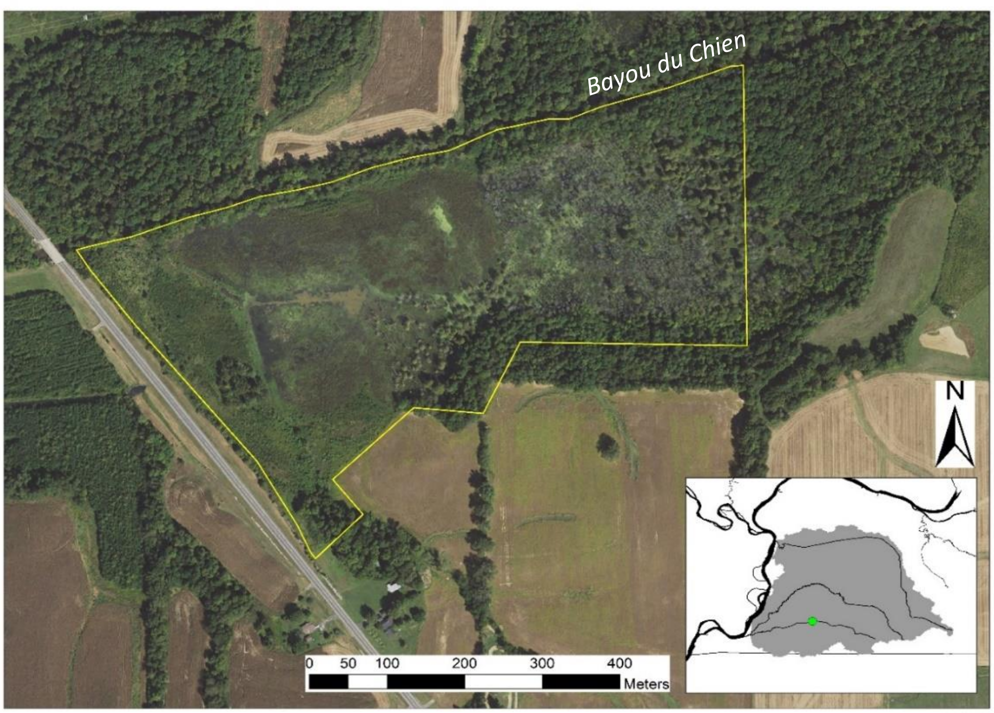

Figure A.3. Aerial photo (USDA NAIP 2018) of ALEN easement boundary and its location within the BDC watershed.

Table A.1. Results of dip-net sampling at ALEN. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				**No.**	**% Cont.**
Annelida				**775**	**26.5**
	Oligochaeta		spp.	771	
	Hirudinea				
		Glossiphoniidae	*Helobdella*	4	
Arachnida				**73**	**2.5**
	Hydrachnida		spp.	73	
Crustacea				**642**	**22.0**
	Branchiopoda		spp.	270	
	Copepoda		spp.	128	
	Amphipoda				
		Crangonyctidae	*Crangonyx*	1	
		Hyallelidae	*Hyallela*	240	
	Isopoda				
		Asellidae	*Lirceus*	1	
	Malacostraca	Cambaridae	spp.	1	
		Palaemonidae	*Paelomonetes*	1	
Hydrazoa		Hydridae	spp.	**3**	**<1**
Insecta				**1396**	**47.6**
	Coleoptera				
		Dytiscidae	*Celina*	1	
		Noteridae	*Hydrocanthus*	1	
			Suphisellus	2	
	Diptera				
		Ceratopogonidae	*Bezzia*	17	
			Serromyia	74	
			Probezzia	1	
			Atrichopogon	1	
			spp.	1	
		Chaoboridae	*Chaoborus*	26	
		Chironomidae	spp.	926	
		Culicidae	*Anopheles*	2	
			Culex	8	
			Mansonia	4	
			Uranotaenia	3	
	Hemiptera				
		Belostomatidae	*Belostoma*	2	
		Corixidae	*Trichocorixa*	154	
			Hesperocorixa	3	
		Naucoridae	*Pelocoris*	1	
		Notonectidae	*Buenoa*	1	
		Pleidae	*Paraplea*	4	
		Veliidae	spp.	3	
	Ephemeroptera				
		Baetidae	*Callibaetis*	33	
		Caenidae	*Caenis*	17	
	Odonata				
		Aeshnidae	spp.	6	
		Coenagrionidae	*Coenagrion*	44	
		Libellulidae	*Erythemis*	21	
			Pachydiplax	20	
			spp.	18	
	Lepidoptera		spp.	2	
Molluska				**83**	**2.8**
	Gastropoda				
		Lymnaeidae	*Pseudosuccinea*	1	
		Physidae	*Physa*	53	
		Planorbidae	*Anyclus*	1	
			Menetus	22	
		Sphaeriidae	*Sphaerium*	6	
Turbellaria				**34**	**1.2**
		Dugesiidae	*Dugesia*	34	

Table A.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in Allen. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	25	<1	15	<1
Collector-Gatherer	11,930	10	2,220	73.5
Predator	1,939	2	438	14.5
Scraper	231	<1	237	7.8
Shredder	67	<1	3	<1
Zooplankton	105,419	88	108	3.6
Total	**119,633**	100	**3,021**	100
Life History				
Emergent	4,786	4.0	1,178	39.0
Non-Emergent	114,847	96.0	1,843	61.0

Table A.3. Dip net results by functional group for Allen. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	<1	73.9	26.1
Collector-Gatherer	58.1	55.8	44.2
Predator	17.0	45.0	55.0
Scraper	2.5	0	100
Shredder	8.1	<1	99.1
Zooplankton	13.3	0	100
Total	100		

Table A.4. Wetted surface area for ALEN based on four separate water depths from Aug 29, 2018 through Aug 29, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	0.350	98.1	204,813	75
Min	0.28	98.1	193,965	71
Max	1.11	98.9	250,722	93
Mode	0.34	98.1	203,396	74

Coffey (COFY)

COFY is a 101.6 ha easement in Hickman County, KY located next to Obion Creek (Fig.B.1). In 2007, the easement was hydrologically restored with the addition of a 10.9 and 13.5 ha shallow water area (Fig. B.2). Water-resistant hardwood trees were planted on the easement in 2012. The easement has several interior ditches which drain southward towards the slough running parallel to Salmon Lane, which then drains into the tract of land to the east. To the north and south of COFY are two tracts of land considered are mixed forest, open land, and some of the best remaining bottomland hardwood forest in Kentucky. The land directly west of COFY is in row-crop agriculture. Extensive flooding and subsequent drying on this easement throughout the year made invertebrate sampling difficult. Only five months were sampled from August 2018-August 2019.

Figure B.1.One of two shallow water areas installed on COFY as part of restoration efforts. Photo of COFY captured November 1, 2019.

The proximity of COFY to the Mississippi River allowed for extreme flooding at the end of 2018 and the beginning of 2019. As a result, invertebrate sampling was sporadic. However, a total of 32 families and at least 36 genera were collected via dip net sampling (Table B.1). Approximately 40% of the invertebrates collected in the dip net sampling were zooplankton, a group of organisms quite capable of surviving flooding and drought. COFY had the most diverse assemblage of coleopterans out of all the easement wetlands sampled. While zooplankton dominated invertebrate abundance, collector-gatherers contributed almost 45% to total biomass (Table B.2). Insects comprised 32% of the invertebrate community, with Chironomidae being by far the most abundant family. Although Chironomids were abundant, less than 5% of total biomass was comprised of invertebrates with terrestrial adult stages.

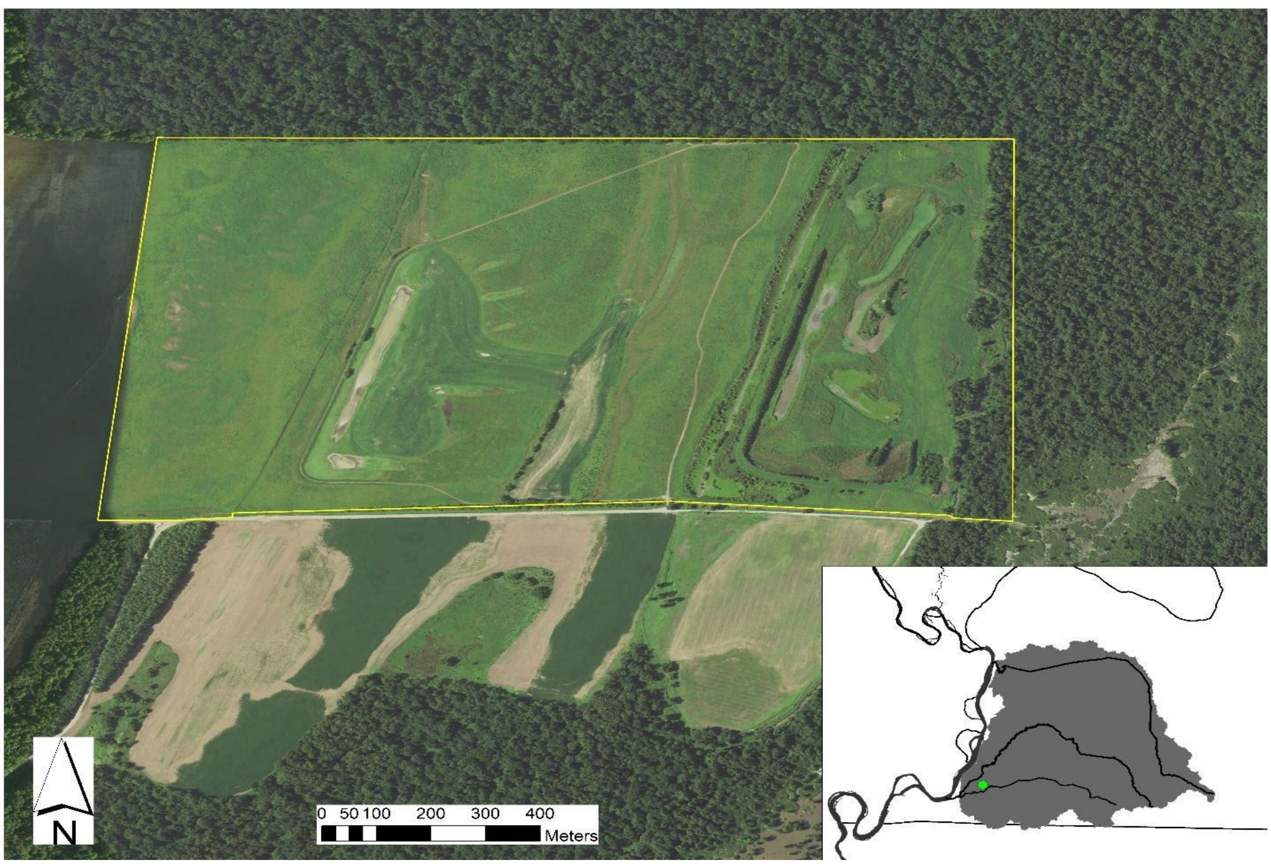

Figure B.2. Aerial photo (USDA NAIP 2018) of COFY easement boundary and its location within the BDC watershed.

Table B.1. Results of dip-net sampling at COFY. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				No.	% Cont.
Annelida				**191**	**18.3**
	Oligochaeta		spp.	190	
	Hirudinea				
		Erpobdellidae	*Mooreobdella*	1	
Crustacea				**440**	**42.1**
	Branchiopoda		spp.	296	
	Copepoda		spp.	124	
	Ostracoda		spp.	5	
	Amphipoda				
		Crangonyctidae	*Crangonyx*	2	
	Isopoda				
		Asellidae	*Lirceus*	4	
	Malacostraca	Cambaridae	spp.	5	
		Palaemonidae	*Paelomonetes*	4	
Insecta				**336**	**32.2**
	Coleoptera				
		Carabidae	spp.	1	
		Dytiscidae	*Copelatus*	1	
			Coptotomus	1	
		Haliplidae	*Peltodytes*	1	
		Hydrophilidae	*Berosus*	1	
			Tropisternus	1	
		Noteridae	*Hydrocanthus*	1	
			Suphisellus	1	
		Ptilidae	spp.	1	
	Diptera				
		Ceratopogonidae	*Probezzia*	4	
		Chaoboridae	*Chaoborus*	3	
		Chironomidae	spp.	204	
		Tabanidae	*Chrysops*	2	
		Stratiomyidae	*Odontomyia*	5	
	Hemiptera				
		Belostomatidae	*Belostoma*	7	
		Corixidae	*Trichocorixa*	5	
		Mesoveliidae	*Mesovelia*	1	
		Notonectidae	*Buenoa*	1	
		Veliidae	spp.	1	
	Ephemeroptera				
		Baetidae	*Callibaetis*	65	
	Odonata				
		Coenagrionidae	*Coenagrion*	28	
	Lepidoptera		spp.	1	
Molluska				**77**	**7.4**
	Gastropoda				
		Physidae	*Physa*	19	
		Planorbidae	*Anyclus*	5	
			Helisoma	9	
			Menetus	12	
		Viviparidae	*Bellamya*	2	
		Sphaeriidae	*Sphaerium*	30	

Table B.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in COFY. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	125	<1	30	<1
Collector-Gatherer	8,272	52.9	3,519	87.2
Predator	221	<1	74	1.9
Scraper	107	<1	311	7.7
Shredder	8	<1	80	2.0
Zooplankton	15,627	64.2	21	<1
Total	**24,360**	100	**4,035**	100
Life History				
Emergent	658	2.7	186	4.6
Non-Emergent	23,702	97.3	3,849	95.4

Table B.3. Dip net results by functional group for COFY. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	2.9	0	100
Collector-Gatherer	45.4	57.2	42.3
Predator	5.9	58.7	41.3
Scraper	4.5	0	100
Shredder	<1	12.5	87.5
Zooplankton	40.3	0	100
Total	100		

Table B.4. Wetted surface area for COFY based on four separate water depths from Aug 24, 2018 through Aug 24, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	2.9	92.3	1,017,380	100
Min	0.0	89.4	0.0	0
Max	6.1	95.5	1,017,380	100
Mode	0.0	89.4	0.0	0.0

Goodman (GDMN)

Goodman is a 46.6 ha easement in Hickman County, KY located adjacent to Obion Creek. A shallow water area (7,186 m^2) was constructed on GDMN in 2015 (Fig. C.1). GDMN has a drainage ditch which runs through the middle of the easement (Fig. C.2). The ditch is maintained for the drainage of agriculture land north of the easement. Water within the ditch flows south towards the Obion Creek. At the time of invertebrate sampling, GDMN was surrounded by row-crop agricultural fields. However, several adjacent tracks were scheduled for conversion into bottomland hardwood forest through the Wetland Enhancement Program.

Figure C.1.The shallow water area of GDMN. Photo captured on July 7, 2018.

GDMN is located close to the Mississippi River and the confluence of the Bayou de Chien and Obion Creek. The easement experienced extreme flooding in the winter of 2018-2019, with a maximum water depth in the shallow water area reaching 5.56m (Table C.4). The high-water levels and periods of drought resulted in sporadic invertebrate sampling. However, a total of 30 families and at least 35 genera were collected via dip net sampling (Table C.1). Insects comprised 64% of all invertebrates collected, the highest relative abundance of all easement wetlands (Table C.1). Water boatman (family Corixidae) were the most numerous of all the insects collected (Table C.1). Gastropods, especially physid snails, also contributed greatly to the assemblage of invertebrates. Predators and scrapers contributed to 27.9% and 20% of overall biomass, respectively. Unlike the other easement wetlands, most predators in GDMN did not have a terrestrial adult stage (Table C.3).

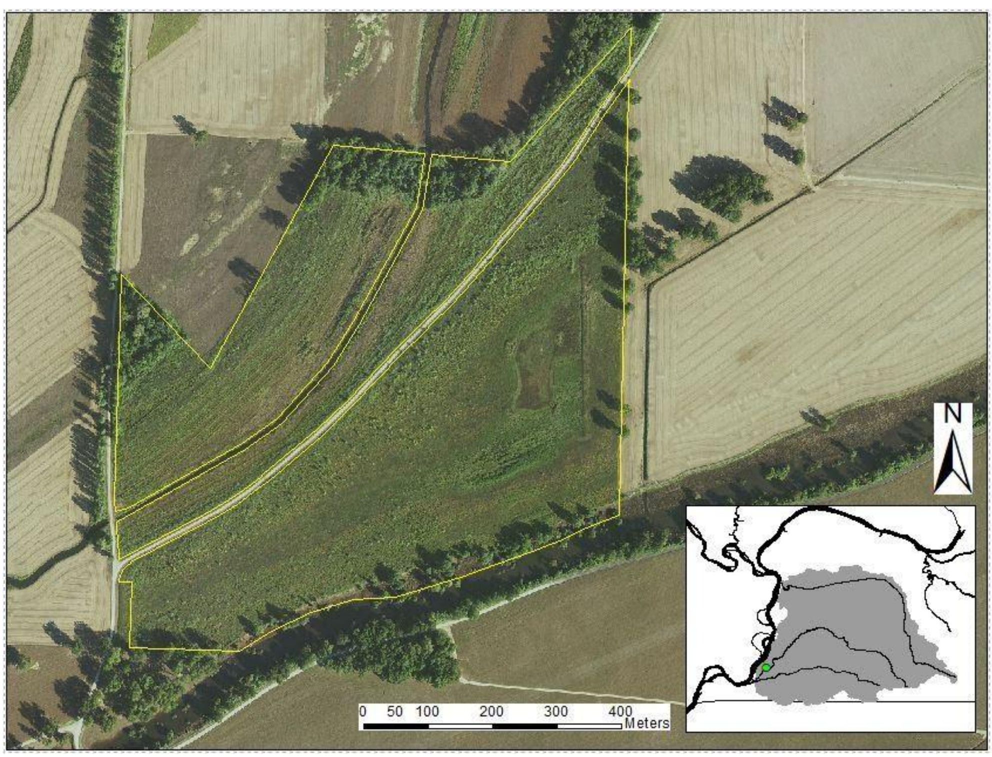

Figure C.2. Aerial photo (USDA NAIP 2018) of GDMN easement boundary and its location within the BDC watershed.

Table C.1. Results of dip-net sampling at GDMN. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				No.	%
Annelida				**79**	**6.8**
	Oligochaeta		spp.	79	
Arachnida				**8**	**<1**
	Hydrachnida		spp.	8	
Crustacea				**81**	**7.0**
	Branchiopoda		spp.	2	
	Copepoda		spp.	49	
	Amphipoda				
		Hyallelidae	*Hyallela*	2	
	Isopoda				
		Asellidae	*Lirceus*	7	
	Malacostraca	Mysidae	*Taphromysis*	13	
	Ostracoda		spp.	8	
Insecta				**740**	**64.0**
	Coleoptera	Carabidae	spp.	1	
		Dytiscidae	*Dytiscus*	2	
			Laccophilus	3	
		Hydrophilidae	*Berosus*	4	
			Tropisternus	8	
		Noteridae	*Notomicrus*	3	
		Staphylinidae	spp.	1	
	Diptera				
		Ceratopogonidae	*Serromyia*	3	
		Chironomidae	spp.	104	
		Culicidae	*Aedes*	111	
		Dolichopodidae	spp.	6	
		Empididae	spp.	2	
		Tabanidae	*Chrysops*	1	
	Hemiptera				
		Belostomatidae	*Belostoma*	1	
		Corixidae	*Trichocorixa*	479	
			Hesperocorixa	1	
		Notonectidae	*Buenoa*	2	
			Notonecta	1	
	Ephemeroptera				
		Baetidae	*Callibaetis*	1	
		Caenidae	*Caenis*	3	
		Heptageniidae	spp.	1	
	Odonata				
		Coenagrionidae	*Coenagrion*	1	
	Lepidoptera		spp.	1	
Mollusca				**243**	**21.0**
	Gastropoda				
		Physidae	*Physa*	142	
		Planorbidae	*Helisoma*	79	
			Menetus	22	
Collembola		Poduridae	*Podura*	**6**	**<1**

Table C.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in GDMN. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	149	1.5	24	1.9
Collector-Gatherer	5,000	49.9	540	42.7
Predator	701	7.0	353	27.9
Scraper	88	<1	251	19.9
Shredder	101	1.0	89	7.1
Zooplankton	3,992	39.4	5	<1
Total	**10,035**	100	**1,261**	100
Life History				
Emergent	1,405	14.0	230	18.2
Non-Emergent	8,630	86.0	1,031	81.8

Table C.3. Dip net results by functional group for GDMN. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	9.6	100	0
Collector-Gatherer	19.0	49.1	50.9
Predator	44.2	2.2	97.8
Scraper	21.1	<1	99.6
Shredder	<1	9.1	90.9
Zooplankton	5.1	0	100
Total	100		

Table C.4. Wetted surface area for GDMN based on four separate water depths from Aug 24, 2018 through Aug 24, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	1.7	92.60	440,637	94.5
Min	0.0	90.90	0.0	0
Max	5.56	96.46	466,193	100
Mode	0.0	90.90	0.0	0

Guthrie (GUTH)

GUTH is a 56.99 ha easement in Graves County, KY. A 7,682 m^2 shallow water area was installed on the easement in the winter of 2018 (Fig. D.1). There are several ditches inside the easement, some of which have been plugged as part of the restoration effort. Obion Creek runs along the southern boundary of the easement (Fig D.2) approximately 500 m uphill of the SWA. The drainage ditch that runs across the easement drains land to the east, which has some trees planted through the Conservation Reserve Program. GUTH is also part of the NRCS/University of Kentucky Edge of Field monitoring study.

Figure D.1. Vegetation had not yet regrown following construction of the shallow water area on GUTH when this photograph was captured April 9, 2019.

Invertebrate sampling at GUTH began in March 2019 approximately 4 months after the shallow water area was completed. Dip net sampling collected 20 invertebrate families and at least 22 genera (Table D.1). At the time of sampling, the SWA was devoid of macrophytes.

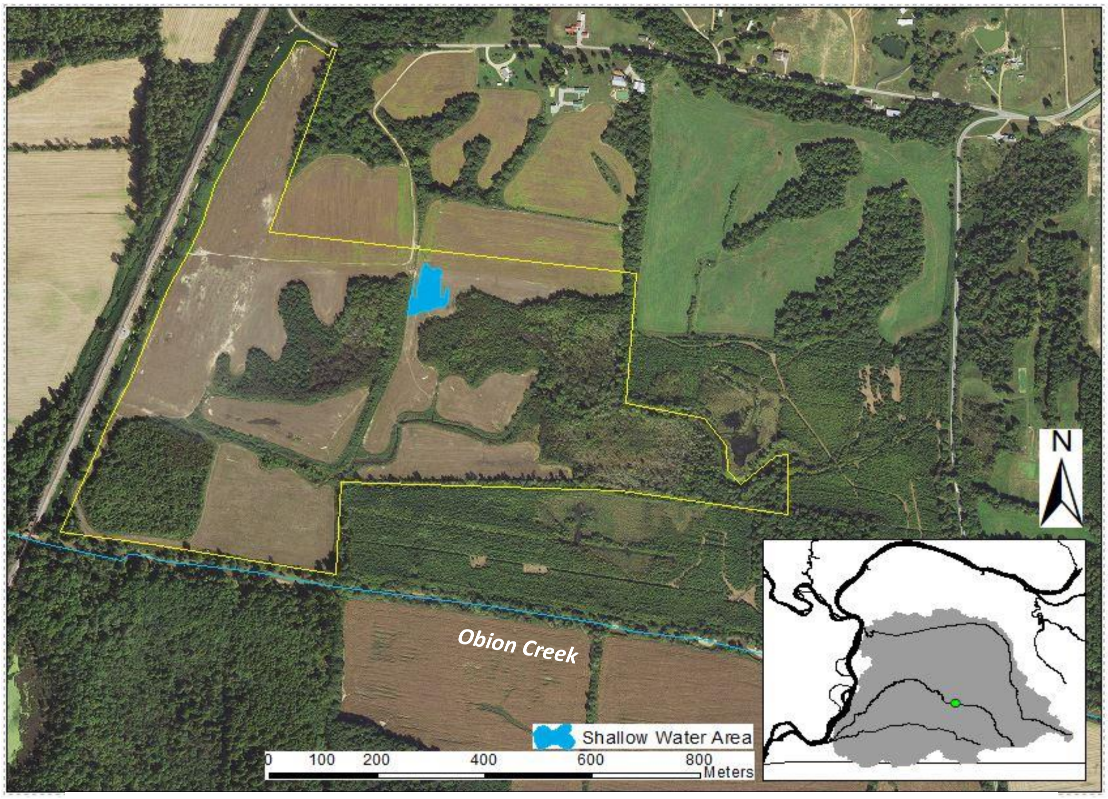

Figure D.2. Aerial photo (USDA NAIP 2018) of GUTH easement boundary and its location within the BDC watershed.

The invertebrate community at GUTH was primarily composed of four taxa: oligochaetes, chironomids, physid snails, and zooplankton. Large chironomids were abundant in the wetland's fine silt substrate, and they contributed greatly to the biomass of emergent taxa found in GUTH (Table D.3). Again, GUTH was a very new wetland when the invertebrate community was sampled. As time passes, a more speciose community may develop there. Available LiDAR imagery was not able to capture the newly constructed SWA on GUTH, so the size of the SWA was measured with high-resolution georeferenced drone imagery. Water depth in GUTH did not vary greatly throughout the year, and changes in water depth seemed to have little effect on the surface area of the SWA. The surface area of the SWA on GUTH is only 1.3% of the entire enrolled easement.

Table D.1. Results of dip-net sampling at GUTH. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				**No.**	**% Cont.**
Annelida				**201**	**13.0**
	Oligochaeta		spp.	201	
Arachnida				**2**	**<1**
	Hydrachnida		spp.	2	
Crustacea				**758**	**48.7**
	Branchiopoda		spp.	730	
	Copepoda		spp.	28	
	Isopoda				
		Asellidae	*Lirceus*	6	
	Malacostraca	Cambaridae	spp.	3	
	Ostracoda		spp.	6	
Insecta				**458**	**29.4**
	Coleoptera				
		Dytiscidae	*Laccophilus*	2	
		Haliplidae	*Peltodytes*	2	
		Hydrophilidae	*Berosus*	4	
	Diptera				
		Ceratopogonidae	*Probezzia*	2	
			Serromyia	4	
		Chironomidae	spp.	412	
		Tabanidae	*Chrysops*	2	
	Hemiptera				
		Corixidae	*Trichocorixa*	25	
			Hesperocorixa	1	
		Gyrinidae	*Gyrinus*	2	
		Notonectidae	*Notonecta*	1	
	Ephemeroptera				
		Baetidae	*Callibaetis*	2	
		Caenidae	*Caenis*	1	
	Odonata				
		Coenagrionidae	*Coenagrion*	1	
Molluska				**120**	**7.7**
	Gastropoda				
		Physidae	*Physa*	120	

Table D.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in GUTH. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	3	<1	4	<1
Collector-Gatherer	6,821	33.2	1,378	64
Predator	96	<1	14	<1
Scraper	72	<1	736	34.1
Shredder	3	<1	2	<1
Zooplankton	13,570	66.0	21	<1
Total	**20,565**	100	**2,155**	100
Life History				
Emergent	5,080	24.7	1,315	61.0
Non-Emergent	15,485	75.3	840	39.0

Table D.3. Dip net results by functional group for GUTH. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	0	0	0
Collector-Gatherer	40.1	66.4	33.6
Predator	2.6	22.0	88.0
Scraper	7.7	0	100
Shredder	<1	0	100
Zooplankton	49.1	0	100
Total	100		

Hopkins (HOPK)

HOPK is a 27.3 ha easement located in Clinton County, KY enrolled in WRP in 2012 (Fig.E.1). The site has two main interior ditches. One was plugged in 2015 and the other remains unplugged because it is on the easement boundary. The land directly west of HOPK was also enrolled in WRP the same year. Like the tract directly west, there is a lot of beaver activity on the easement. HOPK has a very dense and diverse vegetative community.

Figure E.1. Photo of HOPK captured on June 4, 2018

A total of 35 families at least 43 genera of invertebrates were collected in dip net sampling at HOPK (Table E.1). Insects were the most abundant major taxonomic group collected on this wetland, comprising 36.1% of total abundance (Table E.1). HOPK was the only easement wetland where the medicinal leech (*Macrobdella decorum*) was collected. These leeches were quite abundant although hard to collect in the dip net (*personal observation*).

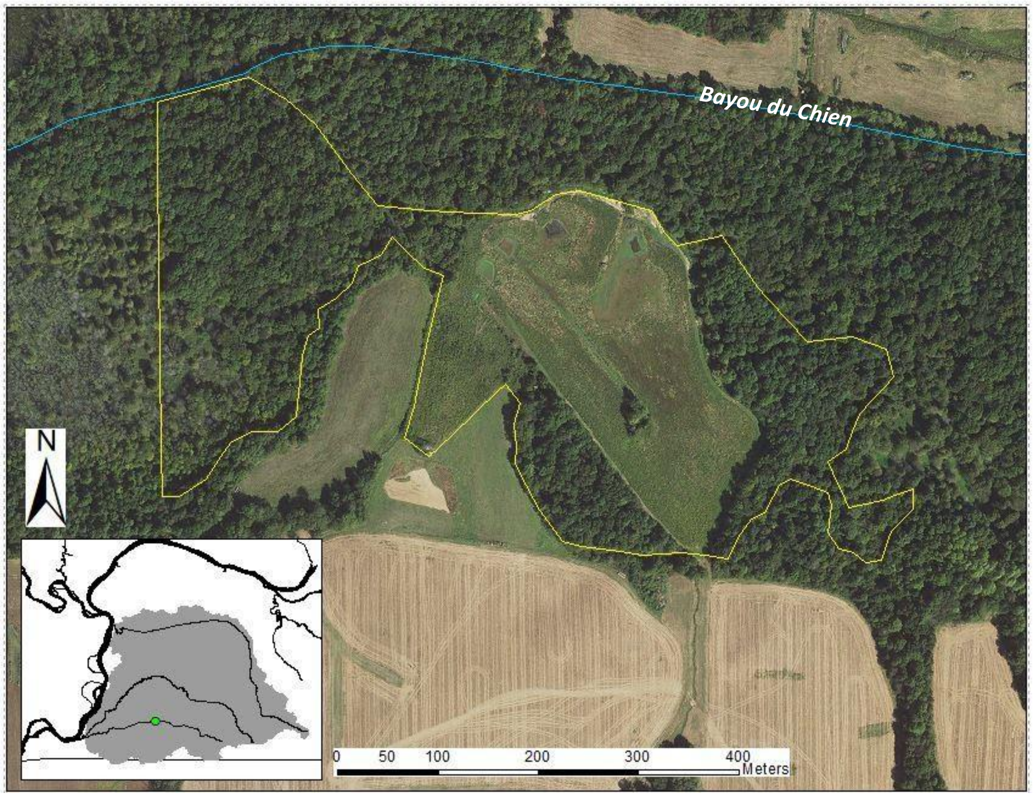

Figure E.2. Aerial photo (USDA NAIP 2018) of HOPK easement boundary and its location within the BDC watershed.

Zooplankton were highly abundant on this easement wetland but comprised less than 1% of total biomass (Table E.2). Collector-gatherers were the second most abundant functional group, and they contribute almost 70% of the biomass found in the wetland (Table E.2). Non-biting midges (family Chironomidae) dominated insect abundance (Table E.1); almost 63% of collector-gatherers had a terrestrial adult stage (Table E.3). Approximately 56% of the easement area was inundated when water levels were at average height (Table E.4).

Table E.1. Results of dip-net sampling at HOPK. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				No.	% Cont.
Annelida				**343**	**14.5**
	Oligochaeta		spp.	340	
	Hirudinea				
		Erpobdellidae	*Mooreobdella*	2	
		Macrobdellidae	*Macrobdella*	1	
Arachnida				**70**	**2.9**
	Hydrachnida		spp.	70	
Crustacea				**749**	**31.7**
	Branchiopoda		spp.	438	
	Copepoda		spp.	124	
	Amphipoda				
		Hyallelidae	*Hyallela*	39	
	Malacostraca	Cambaridae	spp.	11	
	Ostracoda		spp.	137	
Insecta				**854**	**36.1**
	Coleoptera	Chrysomelidae	Donacia	1	
		Curculionidae	spp.	1	
		Dytiscidae	*Desmopachria*	2	
		Haliplidae	*Peltodytes*	9	
		Hydrophilidae	*Berosus*	32	
			Enochrus	1	
			Tropisternus	5	
		Noteridae	*Hydrocanthus*	3	
			Suphisellus	10	
	Diptera				
		Ceratopogonidae	*Bezzia*	8	
			Serromyia	35	
			Probezzia	3	
			spp.	3	
		Chaoboridae	*Chaoborus*	2	
		Chironomidae	spp.	608	
		Culicidae	*Anopheles*	3	
			Culex	1	
		Sciomyzidae	spp.	1	
		Tabanidae	*Tabanus*	2	
	Hemiptera				
		Belostomatidae	*Belostoma*	2	
		Corixidae	*Trichocorixa*	25	
		Notonectidae	*Buenoa*	1	
		Pleidae	*Paraplea*	3	
	Ephemeroptera				
		Baetidae	*Callibaetis*	32	
		Caenidae	*Caenis*	20	
	Odonata				
		Coenagrionidae	*Coenagrion*	35	
		Libellulidae	*Erythemis*	3	
			spp.	2	
	Trichoptera	Phryganeidae	spp.	1	
Molluska				**350**	**14.8**
	Gastropoda				
		Physidae	*Physa*	265	
		Planorbidae	*Helisoma*	11	
			Menetus	8	
		Sphaeriidae	*Sphaerium*	66	
Collembola		Poduridae	*Podura*	**1**	**<1**

Table E.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in HOPK. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	85	<1	154	3.1
Collector-Gatherer	15,133	28.1	3,322	67.4
Predator	1,467	2.7	409	8.2
Scraper	458	<1	994	20.2
Shredder	2	<1	10	<1
Zooplankton	36,708	68.2	39	<1
Total	**53,855**	100	4,927	100
Life History				
Emergent	5,870	9.9	808	16.4
Non-Emergent	47,985	89.1	4,119	83.6

Table E.3. Dip net results by functional group for HOPK. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	3.0	5.7	94.3
Collector-Gatherer	44.9	62.3	37.7
Predator	8.9	44.8	55.2
Scraper	12.0	0	100
Shredder	1.7	0	100
Zooplankton	29.5	0	100
Total	100		

Table E.4. Wetted surface area for HOPK based on four separate water depths from Aug 29, 2018 through Aug 29, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	0.32	98.4	97,738	56.2
Min	0.0	98.1	0.0	0
Max	1.58	99.7	173,559	100
Mode	0.39	98.5	108,886	62.6

House East (HEST)

HEST is a 16-ha easement located in Hickman County, KY (Fig F.1). HEST was enrolled in WRP in 2012. This easement is situated on the Bayou du Chien, with a levee that separates the easement from the stream channel (Fig.F.2). In 2013, a portion of the level broke and was not fixed, which allowed water and sediment to deposit on the easement (Fig. F.3). The land directly east and south of the easement is in row crop production. A drainage ditch along the east and southern perimeter drain water from the adjacent agricultural land before it comes onto the easement. The land directly west of the easement is also in WRP, while the tract of land north is enrolled in WREP.

Figure F.1. The photo of HEST captured on May 11, 2018 shows high water levels following a spring flood event.

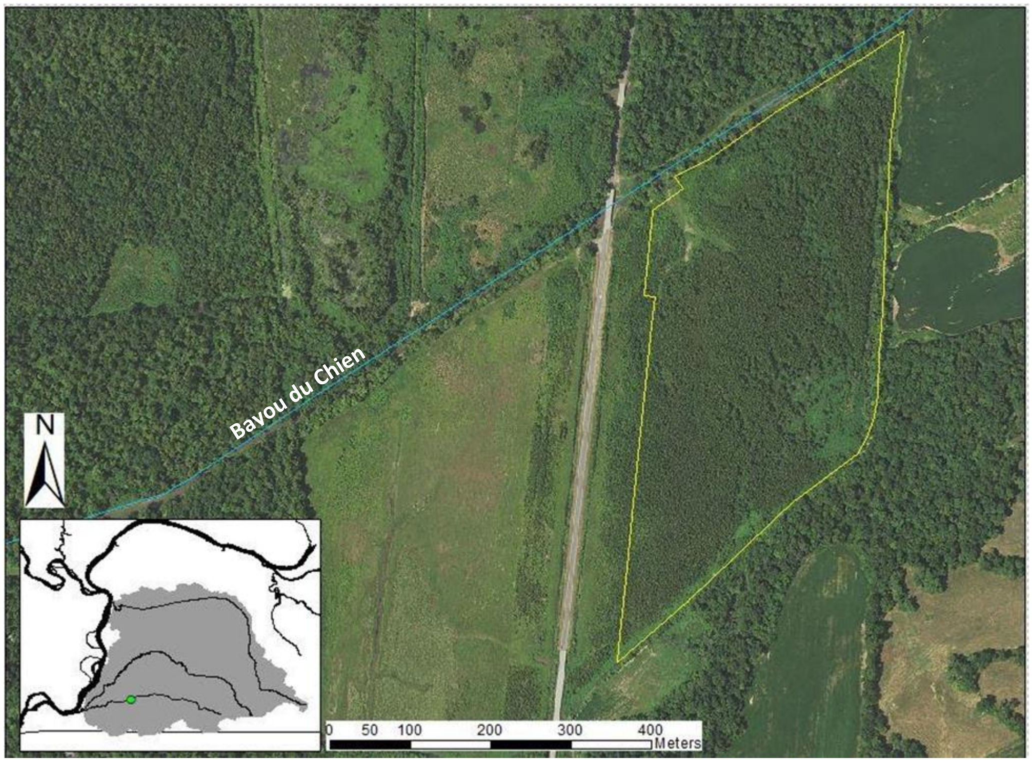

Figure F.2. Aerial photo (USDA NAIP 2018) of HEST easement boundary and its location within the BDC watershed.

Figure F.3. Aerial photo of HEST (USDA NAIP 2014) shortly after the levee blowout.

A total of 42 families and at least 54 genera were collected in HEST via dip net sampling, making it the most speciose of all the easement wetlands sampled (Table F.1). The invertebrate community at HEST had an unusual assemblage of certain taxa, which made it unique among all the wetlands sampled. For instance, aquatic mites comprised almost 6% of all invertebrates collected with the dip net throughout the year (Table F.1). HEST also had the most species-rich community of coleopterans. Furthermore, nearly 20% of the invertebrate community was composed of gastropods, the highest among any easement wetland (Table F.1).

Like other easement wetlands, zooplankton dominated abundance estimates yet contributed very little to overall biomass (Table F.2). Collector-gatherers contributed to almost 50% of the total biomass of the easement, with scrapers contributing 28.4% (Table F.2). HEST also had a highly abundant mosquito community (Family Culicidae); 68.9% of collector-filterers had a terrestrial adult stage (Table F.3).

The hydroperiod of HEST was less flashy and erratic than other easement wetlands. However, the levee break distributed large amounts of sediment onto the wetland during every flood event, which covered or scoured existing macrophytes (*personal observation*). It is possible that this high level of disturbance contributed to the unique assemblage of invertebrates found on the HEST wetland.

Table F.4. Results of dip-net sampling at HEST. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				No.	% Cont.
Annelida				**312**	11.5
	Oligochaeta		spp.	293	
	Hirudinea				
		Erpobdellidae	*Mooreobdella*	19	
Arachnida				**152**	5.6
	Hydrachnida		spp.	152	
Crustacea				**1130**	41.6
	Branchiopoda		spp.	606	
	Copepoda		spp.	346	
	Amphipoda				
		Gammaridae	*Gammarus*	3	
		Hyallelidae	*Hyallela*	106	
	Isopoda				
		Asellidae	*Lirceus*	3	
	Malacostraca	Cambaridae	spp.	3	
		Palaemonidae	*Paelomonetes*	7	
Ostracoda			spp.	56	
Insecta				**580**	21.3
	Coleoptera	Chrysomelidae	*Donacia*	1	
			spp.	1	
		Curculionidae	spp.	1	
		Dytiscidae	*Coptotomus*	1	
			Desmopachria	4	
			Laccophilus	6	
			Pachydrus	2	
		Haliplidae	*Peltodytes*	43	
		Hydrophilidae	*Berosus*	36	
			Enochrus	1	
			Tropisternus	2	
		Noteridae	*Notomicrus*	4	
			Suphisellus	2	
		Ptilidae	spp.	1	
	Diptera				
		Ceratopogonidae	*Bezzia*	1	
			Serromyia	25	
			Probezzia	2	
			spp.	1	
		Chaoboridae	*Chaoborus*	9	
		Chironomidae	spp.	164	
		Culicidae	*Anopheles*	3	
			Aedes	146	
			Culex	8	
		Dolichopodidae	spp.	1	
		Tabanidae	*Chrysops*	1	
		Stratiomyidae	*Odontomyia*	1	
	Hemiptera				
		Belostomatidae	*Belostoma*	1	
		Corixidae	*Trichocorixa*	42	
		Pleidae	*Paraplea*	8	
		Mesoveliidae	*Mesovelia*	2	
		Veliidae	spp.	1	
	Ephemeroptera				
		Baetidae	*Callibaetis*	18	
		Caenidae	*Caenis*	2	
	Odonata				
		Aeshnidae	spp.	1	
		Coenagrionidae	*Coenagrion*	36	
		Libellulidae	*Erythemis*	2	
	Trichoptera	Leptoceridae	spp.	2	
	Lepidoptera		spp.	4	

Table F.4 cont.

Mollusca				**538**	19.8
	Gastropoda				
		Lymnaeidae	*Fossaria*	30	
		Physidae	*Physa*	393	
		Planorbidae	*Helisoma*	9	
			Menetus	35	
		Sphaeriidae	*Sphaerium*	71	
Turbellaria				**1**	<1
	Trichladida	Dugesiidae	*Dugesia*	1	

Table F.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in HEST. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	343	<1	642	13.4
Collector-Gatherer	15,444	11.1	2,362	49.5
Predator	2,015	1.1	274	5.7
Scraper	1,499	1.0	1,354	28.4
Shredder	13	<1	19	<1
Zooplankton	120,013	86.1	126	2.6
Total	**139,330**	100	4,776	100
Life History				
Emergent	1,115	0.8	277	5.8
Non-Emergent	138,215	99.2	4,499	94.2

Table F.3. Dip net results by functional group for HEST. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	8.4	68.9	31.1
Collector-Gatherer	21.0	32.7	67.3
Predator	11.9	24.4	75.6
Scraper	17.2	0	100
Shredder	4.4	3.4	96.6
Zooplankton	37.1	0	100
Total	100		

House West (HWST)

HWST is a 14.3 ha easement located in Hickman County, KY. The easement was enrolled in WRP in 2015. In 2017, the interior ditch that runs south from the Bayou du Chien through the middle of the easement was plugged (Fig. G.1). The Bayou du Chien creates the northern border of the easement (Fig. G.2). Directly east, across the highway, lies another tract of land enrolled within the same WRP easement. To the south of the easement lies row crop land, which is drained via a ditch which creates the southern perimeter of the easement.

Figure G.1. The ditch plug at HWST creates a narrow, shallow wetland with a dense macrophyte community. Photo captured on May 11, 2018.

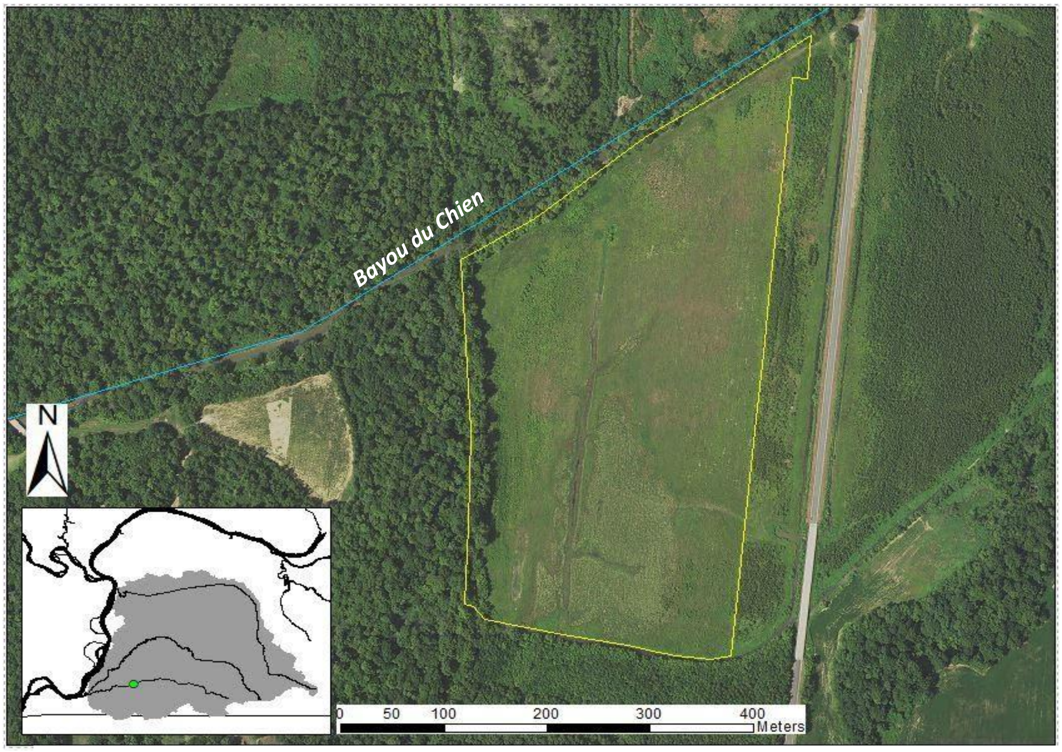

Figure G.2. Aerial photo (USDA NAIP 2018) of HWST easement boundary and its location within the BDC watershed.

A total of 32 families and at least 41 genera were collected from HWST via dip net sampling (Table G.1). The easement was inundated with water throughout the year. However, high water levels limited sampling efforts. Invertebrates were collected during ten months of the year. Oligochaeta and Insecta were the most abundant invertebrate classes collected at HWST (Table G.1). Of the insects, the dipterans and the odonates were the most abundant, with the dragonflies and biting midges making predators a prominent feature of the HWST invertebrate community (Table G.3). A dense oligochaete community contributed greatly to the total biomass of collector-gatherers, which constituted almost 80% of invertebrate biomass (Table G.2). Water collected primarily within the plugged drainage ditch. On average, only 62.7% of the easement surface area was inundated with water (Table G.4).

Table G.1. Results of dip-net sampling at HWST. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				No.	% Cont.
Annelida				**951**	**35.7**
	Oligochaeta		spp.	949	
	Hirudinea	Erpobdellidae	*Mooreobdella*	1	
		Glossiphoniidae	*Helobdella*	1	
Arachnida				**6**	**<1**
	Hydrachnida		spp.	6	
Crustacea				**518**	**19.5**
	Branchiopoda		spp.	106	
	Copepoda		spp.	208	
	Amphipoda				
		Gammaridae	*Gammarus*	2	
		Hyallelidae	*Hyallela*	200	
	Malacostraca	Cambaridae	spp.	1	
		Palaemonidae	*Paelomonetes*	1	
Insecta				**743**	**27.9**
	Coleoptera				
		Chrysomelidae	*Donacia*	1	
		Haliplidae	*Peltodytes*	4	
		Hydrophilidae	*Berosus*	6	
		Noteridae	*Suphisellus*	7	
	Diptera				
		Ceratopogonidae	*Bezzia*	26	
			Serromyia	45	
			Probezzia	3	
			Atrichopogon	1	
			spp.	10	
		Chironomidae	spp.	452	
		Culicidae	*Anopheles*	2	
			Culex	2	
		Tabanidae	*Chrysops*	2	
			Tabanus	1	
		Stratiomyidae	*Odontomyia*	4	
	Hemiptera				
		Corixidae	*Trichocorixa*	12	
		Pleidae	*Paraplea*	1	
		Veliidae	spp.	3	
	Ephemeroptera				
		Baetidae	*Callibaetis*	17	
		Caenidae	*Caenis*	11	
	Odonata				
		Aeshnidae	spp.	4	
		Coenagrionidae	*Coenagrion*	90	
		Libellulidae	*Erythemis*	64	
			Pachydiplax	1	
	Trichoptera	Phryganeidae	spp.	2	
Mollusca				**392**	**14.7**
	Gastropoda				
		Physidae	*Physa*	134	
		Planorbidae	*Anyclus*	3	
			Helisoma	9	
			Menetus	229	
		Sphaeriidae	*Sphaerium*	17	
Turbellaria				**25**	**<1**
	Trichladida	Dugesiidae	*Dugesia*	25	

Table G.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in HWST. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	48	<1	57	<1
Collector-Gatherer	38,701	40.1	13,831	78.5
Predator	3,179	3.3	1,638	9.3
Scraper	1,914	2.0	2,033	11.5
Shredder	4	<1	2	<1
Zooplankton	52,617	54.5	56	<1
Total	**96,463**	100	**17,618**	100
Life History				
Emergent	12,733	13.2	2,572	14.6
Non-Emergent	83,730	86.8	15,046	85.4

Table G.3. Dip net results by functional group for HWST. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	<1	19.0	81.0
Collector-Gatherer	54.4	33.6	66.4
Predator	11.2	82.3	17.7
Scraper	14.1	0	100
Shredder	7.6	0	100
Zooplankton	11.8	0	100
Total	100		

Table G.4. Wetted surface area for HWST based on four separate water depths from August 29, 2018 through Aug 29, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	0.78	92.82	89,458	62.7
Min	0.0	92.26	2342	1.6
Max	3.4	95.69	141,821	99.4
Mode	0.28	92.32	3443	2.4

St. Arbor (SWAN and SAOF)

St. Arbor is a 46.6 ha easement located in Carlisle County, KY. A severely channelized dredge ditch portion of Mayfield creek runs through the middle of the easement (Fig. H.1). The levee along the Mayfield creek dredge ditch was intentionally breached in 5 locations as part of site restoration. During overbank flooding events, the breaches allow the sheet flow of water to distribute sediment onto the easement several yards downhill of the ditch (*personal observation*). The easement is situated within a larger area of mixed crop and bottomland hardwood forest. Nearby agricultural drainage ditches have little influence on the easement.

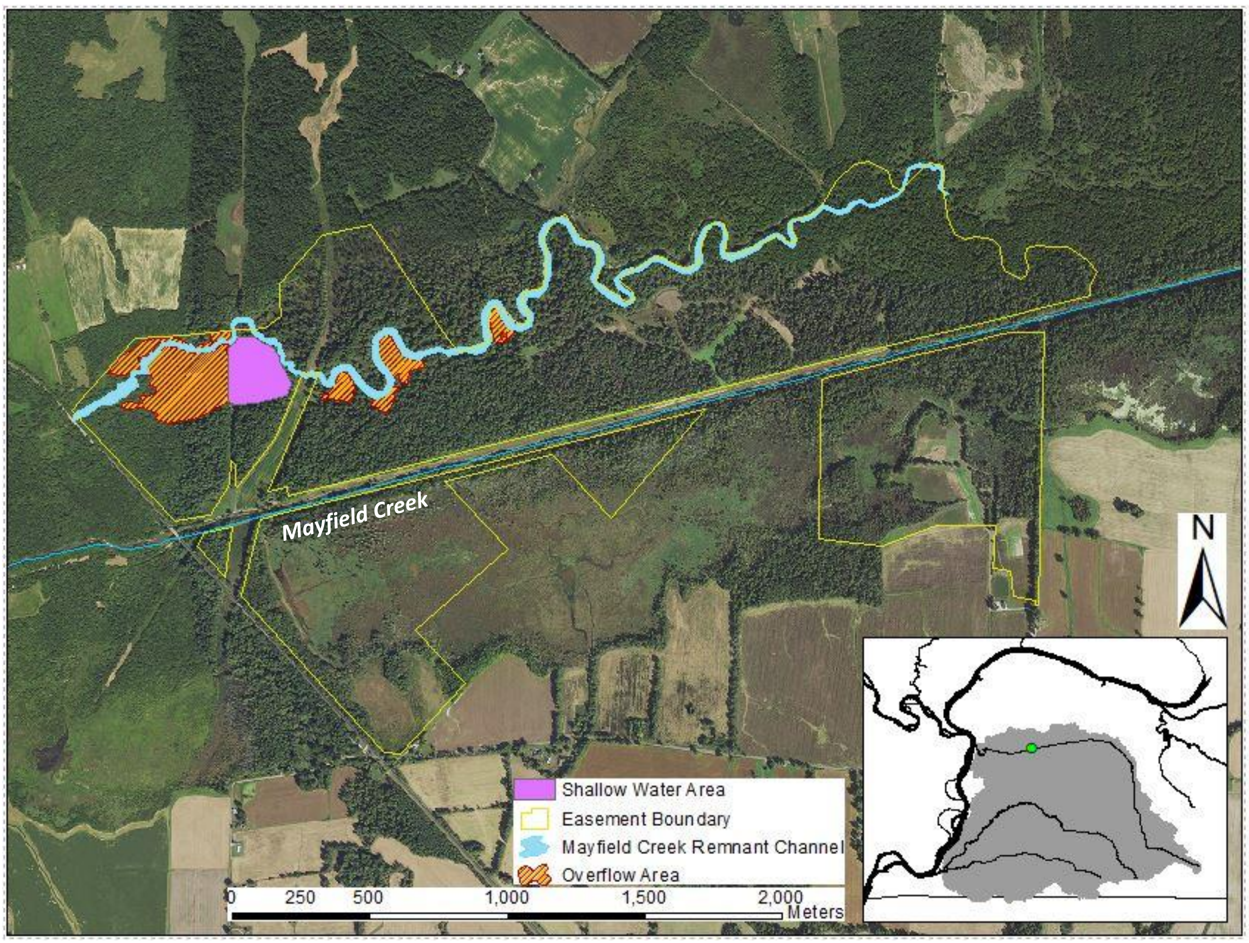

Figure H.1. Aerial photo (USDA NAIP 2018) of St. Arbor easement boundary and its location within the BDC watershed.

The remnant Mayfield Creek channel creates the northern border of most of the easement. There are multiple ditches, shallow water crossings, and hydrological modifications throughout the easement between the historic channel and the dredge ditch. Of these, invertebrate sampling occurred on two: the northern shallow water area (SWAN) and tree planting sites (SAOF). Both sites border the remnant Mayfield Creek channel, and they regularly receive the channel's floodwaters. The 4.5 ha SWAN was installed in 2017 (Fig. H.2). Tree seedlings were planted in several overflow areas adjacent to the remnant creek channel (Fig I.1).

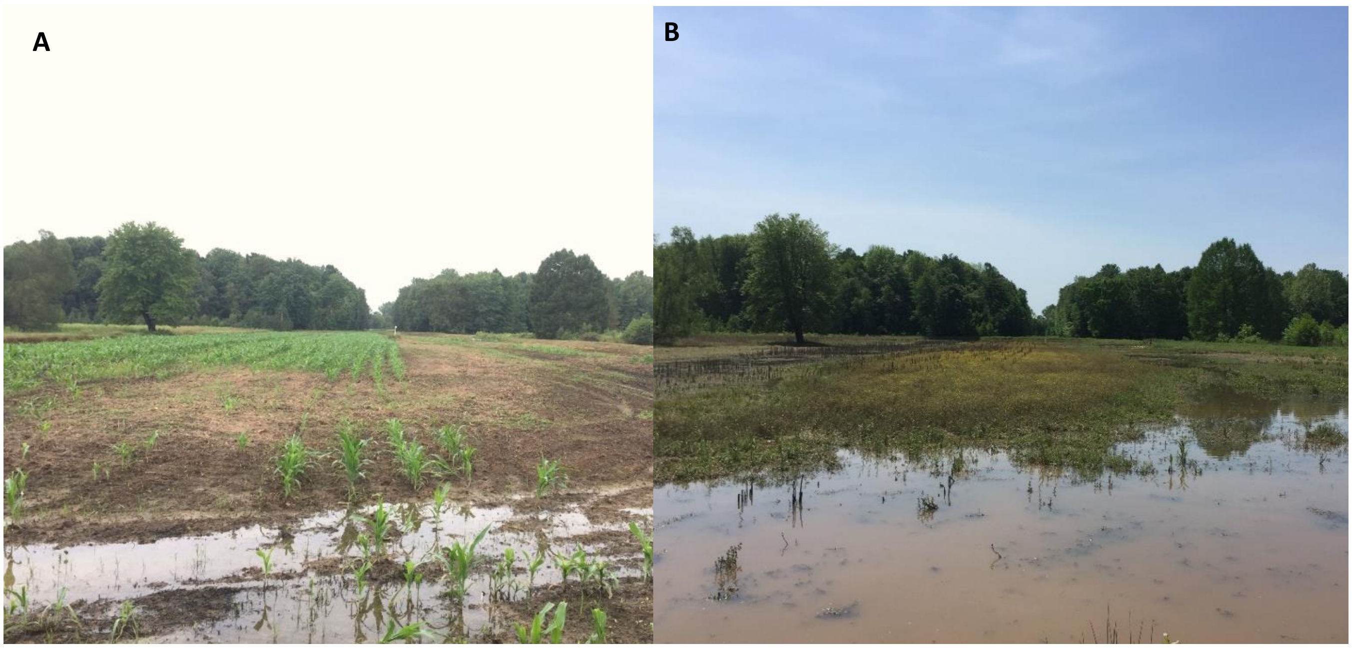

Figure H.2. A food plot is planted on one of the shallow water areas in the St. Arbor easement the summer before invertebrate sampling occurred. The photos of SWAN were captured on (A) September 12, 2018, and (B) May 7, 2019.

Figure I.1. On the St. Arbor easement, several areas adjacent to the remnant channel of Mayfield Creek hold water after flood events. Trees were planted in this area to restore bottomland hardwood forests. The photo of this overflow area was captured on June 4, 2018.

A total of 24 families and at least 26 genera were collected from dip net samples in SWAN (Table H.1). SWAN had an intermittent hydroperiod and invertebrates were only sampled for five months. During the dry summer months, SWAN was disked and planted with corn to make a food plot. Very few clinger-crawlers (orders Odonata and Ephemeroptera) were collected via dip net (Table H.1). Like every easement wetland, zooplankton and collector-gatherers dominated abundance (Table H.3 and H.4). However, because oligochaetes were the primary collector-gatherer in the community, only 7.0% of the total biomass belonged to invertebrates with an emergent adult stage (Table H.3). On average, when water was present, almost 95% of the SWAN was inundated (Table H.4). It will be interesting to see how the invertebrate community changes if natural vegetative succession is allowed to occur.

Like SWAN, invertebrates were only collected during five months of the year. Even though both sites were situated next to the remnant channel, the invertebrate community of SAOF was vastly different. A total of 31 families and at least 33 genera were collected in SAOF from the dip net sampling (Table I.1). *Lirceus* sp. (order Isopoda) and *Crangonyx* sp. (order Amphipoda) were prominent features of the SAOF invertebrate community (Table I.1). Shredders contributed to almost 23% of the total biomass (Table I.2), a figure much higher than any other easement wetland. Diptera was the most abundant insect order in SAOF (Table I.1). Therefore, approximately 33% of all collector-gatherers in SAOF had a terrestrial adult stage (Table I.3). Almost 96% of the remnant channel's overflow surface area was inundated when water was at its average depth (Table I.4).

Table H.1. Results of dip-net sampling at SWAN. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				No.	% Cont.
Annelida				**258**	15.0
	Oligochaeta		spp.	258	
Arachnida				**3**	<1
	Hydrachnida		spp.	3	
Crustacea				**1199**	69.6
	Branchiopoda		spp.	535	
	Copepoda		spp.	483	
	Amphipoda				
		Crangonyctidae	*Crangonyx*	29	
		Gammaridae	*Gammarus*	7	
		Hyallelidae	*Hyallela*	28	
	Malacostraca	Cambaridae	spp.	6	
	Ostracoda		spp.	111	
Hydrazoa		Hydridae	spp.	**4**	<1
Insecta				**152**	8.8
	Coleoptera				
		Haliplidae	*Peltodytes*	1	
		Hydrophilidae	*Berosus*	1	
	Diptera				
		Ceratopogonidae	*Bezzia*	2	
			Serromyia	6	
			Probezzia	1	
		Chaoboridae	*Chaoborus*	1	
		Chironomidae	spp.	124	
	Hemiptera				
		Corixidae	*Trichocorixa*	12	
	Ephemeroptera				
		Baetidae	*Callibaetis*	2	
		Caenidae	*Caenis*	1	
	Trichoptera	Phryganeidae	spp.	1	
Mollusca				**104**	6.0
	Gastropoda				
		Lymnaeidae	*Fossaria*	2	
		Physidae	*Physa*	91	
		Planorbidae	*Menetus*	10	
		Sphaeriidae	*Sphaerium*	1	
Turbellaria				**1**	<1
	Trichladida	Dugesiidae	*Dugesia*	1	

Table H.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in SWAN. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	64	<1	20	<1
Collector-Gatherer	13,912	29.5	3,068	88.2
Herbivore-Piercer	0	0	0	0
Predator	283	<1	42	1.2
Scraper	72	<1	307	8.8
Shredder	0	0	6	<0
Zooplankton	23,467	69.6	36	1.0
Total	**37,799**	100	**3,478**	100
Life History				
Emergent	1,361	3.6	233	7.0
Non-Emergent	36,438	96.4	3,245	93.3

Table H.3. Dip net results by functional group for SWAN. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	<1	0	100
Collector-Gatherer	22.9	32.5	67.5
Predator	1.7	33.3	66.7
Scraper	6.0	0	100
Shredder	3.7	0	100
Zooplankton	65.6	0	100
Total	100		

Table H.4. Wetted surface area for SWAN based on four separate water depths from September 12, 2018 through September 12, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	1.7	92.6	42,000	94.5
Min	0.0	90.9	0.0	0
Max	5.56	96.5	45,000	100
Mode	0.0	90.9	0.0	0

Table I.1. Results of dip-net sampling at SAOF. No. is the total number of individuals of each taxon collected throughout the entire sampling period. % Cont. indicates the relative abundance of each major taxonomic group.

Taxon				**No.**	**% Cont.**
Annelida				**125**	**6.0**
	Oligochaeta		spp.	125	
Arachnida				**10**	**<1**
	Hydrachnida		spp.	10	
Crustacea				**1628**	**77.9**
	Branchiopoda		spp.	587	
	Copepoda		spp.	576	
	Amphipoda				
		Crangonyctidae	*Crangonyx*	190	
		Gammaridae	*Gammarus*	8	
		Hyallelidae	*Hyallela*	4	
	Isopoda				
		Asellidae	*Lirceus*	182	
	Malacostraca	Cambaridae	spp.	42	
	Ostracoda		spp.	39	
Hydrazoa		Hydridae	spp.	**3**	**<1**
Insecta				**150**	**7.2**
	Coleoptera				
		Curculionidae	spp.	1	
		Dytiscidae	*Laccophilus*	1	
		Hydrophilidae	*Tropisternus*	1	
		Lampyridae	spp.	1	
		Ptilidae	spp.	1	
	Diptera				
		Ceratopogonidae	*Serromyia*	4	
		Chaoboridae	*Chaoborus*	25	
		Chironomidae	spp.	76	
		Culicidae	*Aedes*	13	
			Anopheles	2	
	Hemiptera				
		Corixidae	*Trichocorixa*	14	
	Ephemeroptera				
		Baetidae	*Callibaetis*	1	
		Caenidae	*Caenis*	1	
		Heptageniidae	spp.	1	
	Odonata				
		Aeshnidae	spp.	6	
		Coenagrionidae	*Coenagrion*	2	
Molluska				**177**	**8.5**
	Gastropoda				
		Physidae	*Physa*	85	
		Planorbidae	*Helisoma*	10	
			Menetus	51	
		Sphaeriidae	*Sphaerium*	31	
Collembola				**3**	**<1**
		Poduridae	Podura	2	
		Sminthuridae	spp.	1	

Table I.2. Benthic core results. Abundance and biomass estimate for invertebrate functional feeding groups (FFG) and life histories in Remnant Channel Overflow. Results are to the nearest individual and milligram.

	Abundance (no./m²)	%	Biomass (mg/m²)	%
Functional Group				
Collector-Filterer	64	<1	210	4.8
Collector-Gatherer	4,136	14.9	2,673	60.5
Predator	59	<1	46	1.0
Scraper	189	<1	263	6.0
Shredder	168	<1	1,200	27.2
Zooplankton	23,059	83.3	26	<1
Total	**27,675**	100	**4,418**	100
Life History				
Emergent	3,293	1.9	1,003	22.7
Non-Emergent	24,382	88.1	3,415	77.3

Table I.3. Dip net results by functional group for SAOF. % Contributing is the relative abundance of each functional group. The numbers in the last two columns indicate the relative abundance of invertebrates with emergent or non-emergent life histories within each functional group.

	% Contributing	Emergent	Non-Emergent
Functional Group			
Collector-Filterer	2.2	32.6	67.4
Collector-Gatherer	11.9	31.3	68.7
Predator	2.8	52.5	47.5
Scraper	7.1	0.01	99.9
Shredder	18.4	0.01	99.9
Zooplankton	57.6	0.0	100
Total	100		

Table I.4. Wetted surface area for SAOF based on four separate water depths from September 12, 2018 through September 12, 2019. % Inundation is wetted surface area divided by the easement size.

Metric	Water depth above HOBO (m)	Water elevation (MASL)	Wetted surface area (m²)	% Inundation
Average	0.3	98.7	11.3	95.6
Min	0.0	98.4	0.0	0
Max	1.75	100.1	11.8	100
Mode	0.0	98.4	0.0	0