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Crane Creek Estuary USACE Photograph 2012

Cooperator Report

2011 Summary: Coastal Wetland Restoration Research

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New Strategies for Restoring Coastal Wetland Function

Summary Annual Report - 2011
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Executive Summary

The Great Lakes Restoration Initiative (GLRI) projects currently taking place in Great Lakes coastal wetlands provide a unique opportunity to study ecosystem response to management actions as practitioners strive to improve wetland function and increase ecosystem services. Through a partnership between the U.S. Geological Survey – Great Lakes Science Center (GLSC), U.S. Fish and Wildlife Service (USFWS), and Ducks Unlimited, a GLRI-funded project has reestablished the hydrologic connection between an intensively managed impounded wetland (Pool 2B) and Crane Creek, a small Lake Erie tributary, by building a water-control structure that was opened in the spring of 2011. The study site is located within the USFWS Ottawa National Wildlife Refuge (ONWR) and lies within the boundaries of the U.S. Environmental Protection Agency (EPA)-designated Maumee River Area of Concern. The broad objective of the project is to evaluate how hydrologically reconnecting a previously diked wetland impacts fish, mollusks, and other biota and affects nutrient transport, nutrient cycling, water quality, flood storage, and many other abiotic conditions. The results from this project suggest large system-wide benefits from sustainable reestablishment of lake-driven hydrology in this and other similar systems.

We comprehensively sampled water chemistry, fish, birds, plants, and invertebrates in Crane Creek coastal wetlands, Pool 2A (a reference diked wetland), and Pool 2B (the reconnected wetland) in 2010 and 2011 to:

1) Characterize spatial and seasonal patterns for these parameters.
2) Examine ecosystem response to the opening of a water-control structure that allows fish passage

Our sampling efforts have yielded data that reveal striking changes in water quality, hydrology, and fish assemblages in our experimental unit (2B). Prior to the reconnection, the water chemistry in pools 2A and 2B were very similar. Afterwards, we found that the water chemistry in reconnected Pool 2B was more similar to Crane Creek (e.g., greater turbidity, higher concentration of nitrogen). Sites closest to the structure showed the most creek influence with that influence decreasing with distance from the structure, suggesting that input water from Crane Creek is not mixing fully with the pool water. We also found that water level fluctuations were much greater in the reconnected wetland due to the influence of seiches in Lake Erie. We measured the nutrient concentrations of water flowing into and out of Pool 2B during seiche events and found that the phosphorous and nitrogen concentrations generally were drastically reduced after pulsing through the reconnected wetland. Fish response to the reconnection was equally striking. High-resolution sonar revealed extensive bidirectional movement of fish through the structure on a daily and seasonal basis. There also were significant increases in both the catch per unit effort (CPUE) and the species richness of all sites in Pool 2B from 2010 to 2011. Reconnecting the diked pool to the larger Crane Creek wetland complex, and therefore Lake Erie, has opened up rich new habitat for many fish species. Thirteen species of fish not previously found in the pool entered through the

structure and actively used the reconnected wetland. We also found that the wetland functions as a productive spawning ground and nursery area with notable shifts in the predominant age-class of several species of fish, especially northern pike. We observed no negative effects of reconnection on the avian or vegetative communities. All sites within the connected pool had increases in diversity and abundance in the avian community and decreases in the species richness and Floristic Quality Assessment Index values for vegetative communities. After one year of study, data suggest that maintaining a hydrologic connection between diked and coastal wetlands in Lake Erie allows fishes to use vegetated habitats regularly, reduces the concentration of nutrients in coastal waters, and maintains productive habitats for birds and other biota. It will be important to continue to monitor the status of the reconnected wetland to determine the effect of long-term connection to Crane Creek and Lake Erie. If conditions degrade, periodic management actions involving hydrologic isolation of the rehabilitated coastal wetland could be used to mimic intermediate levels of disturbance and maintain wetland vegetation.

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Introduction

Over 95% of the original wetlands along the U.S. shoreline of western Lake Erie have been lost since the 1860s (Herdendorf 1987, Mitsch and Wang 2000). Most remaining coastal wetlands have been isolated by earthen dikes to protect them from wave action and to allow for waterfowl management by federal, state, private, and non-profit organizations. Although these diked wetlands are adjacent to the Lake Erie shoreline, they are separated from the lake hydrologically and no longer provide many of the valuable functions of coastal wetlands (e.g., fish habitat, water quality improvement).

Crane Creek, a drowned rivermouth wetland complex, is a prime example of a coastal landscape that has been modified through earthen dike construction and is under pressure from many stressors. The Crane Creek watershed lies within the Maumee River Area of Concern (AOC), as identified by the EPA's Great Lakes National Program office, with impairments noted in the areas of degraded fish, wildlife, and benthos populations; the presence of fish tumors or other deformities; beach closings; degraded aesthetics; and loss of fish and wildlife habitat (http://www.epa.gov/greatlakes/aoc/maumee.html). Furthermore, while not in the AOC proper, massive harmful algal blooms have been observed in Lake Erie offshore of this area in recent years.

With funding from the Great Lakes Restoration Initiative (GLRI) and a partnership between the U.S. Geological Survey - Great Lakes Science Center (GLSC), the U.S. Fish and Wildlife Service (USFWS), and Ducks Unlimited (DU), a wetland rehabilitation project was designed to reconnect a diked wetland to the Crane Creek wetland complex that experiences lake hydrology. Researchers at the GLSC have been collecting data to evaluate how hydrologically reconnecting a diked wetland would affect the transport of nutrients, nutrient cycling, water quality, flood storage, and many other abiotic conditions as well as how it would impact biota such as fish, birds, mollusks, and other invertebrates.

Site and Project Description: The Crane Creek wetland complex is located within the USFWS Ottawa National Wildlife Refuge (ONWR) along the southern shore of western Lake Erie, approximately 30 kilometers southeast of Toledo, Ohio (Figure 1). Within ONWR, the specific areas of interest for the study are Pool 2A, Pool 2B, Crane Creek where it flows by these pools, and Lake Erie around the nearby mouth of the creek (Appendix 1). Pools 2A and 2B were created in the 1940s by building earthen dikes around existing wetlands and were hydrologically isolated from Crane Creek since that time, except during infrequent flood events (e.g., 1973). Diesel pumps and gravity flow are used to move water into or out of the pools to achieve specific management objectives.

As with other drowned rivermouth wetlands, water levels in Lake Erie drive the water levels in the adjoining coastal wetlands (Keough *et al*. 1999). A water-control structure connecting Pool 2B with Crane Creek was designed to allow for water, nutrients, sediment, zooplankton, and fish to freely exchange between Lake Erie, Crane Creek, and Pool 2B. Construction began in late 2010, and the structure was fully operational by March 2011. The approximately 9-m wide structure dissects the levee on the northwest corner of Pool 2B and consists of two 1.2 m diameter culverts that are less than 1 m in length. The culverts were designed with the capability to be opened and closed but have remained open since the structure was completed. In addition,

movable metal grates with a 5-cm wide bar spacing (French *et al*. 1999) were installed on the structure to prevent the ingress of spawning common carp (*Cyprinus carpio*) while still allowing other species, such as northern pike (*Esox Lucius*), to access the reconnected wetland habitats. Following an integrated pest management strategy, the grates were removed after carp spawning season was over to allow unimpeded fish access. This project explores 1) the differences between Crane Creek and the adjacent pools, 2A (28 ha) and 2B (40 ha), and 2) the effects of the reconnection between Crane Creek and Pool 2B on the biota and the abiotic conditions therein.

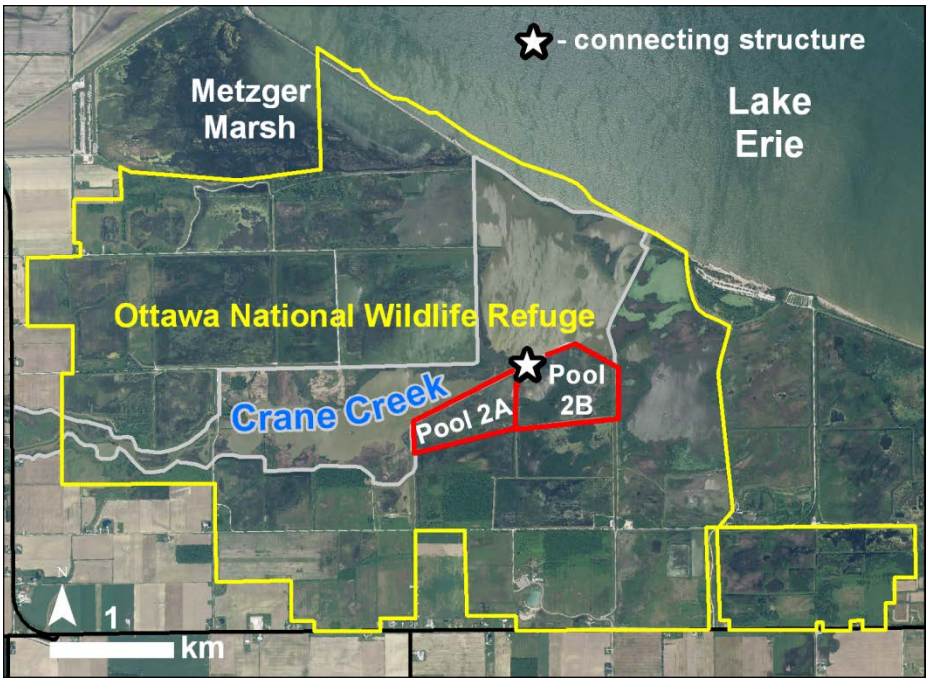

Figure 1: Map of project location.

<u>*Project Goal*</u>: There was one primary goal of this project.

1) Explore hydrological reconnection of diked wetlands as a Great Lakes coastal wetland rehabilitation strategy.

<u>*Project Objectives*</u>: The following objectives were identified to help us achieve our goal.

1) Hydrologically reconnect a diked wetland to Lake Erie to reestablish variable water-level patterns and promote movement of water and biota.
2) Establish a comprehensive dataset (i.e., water chemistry, hydrology, fish, birds, plants, invertebrates) for Crane Creek, Pool 2A, and Pool 2B prior to hydrologic reconnection.
3) Develop and implement a short- and long-term monitoring design to characterize responses of biotic and abiotic ecosystem elements, especially those relating to Beneficial Use Impairments, after restoration actions.
4) Communicate project results to researchers, managers, policy makers, and the general public, to ensure outcomes of the project can guide future management and restoration efforts throughout the Great Lakes basin.

To convey findings from this study to ONWR staff, collaborators, partners, and other interested parties, as well as to the public, GLSC researchers will give presentations, generate USGS fact sheets, and create web pages. Results will be added to the scientific record through manuscripts and other written projects. This report summarizes the research completed by the GLSC in 2010 and 2011, thus fulfilling the requirements of the USFWS Special Use Permit. The following sections of the report are grouped by focus area (i.e., "Water Quality", "Fish Community", and "Invertebrate Community") where preliminary analyses, results, and implications for each area are highlighted. The final section, "Future Research," offers a glimpse into how the work undertaken thus far is shaping future directions.

Water Quality

High nutrient loads from agricultural and point-source discharges in the Crane Creek watershed contribute to poor water quality (e.g., high concentrations of nitrate, ammonia, and soluble reactive phosphorus) in the creek itself as it flows toward Lake Erie (Kasat 2006). Cultural eutrophication, caused by this increased nutrient loading to the Great Lakes, has been linked to the anoxic zone in Lake Erie's central basin (Rosa and Burns 1987) and impairments or degradation of beneficial uses as identified within areas of concern (Ludsin *et al*. 2001, USEPA 2011). The major causes of cultural eutrophication in the Great Lakes are considered to be phosphorus and nitrogen that result from agricultural and urban land-use practices (Carpenter *et al*. 1998). Coastal wetlands, especially drowned rivermouth wetlands such as the Crane Creek complex, provide sediment and nutrient trapping capacity (e.g., Matisoff and Eaker 1992). Therefore, restoring coastal wetlands generally is thought to improve water quality by allowing nutrient uptake by plants and settling of sediments prior to their entering the lake (Mitsch and Wang 2000).

To quantify water chemistry dynamics within the study area, we looked at site-wide water quality parameters, impacts of seiche movement on nutrient dynamics, and mixing of waters from the wetland, Crane Creek, and Lake Erie via stable isotope analysis. Water quality samples were taken at eight ONWR locations (two in 2A, four in 2B, one in Crane Creek, one in Lake Erie; for map, see Appendix 1) during the 2010 and 2011 field seasons. We hypothesized that after the installation of the water-control structure we would see reductions in sediment loads and nutrient concentrations of water as it pulsed through 2B, due to the sediment and nutrient trapping capacity of the wetland and to nutrient uptake by vegetation within Pool 2B.

Methods

Sample collection: In 2010, we sampled water monthly from May-November. In 2011, we took samples monthly from March-November. Either a jon boat or kayak was used to reach the designated water sampling sites, and we made sure to pause long enough between arriving at a site and sample collection to minimize disturbance of the water column. Quart-sized sample jars were triple rinsed onsite and capped underwater to prevent contamination by surface particles or atmospheric inputs. Any sample containing a bubble larger than a dime was discarded and recollected. Three replicate samples were taken from each location and immediately stored on ice. Concurrent with the water collections; pH, temperature, specific conductivity, dissolved oxygen, and turbidity data were recorded using a YSI 6920 sonde (calibrated monthly).

Sample processing and analysis: Within two hours of collection, water samples were transported to a central station on the refuge to undergo the initial processing that would prepare them for subsequent analyses at the USGS National Water Quality Laboratory (NWQL) in Denver, CO. Following NWQL standard operating procedures (SOPs; NWQL, Appendix 2), water samples were processed for total particulate carbon and nitrogen (TPCN); dissolved organic carbon (DOC); filtered nitrogen and phosphorus; total ammonium, organic nitrogen, and total phosphorus; suspended solids (SUSO); turbidity; and acid neutralizing capacity (ANC; the equivalent of alkalinity for unfiltered water. See Appendix 2 for specific methods. After the initial onsite processing, samples were packed on ice and shipped overnight to the NWQL lab. Included with the samples were sonde data and the results from onsite turbidity and ANC tests to aid analysis. All water samples were processed at the NWQL lab following established SOPs (NWQL, Appendix 2) and the resulting data were sent electronically to the GLSC for interpretation.

Results & Discussion

Pre-structure: Crane Creek and Lake Erie water samples contained high concentrations of nitrate + nitrite (reported as one unit) and of total Kjeldahl nitrogen (TKN, a measurement of the sum of ammonia and organic nitrogen). Chemical composition of water in the isolated pools (2A and 2B) was very similar prior to the opening of the structure: all nutrient concentrations except for TKN were low. Figure 2 shows the general trend in these concentrations, as exemplified by the data from location 2BNW, the site nearest the structure in Pool 2B.

Ammonia in water can result from fertilizer runoff, plant decomposition, and animal waste. Since ammonia levels in pools 2A and 2B were low, it is likely that the high TKN levels during the summer of 2010 were due to organic nitrogen. Organic nitrogen, which is mainly derived from animal waste and decomposition of organic material, could have been present at higher concentrations during periods of warm weather due to higher rates of decomposition. Water levels also were very low in 2010, which could have led to the concentration of organic nitrogen as the season progressed.

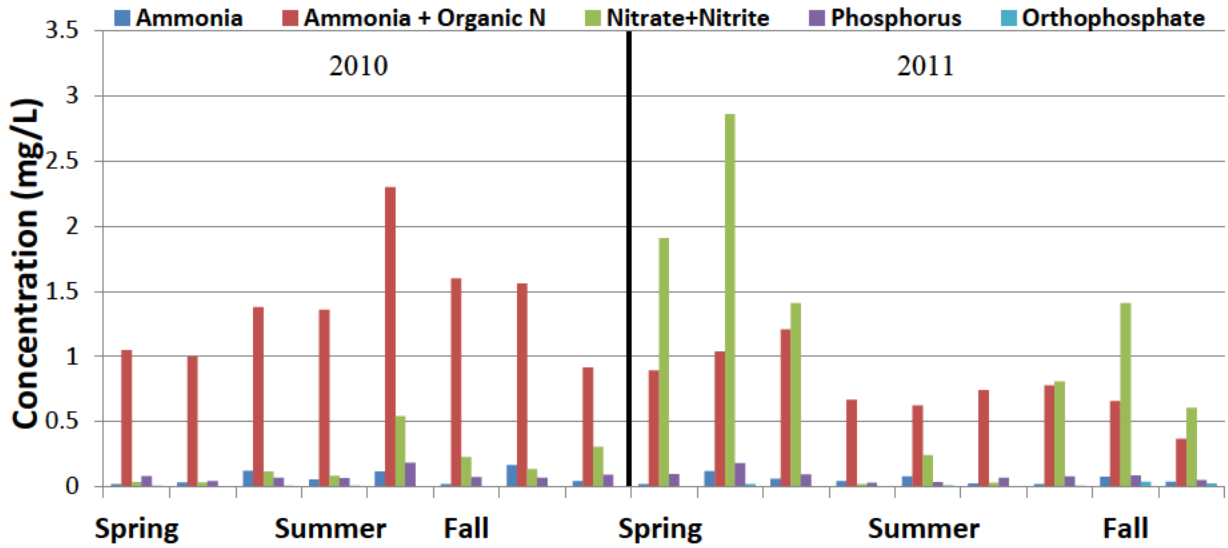

Figure 2: Nutrient concentrations in 2BNW before (2010) and after the opening of the structure (2011).

Post-structure: After the installation of the water-control structure in early spring 2011, the water chemistry of Pool 2B quickly began to reflect conditions in Crane Creek and Lake Erie (Figure 2). A rapid decrease in TKN concentrations and concurrent increase in nitrate + nitrite was the most notable change in water quality parameters in 2B post-connection (Figure 2). The 2011 nitrogen (nitrate + nitrite) concentrations of Pool 2B (0.63 mg/L) were higher than the average Lake Erie levels (0.25 mg/L) (USEPA 2011). The observed decrease in TKN in 2B post-connection suggests that the hydrologic reconnection and the concurrent increase in the volume of water in Pool 2B may have diluted the concentration of organic nitrogen within the pool.

Orthophosphate, which is also known as soluble reactive phosphorus (SRP) and is one of the parameters analyzed by NWQL, was the only other nutrient to show an increase in 2011 (Table 1). The increase in orthophosphate concentration post-connection is likely related to fertilizer inputs from the Crane Creek watershed. All other nutrients and carbon-based metrics decreased (Table 1). Total phosphorus concentrations decreased after reconnecting Pool 2B, although the large standard error suggests that the difference in concentrations is not significant. The concentrations of phosphorus and orthophosphate found in Pool 2B and Crane Creek in 2011 were comparable to concentrations found in other regional locations such as the Maumee River (Baker 2007), Lake Erie (USEPA 2011), and the Detroit River (Charlton 2008). Orthophosphate is the form of phosphorus most available for biological uptake, so high concentrations often lead to eutrophication, algal blooms, and ecosystem degradation.

Table 1: Mean annual nutrient and carbon concentrations in Pool 2B for 2010 and 2011 (mg/L; annual mean ± 1 s.e.). TKN= total Kjeldahl nitrogen; PIC= particulate inorganic carbon; POC= particulate organic carbon; TPC= total particulate carbon; TPN= total particulate nitrogen; ROE= residue on evaporation at 105ºC.

Year	Ammonia	TKN	Nitrate + nitrite	Total phosphorous	Ortho-phosphate
2010	0.05 ± 0.05	1.38 ± 0.41	0.09 ± 0.12	0.09 ± 0.05	0.006 ± 0.002
2011	0.04 ± 0.03	0.71 ± 0.21	0.62 ± 0.91	0.06 ± 0.05	0.01 ± 0.01
Change	-20.0 %	-48.7%	606.3%	-29.2%	73.5%

Year	Organic Carbon	PIC	POC	TPC	TPN	ROE
2010	10.7 ± 2.1	0.08 ± .07	3.2 ± 1.8	3.3 ± 1.8	0.49 ± 0.29	76.9 ± 73.0
2011	6.2 ± 1.8	0.06 ± 0.09	1.5 ± 1.4	1.6 ± 1.5	0.22 ± 0.20	30.7 ± 45.2
Change	-41.9%	-26.8%	-52.1%	-51.3%	-55.2%	-60.1%

Water quality parameters varied spatially within Pool 2B, with nutrient concentrations decreasing with distance from the connecting structure. Site 2BNW, the site having the most influence from Crane Creek, had the highest concentrations of nitrogen and phosphorus of all Pool 2B locations. The relationship between nutrient concentration and distance from the structure was most evident in the spring and fall of 2011 when there were large influxes of nitrate + nitrite and orthophosphate (Figures 3 and 4). Nitrogen and orthophosphate concentrations were the greatest during these same times throughout Pool 2B, Crane Creek, and Lake Erie, likely as a result of agricultural fertilizer/waste inputs.

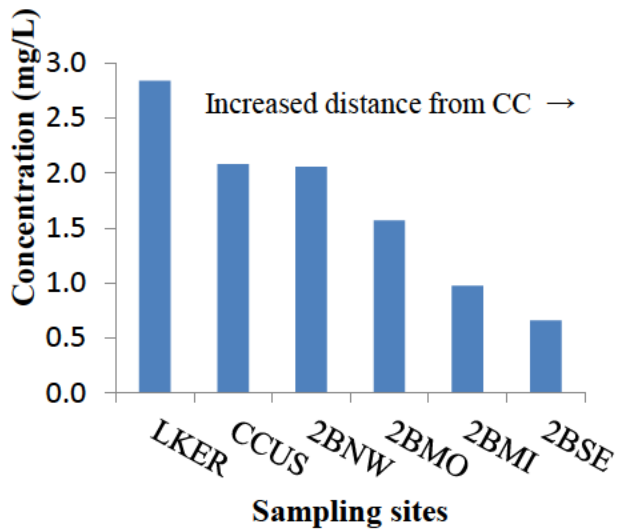

Figure 3: Average nitrate + nitrite concentrations in spring 2011 in 2B. For site locations see Appendix 7.

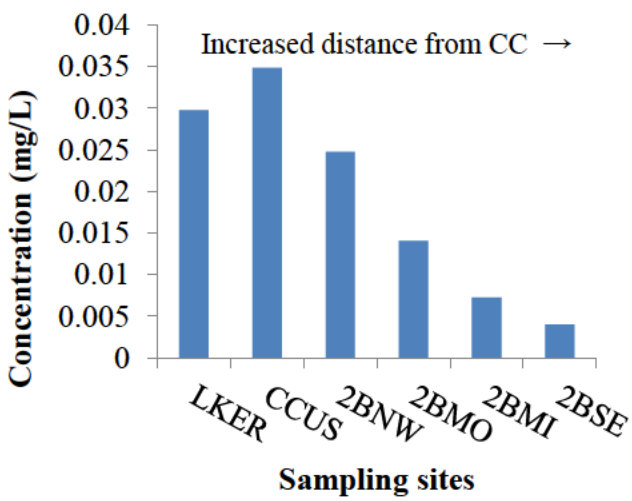

Figure 4: Average orthophosphate concentrations in fall 2011 in 2B. For site locations see Appendix 7.

We also found a spatial pattern to the reduction in organic carbon within Pool 2B. At 2BNW, organic carbon concentrations were roughly 50% less in 2010 compared to 2011, whereas the concentration of organic carbon at the whole-pool level (average of all 2B sample sites) was 24% less than in 2011. This suggests that Pool 2B, especially the section closest to the structure has become an "active marsh," meaning that it produces organic matter that is exported to the lake and could be used as a source of energy for plant and benthic production (Bouchard 2007).

Seiche Activity and Nutrient Retention

Background

The term "seiche" describes the movement of water in a closed body, such as a lake, where water oscillates back and forth until it reaches equilibrium—like water sloshing in a bucket. In the Great Lakes, these events are driven by changes in wind and atmospheric pressure. In Lake Erie, seiche events can occur over a few hours or a few days and water level changes can be greater than 1 m. Coastal wetlands receive intrusions of lake water during seiche events (Keough *et al.* 1999). Intrusions in the Crane Creek system are a mixture of water from the creek and Lake

Erie, with the proportion of each source dependent on seiche magnitude and precipitation. These influxes of lake water have been shown to drive nutrient retention within coastal wetlands (Mitsch and Reeder 1992).

To quantify the effect that reconnecting Pool 2B to Crane Creek and Lake Erie had on the dynamics of nutrient retention, we collected water coming into and exiting Pool 2B during the rising and falling water levels during seiche events. This allowed us to look at temporal changes in nutrient concentrations in our water samples and estimate nutrient retention in the wetlands. We hypothesized that we would see a decrease in the concentration of nutrients in water leaving Pool 2B because wetlands are known to retain nutrients such as nitrogen and phosphorus (Matisoff and Eaker 1992).

Methods

Sample collection: We measured differences in nutrient concentrations of water entering Pool 2B and water exiting Pool 2B during five seiche events in 2011. Water samples and multi-probe measurements (pH, temperature, dissolved oxygen, specific conductivity, ANC, and turbidity) were taken during the rising and falling stages of the seiche inside the structure in Pool 2B. While there are differences in the size, shape, and duration of each seiche event, our goals were to take a sample at the peak of the seiche after the most water had flowed into Pool 2B and another sample after most of the water had flowed back out of the pool. This sampling scheme was designed to capture the water with the strongest signal as either source water (water entering the pool) or wetland water (water exiting the pool) and to maximize residence time in the wetland to allow for the greatest length of time for nutrient transformation and uptake. However, due to the unpredictable nature of seiches, many of our samples were not taken at the most ideal times. The example in Figure 5 shows the timing of sample collection during a seiche event in December 2011.

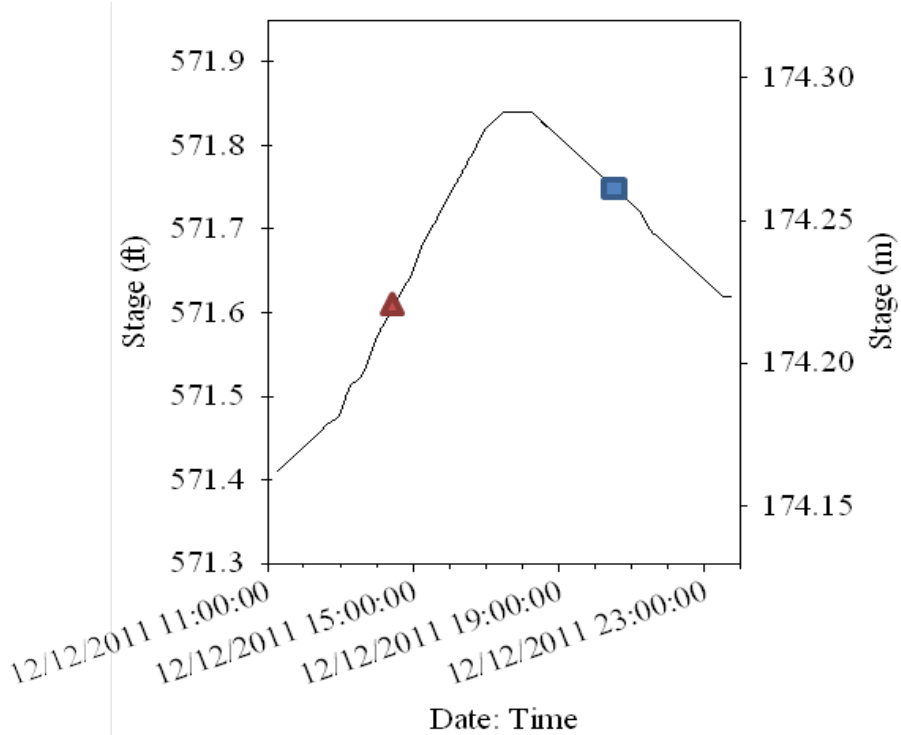

Figure 5: Seiche collection times for Dec 12-13, 2011. The red triangle represents the collection of water entering Pool 2B; the blue square represents the collection of water leaving Pool 2B.

In determining when to sample a seiche, we monitored water levels in Toledo via a website produced by the National Oceanic and Atmospheric Administration (NOAA) and took into consideration climatic conditions which can drive seiches, including duration, direction, and strength of wind; changes in barometric pressure; and the movement of storm systems within the Great Lakes region. The timing of actual sample collection was dependent on our ability to predict patterns and to travel to ONWR from Ann Arbor, MI.

For a description of the water sample collection process, please refer to the Water Chemistry Methods sections: "Sample collection" and "Sample processing and analysis."

Analysis: Estimation of total retention of nutrients [ammonia (NH_4^+), nitrate + nitrite (NO_3 + NO_2), total phosphorus] during a seiche event was a multistep process. Uniform mixing of each parameter was assumed for each of the "seiche in" and the "seiche out" samples. We selected "peak" and "trough" surface water elevations during seiche events (from stage data) and combined those with existing topographic and bathymetric data to calculate volumes with ArcGIS (ESRI ArcMap; 10.0 Service Pack 2) that reflected water levels within Pool 2B at these times. These data were used to produce volumetric estimates of water discharge into and out of the pool. Then, using the water chemistry data generated by NWQL, we estimated nutrient loading into the pool by using concentrations (mg/L) of nutrients entering Pool 2B multiplied by the volume of the water that entered the pool. We estimated the nutrient load exported from the wetland by using nutrient concentrations (mg/L) of water leaving Pool 2B multiplied by the total volume of the seiche out. Then, nutrient retention was estimated by subtracting the amount of

loading (amount in) by the export (amount out). We then calculated the amount of nutrient retention per hectare by dividing the amount of retention by 40 (the size of Pool 2B in hectares). Total retention (mg/Ha) =

$$\frac{\left(Volume\ of\ H_2O_{in} * Concentration(\frac{mg}{L})_{in}\right) - \left(Volume\ of\ H_2O_{out} * Concentration(\frac{mg}{L})_{out}\right)}{40}$$

Seiche characteristics may impact nutrient retention in the wetland (e.g. longer seiche in than out could promote more nutrient retention even if concentration was minimally reduced). Therefore, we also calculated the total nutrient concentration reduction to assess nutrient retention in Pool 2B independent of the shape of the seiche.

$$\text{Concentration reduction } (\mu g/L) = Concentration_{in} - Concentration_{out}$$

Results & Discussion

Early analyses suggest a complex relationship between season, retention time, and the slopes of the rising/falling arms of the seiche on the amount of nutrient retention during any given seiche event (Table 2). Events in July, September, and December retained large quantities of ammonia (>40 g/Ha), while those in April and October exported ammonia from Pool 2B (Figure 6). Ammonia levels vary with fertilizer inputs, decomposition of organics, and waste (e.g., fish and waterfowl). The high retention levels in July and September may have been due to high levels of runoff from agricultural fields due to seasonal rains and nutrient uptake by active wetland plants, while lack of plants and seiche duration in April and October may have led to lower ammonia retention during these months. Nitrate + nitrite were retained during events in July, September, and December (Figure 6). The presence of high nitrate + nitrite concentrations also suggests large agricultural inputs (fertilizer/manure) to surface waters, which often can lead to eutrophication and reduced overall wetland health. The seiche event captured in September had much higher levels of retention for ammonia and nitrate + nitrite than was found during other events. Currently, we are investigating how precipitation in the Crane Creek watershed impacts seiche nutrient concentrations and how seiche shape ultimately impacts nutrient retention.

Table 2: Monthly nutrient concentration reduction (red, in µg/L), total retention (ret, in kg/Ha) and residence time (hrs).

	Total Phosphorus		Orthophosphate		Ammonia		Nitrite + Nitrate		Residence Time
	red	ret	red	ret	red	ret	red	ret	hrs
April	170	167.8	12.7	11	14.8	-19.8	320	-728	24
July	35	44.8	8.2	7.6	22.6	21.7	152	261.4	11.45
Sept	119	164.3	25	30	69.2	88.1	1560	2174.6	11.25
Oct	25	35.3	0.9	-3.5	-2.4	-24.2	27	-91.8	26.5
Dec	-4	41.2	16	27.1	-0.3	19	820	786.2	5.75

As opposed to the other nutrients measured, total phosphorus was retained during all seiche events, with especially high retention in April and September. Since phosphorus can be related to sediment transport and deposition, we are currently exploring relationships between phosphorus and turbidity/total suspended solids to better understand phosphorus retention in Pool 2B. All seiche events except October showed retention of orthophosphate. Events in

September and December retained the most per hectare (~70 g/Ha). Orthophosphate is the form of phosphorus most available for uptake by plants (algae) and animals, so high concentrations often lead to eutrophication, algal blooms, and degradation of ecosystem functions and services. Surprisingly, the months of September and December, when plants are mostly inactive, had the highest levels of retention.

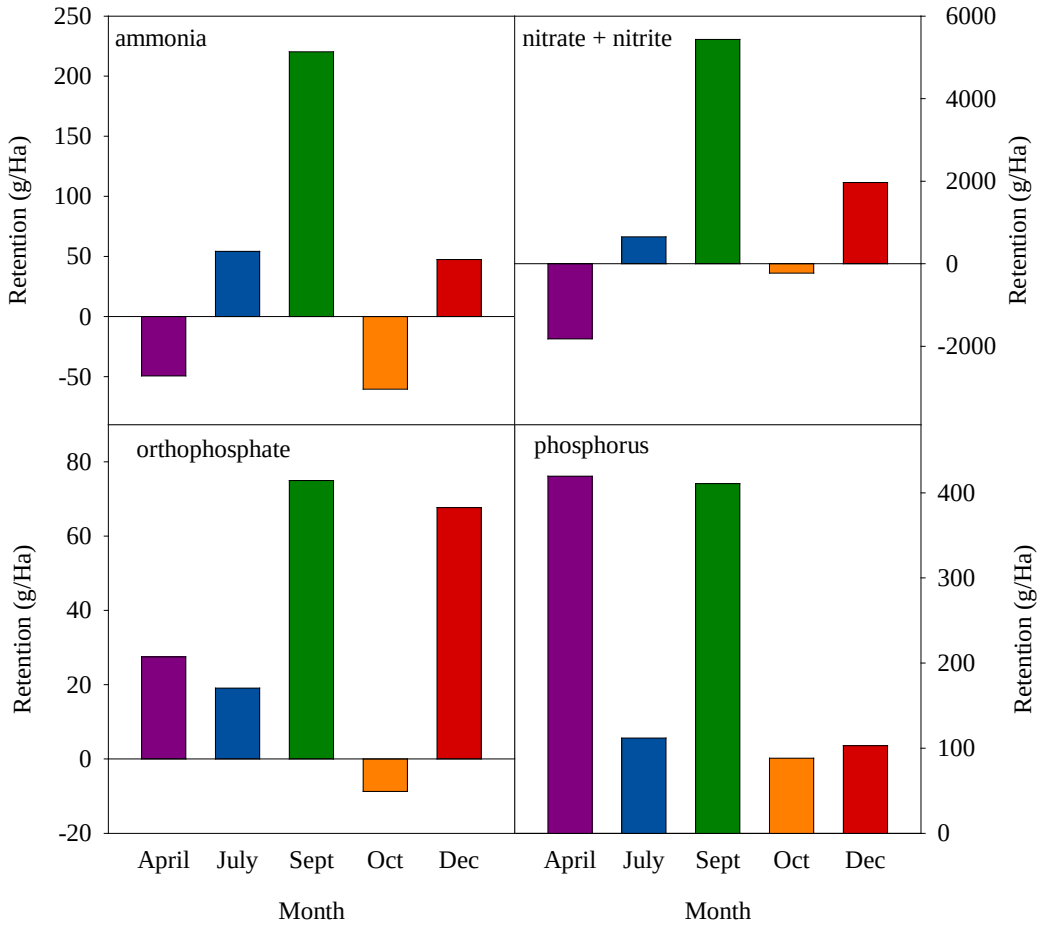

Figure 6: Monthly retention (g/Ha) of ammonia, nitrate + nitrite, orthophosphate, and phosphorus during seiche events in 2011.

Isotopes

Background

Elements such as hydrogen and oxygen have several stable isotopic forms. Stable isotopes are variations of an element having different numbers of neutrons and therefore different atomic weights. Water is primarily composed of the most common isotopes of hydrogen and oxygen (hydrogen and oxygen-16), but heavier isotopes (deuterium and oxygen-18) are also present in smaller amounts. Due to the increased mass of the heavier isotopes, the rate of evaporation of water composed of lighter isotopes happens faster than evaporation of water composed of heavier isotopes. Therefore, the isotopic signature of any water source is determined by the influence of evaporation and meteoric water, which is ground water that results from precipitation. We used the ratios of the stable isotopes found in water, oxygen-18 (^{18}O) and deuterium (δD), to evaluate the degree of mixing between the wetland (Pool 2B), Crane Creek, and Lake Erie following the opening of the structure. We had several hypotheses: 1) water from

wetland sites where there is little input from groundwater or other sources would be isotopically heavier because of the influence of evaporation; 2) water from creek sites where water inputs are mainly from meteoric water would be isotopically lighter because precipitation and groundwater are composed of the previously evaporated, lighter water molecules; and 3) that Lake Erie water would have an isotopic ratio between the wetland and the creek samples because the lake is influenced by both evaporation and meteoric water inputs.

Methods

Sample collection and processing: In 2011, water samples were collected at up to 11 sites twice in March (both before and after opening the structure), once in July, and once in October. For collection and field processing methods, refer to the Water Chemistry section "Sample collection" under "Methods" above. Analysis was conducted by Dr. Richard Doucett at the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University (for methodology see http://www.mpcer.nau.edu/isotopelab/isotope.html).

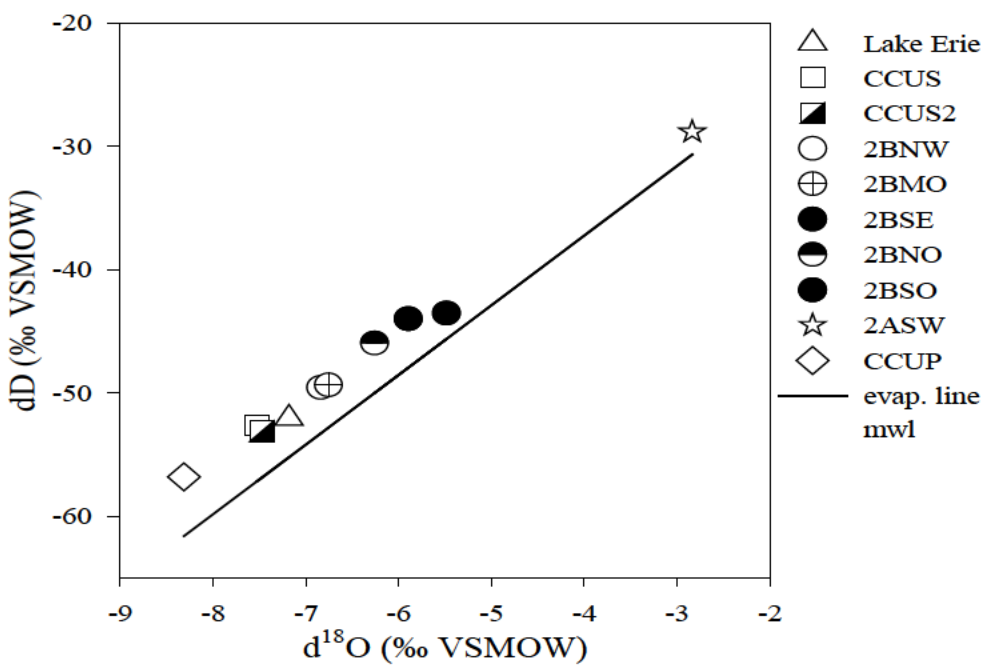

Figure 7: Mean isotope ratios for each sample location. Greater values indicate greater influence by evaporation.

Analysis: First, we assessed the relative impact of evaporation vs. meteoric water inputs on each sample by graphing the mean isotope ratios for each sample location (Figure 7). Data from the pre-structure measurements from 2B were not included in the mean isotope ratios to avoid skewing the data. Second, we looked for similarities between both sets of March samples, the samples collected in July, and those from October to assess the amount of mixing occurring between sites though time. Samples in which mixing had occurred would show isotopic signatures similar to surrounding sites. We plotted the isotope ratios and the local evaporation line ($y=5.65* \delta^{18}O-14.64$) and the local meteoric water line ($y=6.5* \delta^{18}O-3.9$). These equations were calculated in Bouchard (2007) and Leavitt *et al*. (2006), respectively.

Results & Discussion

The hydrologically isolated wetland site (Pool 2A) had heavier isotopic ratios, creek sites were usually isotopically lighter, and lake samples were intermediate between the wetland and the creek (Figure 7).

We also found evidence for high levels of mixing between sites in 2B that are closest to the structure (i.e., 2BNW and 2BMO), Crane Creek, and Lake Erie. There appeared to be little mixing between Pool 2A and the other bodies of water (Figure 7), which is to be expected as this pool is normally isolated from the other waterbodies sampled.

When we graphed the isotope ratios for all sample locations for all sampling events, it became clear that location as well as timing influenced isotopic ratios and the degree of mixing (Figure 8). These patterns might have been driven by the level of mixing and different levels of evaporation occuring at each site at the time of sampling. For example, both sets of the samples taken in March were very similar to one another and were isotopically lighter. This suggests that there were high levels of mixing between sample locations and that evaporation had little influence on any of the sample locations. This pattern could also reflect the signature of melting ice rather than evaporation or precipitation. We saw a much greater spread of weights among samples in July and October—indicating that the influence of evaporation had increased.

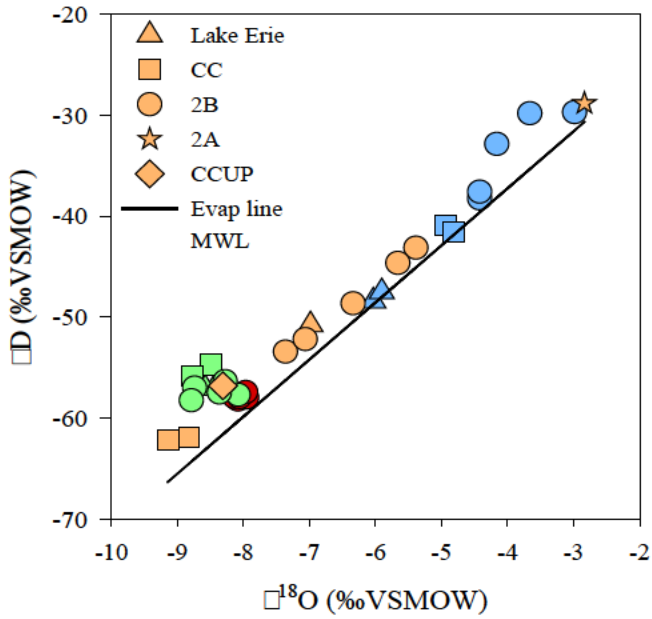

Figure 8: The isotope ratios for all sample sites at all sampling events (red = March prior to opening the structure, green = March following the opening of the structure, blue = July, orange = October).

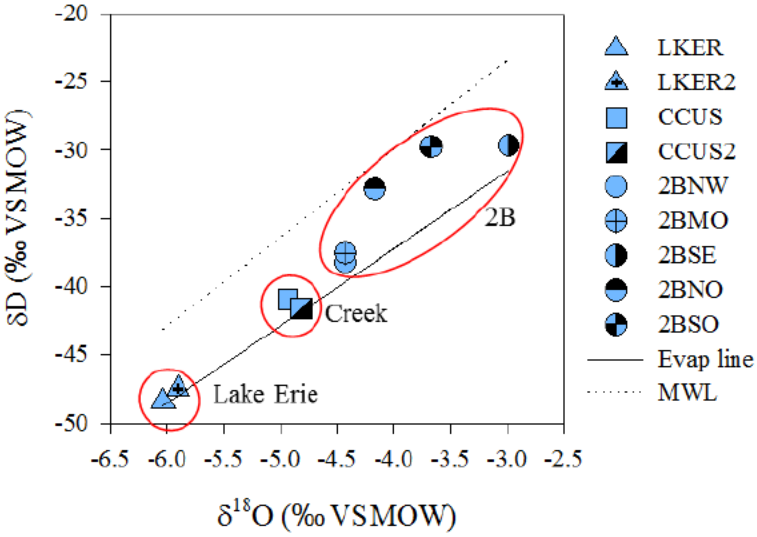

Figure 9: Isotope ratios for each sampling location taken in July 2011

Our results from July and October were quite dissimilar (Figures 9 and 10). In July, we saw no evidence of mixing between Lake Erie and Pool 2B (Figure 10). In October, we saw mixing occurring between Lake Erie and the two sites in 2B that were closest to the structure. There appeared to be a relationship between isotopic weight and distance from the structure, suggesting that incoming water from Lake Erie had less of an influence as distance from the structure increases (Figure 10). We think that the differences between July and October could have been due to differences in plant biomass and climatic conditions (i.e., seiche activity). Greater plant biomass could possibly restrict water flow and with fairly unchanging water levels, as preceded the July sample (Figure 11A), there would have been little potential for mixing of water in 2B. Higher levels of seiche activity prior to sampling, as occurred in the week prior to the October sampling event (Figure 11B), may have lead to greater amounts of mixing between sites due to the influx of Lake Erie water. Overall, our isotopic analysis suggests that there are variable levels of mixing among and within sites, depending on distance from the structure, amount of plant biomass, and climatic conditions.

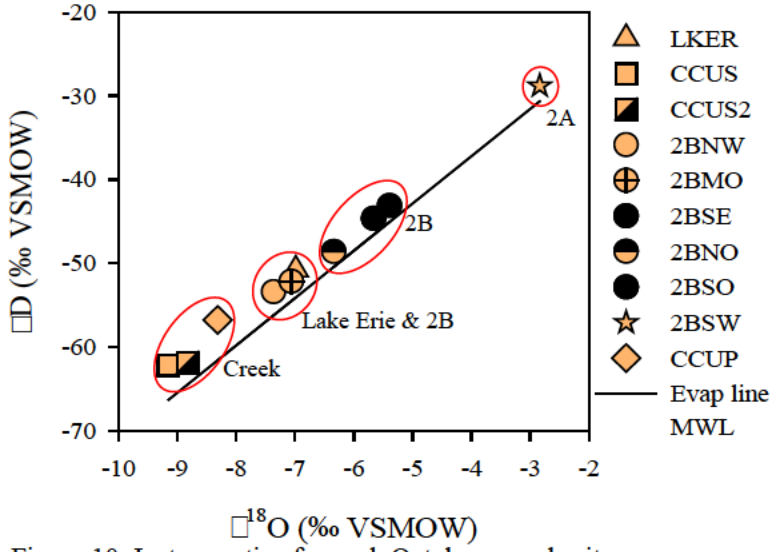

Figure 10: Isotope ratios for each October sample site

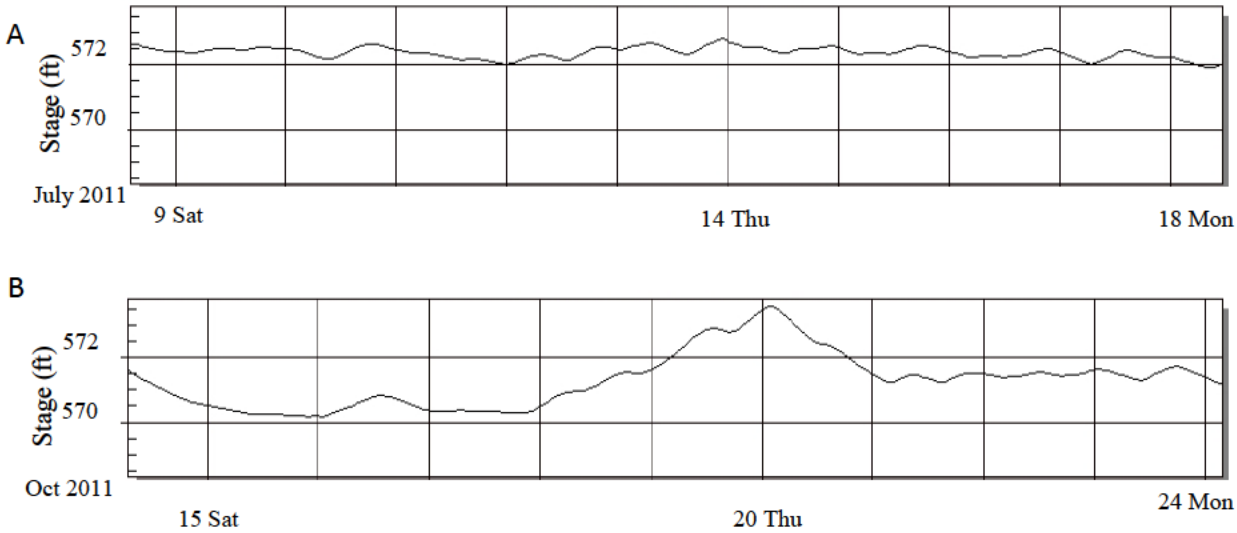

Figure 11 A & B: Differences in water level (possible seiche activity) in the week previous to the sampling dates in A) July (18th) and B) October (24th). Note that the end bar represents the sample date.

Fish Community

Background

Previous research by the U.S. Geological Survey – Great Lakes Science Center (GLSC) in the coastal and diked wetlands within the Ottawa National Wildlife Refuge (ONWR) has shown that diked wetland units and adjacent coastal wetlands have fish assemblages that differ greatly (Kowalski *et al*. 2006). Only 28 fish species (mainly centrarchids) were found in the diked wetlands, while 58 species (mainly cyprinids) were found at various locations within the Lake Erie-connected waters of Crane Creek (Kowalski 2010). Unfortunately, the majority of Lake Erie undiked wetlands are severely degraded (Herdendorf 1987, Maynard and Wilcox 1997, Kowalski and Wilcox 1999). While they remain connected to the lake hydrologically, these altered and degraded wetland habitats provided little benefit to the approximately 43 species of Great Lakes fishes (i.e., those fish that use open water habitats of the Great Lakes) that used historically wetland habitats as spawning and nursery locations (Jude and Pappas 1992). By installing a fish passage structure in a diked wetland, fish that previously had been excluded from these wetlands would have access to potentially better quality habitat containing more submersed and emergent vegetation and having greater water clarity.

Many commercially and recreationally important fish species depend on productive coastal habitats to feed (e.g., channel catfish (*Ictalurus punctatus*)), spawn (e.g., northern pike (*Esox lucius*), yellow perch (*Perca flavescens*)), or provide protection to young-of-year (YOY or age-0) or juvenile fish (e.g., largemouth bass; see Appendix 3 for full list of common and scientific names). Wetlands also support important open-water species, such as walleye, by supporting prey fish production (e.g., emerald shiner, gizzard shad). Since wetlands provide critical habitats for fish, it was important that we assess the extent of use of Crane Creek, Pool 2A, and Pool 2B by fishes to understand the effects of installing the fish passage structure and reconnecting Pool 2B to Lake Erie via the Crane Creek wetland complex. There were two components of our investigation into fish activity in the study area: 1) Dual-frequency Identification Sonar (DIDSON™) surveillance and 2) fish capture with fyke nets. We used the DIDSON (i.e., acoustic-based sampling) to observe patterns of fish passage between Crane Creek and Pool 2B. We used fyke nets to quantitatively assess fish community composition. Prior to sampling, we hypothesized that 1) we would see an increase in fish species richness and catch per unit effort (CPUE) in Pool 2B, and 2) Great Lakes fishes would use newly available wetland habitat in Pool 2B extensively.

DIDSON

Background

By using DIDSON technology, we were able to passively study fish movement through the structure connecting Pool 2B and Crane Creek. The water here is often very turbid, making visual observation impossible. Not only is this a non-intrusive way to document fish movement to and from the creek and pool via the structure (i.e., flux), but it also allows for estimation of fish abundance and some very limited fish identification based on distinctive body shapes or schooling patterns. This is all done without sacrificing the fish being studied. Another benefit of the DIDSON is that it allows for continuous, multi-day observations.

Methods

Sample collection: We used a Sound Metrics DIDSON 300 m sonar unit (Figure 12) to monitor fish movement through the structure for 48-hours during each biweekly fyke-netting trip. The DIDSON unit, which was attached to a frame located on an I-beam supporting the platform on the wetland-side of the structure, was lowered to 1 m below the water's surface using a cable winch. A data cable connected the unit to a laptop computer that was housed inside a cargo trailer. The trailer was outfitted with solar panels that fed into a line of batteries. An inverter was then used to power the DIDSON unit, laptop, and other accessories.

Figure 12: DIDSON unit

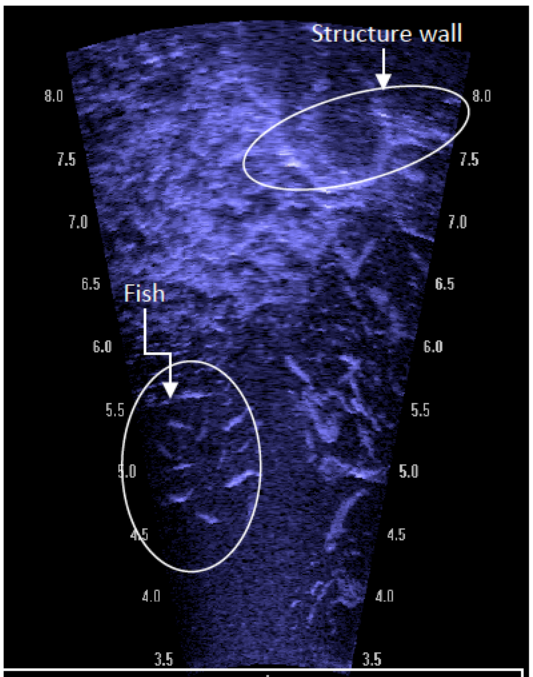

Figure 13: DIDSON image

Sound pulses were emitted from the unit and reflected back as echoes, which were then converted into digital images (Figure 13). Data were filed on the laptop in one hour increments and downloaded onto a portable hard drive every 8-10 hours. A typical data collection event (i.e., 60-72 hours) occupied 75-100 gigabytes of space.

Analysis: DIDSON data are being analyzed using a hydroacoustic data analysis program called Echoview v5.0.82 (Myriax Software Pty Ltd, Hobart, Australia). Within the Echoview program, individual fish will be counted automatically and time-stamped, minimizing the need to view and annotate each data file manually. Fish abundance data will be analyzed statistically to identify patterns in flux and abundance.

Results & Discussion

Analysis of the DIDSON data are ongoing, but qualitative results show that large numbers of fish of all sizes are using the structure to access Pool 2B wetland habitat. Many thousands of fish moved through the structure daily in both directions. Complexities in the data make visual or automated fish counting difficult, but new analysis methods are being developed.

Fish Capture

Background

As the DIDSON unit was recording information on fish passage through the structure, fyke nets were deployed in different locations in Crane Creek, Pool 2A, and Pool 2B to assess fish community composition. The nets allowed us to identify the fish species present, document their sizes and life stages, and study variation in fish assemblages among vegetative habitats. Most importantly, it allowed us to compare pre- and post-connection fish communities with

Pool 2B. With the installation of the fish passage structure, we hypothesized that fish would move from the creek into 2B and make use of previously inaccessible features including vegetated habitat, less turbulent water, and new food sources. We expected to see additional species of fish using Pool 2B, but to not necessarily have the fish community composition in the wetland duplicate that of Crane Creek.

Methods

Sample collection: Fyke nets were set at three different sites within each habitat: Crane Creek, Pool 2A, and Pool 2B (Appendix 1). Each fyke net consisted of a mesh lead, a pair of mesh wings that helped funnel fish into the net, and a square, metal frame connected by mesh to a series of circular hoops that led to a narrow cod end. Frames were either 1 m x 1 m or 0.5 m x 0.5 m; the netting used for the leads, wings, and trap bodies was either 0.4 cm mesh or 1.3 cm mesh; and the lead length was 7.6 m, 15.2 m, or 30.5 m (Table 3). Water depth and slope of the substrate were used to determine the size of the frames and corresponding leads used at each site.

Sites were selected following a stratified random design. Nets were set at locations within each site that allowed the nets to fish properly (e.g., appropriate water depth). When changes in water levels necessitated the relocation of a net, the net was shifted perpendicular to the shoreline until the proper depth was encountered. If a suitable depth could not be found, then the net was set as near to its original location as was possible. The exception to this was 2BGLRI3 (the small frame net) which could not be fished due to the lack of suitable habitat following the dramatic water level rise in Pool 2B in 2011. Other than slight location adjustments that resulted from seasonal and annual changes in water levels, the fishing sites remained fairly fixed throughout the field season.

Table 3: Location ID, frame size, mesh size and length of lead for all nets.

	Location ID	Frame (m) & Mesh (cm) size	Lead length (m)
Crane Creek	CCGLRI2	1 m x 0.4 cm mesh net	15.2
	CCGLRI3	0.5 m 0.4 cm mesh net	15.2
	CCGLRI4	1 m x 1.3 cm mesh net	15.2
Pool 2B	2BGLRI2	1 m x 0.4 cm mesh net	15.2
	2BGLRI3	0.5 m x 0.4 cm mesh net	7.6
	2BGLRI4	1 m x 1.3 cm mesh net	15.2
Pool 2A	2AGLRI2	1 m x 0.4 cm mesh net	30.5
	2AGLRI3	0.5 m x 0.4 cm mesh net	7.6
	2AGLRI4	1 m x 1.3 cm mesh net	15.2

To capture short- and long-term patterns of fish usage at the sites, biweekly sampling occurred from mid-June until ice-in (November) in 2010 and from ice-out (early March) until ice-in (November) in 2011. Nets were set for two consecutive 24-hr periods during each sampling trip. After the first 24-hr period, all nets were pulled. The fish were removed from each net, identified to species or to the lowest taxonomic level possible, counted, and the first 100 randomly selected individuals of each species were measured for total length to the nearest tenth centimeter before being released. These data were recorded on a datasheet along

with the net ID, weather conditions, the beginning and ending times for processing the sample, the set time, and any physical anomalies noticed on the fish. If any fish could not be positively identified in the field, representative specimens were preserved in ethanol and brought back to the GLSC to be identified using keys in Fishes of Ohio (Trautman 1981) for ID verification. Any net damage was repaired onsite and the net was reset. The next day, the same process was followed, except the nets were not reset. After all the nets had been pulled and dried, they were rolled up and stored at the refuge for future use.

Analysis: Fish catch data were entered into an Oracle database at the GLSC. Each 24-hour net set was considered a discrete sampling event. Species richness, CPUE, and relative abundance were calculated for each net over the course of the sampling season. The CPUE was calculated by dividing the number of fish caught in a net by the number of days the net was set. CPUE of the different pools was used as a comparison, over raw abundance, to allow for easier comparison of overall fish catch per net day at the three different sites through time and account for variation in effort related to net malfunction, weather delays, etc. We used paired t-tests in the software program SigmaPlot (Systat Software Inc, San Jose, California) to assess the differences of CPUE, species richness, and relative abundance between the two sampling years (significance level = 0.05).

Length measurements were used to determine age class distribution over time for particular species of interest (e.g., northern pike, gizzard shad, emerald shiner). Trautman (1981) was used to identify the length cutoffs to assign age classes.

To get a sense of the health of the wetlands and creek, we also classified each fish species as native or non-native and ranked all species along a tolerance continuum of pollution and water turbidity (1 being the most intolerant and 3 being the most tolerant). This information was then used to estimate percent composition of each type to the fish community.

In some instances, data were excluded from analysis due to compromised sampling gear (e.g., wind and wave events knocking down leads or wings, non-targeted animals tearing holes in the netting, large carp became wedged in a net hoop and blocking other fish from entering the net). The issue was recorded on the data sheet for that particular catch and the corresponding data were flagged in the database so that the values would not be included in any analyses. There were nine instances of net failure in 2010 and two in 2011.

Results & Discussion

Species composition: Overall, 60 species and hybrids representing 19 families were identified from the nets set in Crane Creek, Pool 2A, and Pool 2B (total abundance was 246,206 individuals; Appendix 3.1). Fish that were found exclusively in 2010 included walleye, black buffalo, blacknose shiner, banded killifish, and blackside darter. The following fish were identified in 2011, but not 2010: northern hogsucker, shorthead redhorse, white sucker, quillback, smallmouth buffalo, creek chub, mimic shiner, spotted gar, trout-perch, silver lamprey, and rainbow trout. Several factors, including our sampling design, equipment bias, and population change, could influence the presence or absence of species in any given year. In 2010, sampling started in June rather than in March, which may have implications for detecting fish that frequent the Crane Creek wetlands only in the spring. Some fish similarly

may avoid capture due to behavioral habits (e.g., banded killifish which are surface-swimmers). Fish whose populations have shown drastic declines or that are fairly uncommon may require more effort to detect individuals. On rare occasions, fish collections reflected an anomaly that could not be explained (e.g., rainbow trout in Pool 2B). Many of the species unique to 2011 are riverine or lake species, reflecting the fact that these species were finally able to access habitats in Pool 2B. Overall, the additional effort in 2011 (i.e., March through June), combined with the availability of new habitat, may be responsible partially for some fish collected in 2011 that were not observed in 2010. With the opening of the fish passage structure, 15 species previously found previously only in Crane Creek were found in Pool 2B. New species for 2B included longnose gar, gizzard shad, and multiple species of shiners.

Abundance: The CPUE values for Crane Creek and Pool 2A, averaged over the entire field season, showed no significant change from 2010 to 2011 sampling. However, there was a significant increase in CPUE for reconnected Pool 2B in 2011 as compared to 2010 ($p < 0.05$; Figure 14). The 2010 CPUE data are more consistent than in 2011, as would be expected given seasonal movements of species in Lake Erie and Crane Creek and their access to the wetland in 2011.

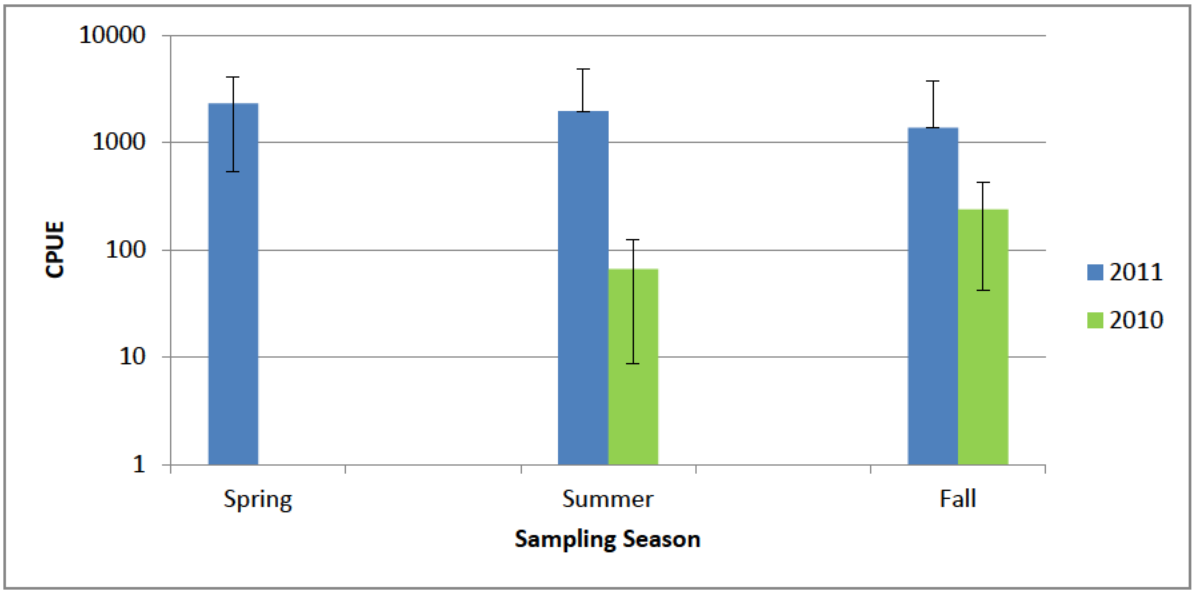

Figure 14: CPUE comparison between sample years of Pool 2B nets. 2010 catch begins June 14-15.

Species richness: As with CPUE, species richness was greater in Pool 2B in 2011, but not quite at the same levels as Crane Creek ($p < 0.05$; Figure 15), while no significant change occurred at the other two sites. These data suggest that reconnecting the wetland to Lake Erie via the creek had a positive impact on species richness in 2B.

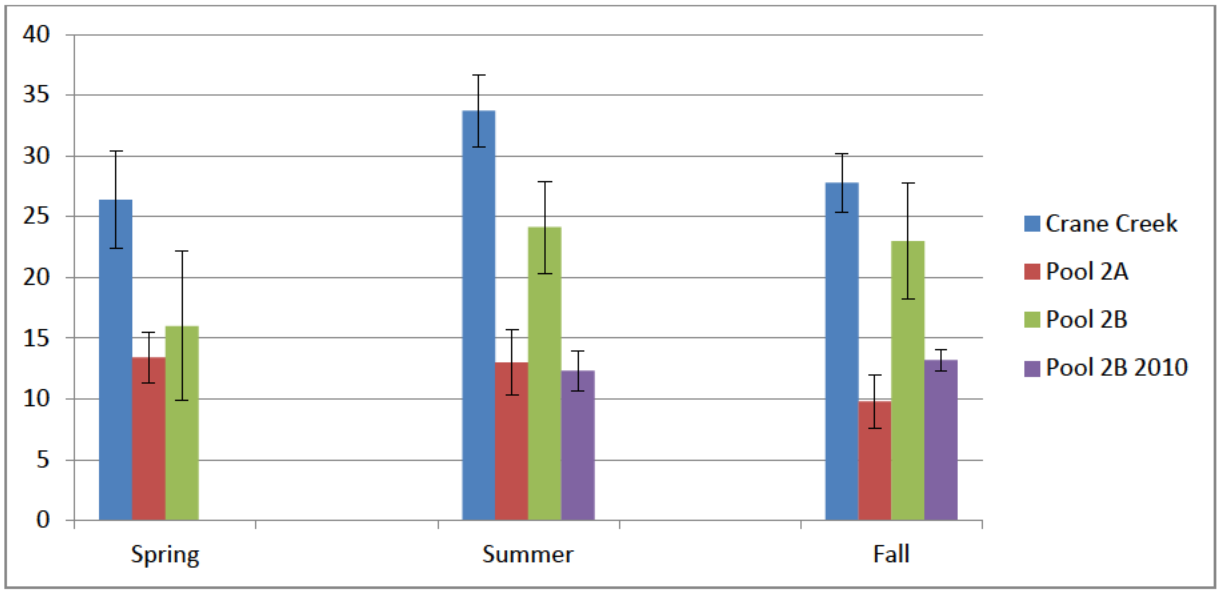

Figure 15: Species richness for 2011 in Crane Creek, Pool 2A, and Pool 2B.

Ecological traits: Our results also show that most of the fish species captured at all sites were native and were also relatively tolerant of pollution and turbid waters (89% of the species collected were native and 11% were non-native (Ohio DNR)). In describing tolerance, 30% of fish species caught were categorized as being tolerant to both turbid and polluted waters, 36% having an intermediate tolerance, 6% intolerant, and 28% of species caught were unable to be categorized. The predominance of tolerant and native fish species suggests that abiotic factors may limit the presence of intolerant fish species. Future analysis may compare tolerance levels of fish found in Crane Creek to those found in Pool 2A as a way to compare habitat types, and then examine tolerance of fish in Pool 2B before and after the structure opening. More research is needed to complete the categorization of tolerance and native vs. non-native classification of all species caught.

It is important to note that in October 2010, a significant number of goldfish with "bubble head" type hemorrhages were caught. Refuge staff suggested that it may have been caused by a pathogen found in the environment, so infected specimens were sent to the USFWS La Crosse Fish Health Center where it was confirmed that a *Myxobolus* virus was the cause of the hemorrhages. To prevent the spread of the virus, all equipment and personal gear are thoroughly cleaned and dried upon returning to the GLSC after each sampling effort.

Age class: As we hypothesized, we found shifts in age structure of fish inhabiting Pool 2B.

Case study, northern pike:
The northern pike is a native piscivore that has been caught consistently throughout both sample years in Crane Creek and Pool 2B. Pike play an important role as top predators in wetland ecosystems, they used to be a large component of the pre-development fish community, and are a highly sought-after game fish. However, loss of spawning habitat has severely decreased pike populations in many areas.

Adult northern pike seek out emergent vegetation in shallow water to spawn in early spring (March - May) when the water temperature is between 4 and 11 degrees Celsius. Adhesive eggs and larval fry will attach to graminoids, sedges, and other vegetation. During the summer months, the age-0 and yearling northern pike will remain in weedy vegetation. Larger pike may move to deeper, cooler waters (e.g., in Lake Erie) to avoid becoming stressed by warm temperature. Generally, age-0 can grow to 15-25 cm long in one year and reach to 48.3-93.9 cm when mature (Trautman 1981). Pike usually are approximately 43 cm long when they become sexually mature around their third year. In larval studies, larger individuals were observed forcing smaller, less dominant fish out of the most desirable habitat. Cannibalism within dense pike populations has also been observed (Giles 1986).

We observed changes in the age structure of the Pool 2B northern pike population after it was hydrologically reconnected to Lake Erie in 2011. In 2010, the vast majority of fish caught were adults. No age-0 fish were captured. After reconnection in 2011, the majority of fish caught were age-0 and juvenile fish (Figures 16, 17, 18). A likely explanation for the shift in age structure could be the drastic increase of available habitat within Pool 2B between the 2010 and 2011 sampling seasons. In 2010, water levels were very low, possibly confining fish to a small but deep borrow pit in the northwest corner of 2B. A limited range may have concentrated fish and inflated density estimates. An increased fish density may have also increased the occurrence of cannibalism (possibly the reason for not seeing any age-0 fish in 2010), and also may have caused the dominant larger fish to push smaller individuals to less desirable open water habitat which could not be sampled by fyke nets. After the structure opened in 2011, the area of usable habitat increased significantly and likely reduced some of the stressors put on the northern pike population. In addition, northern pike were able to enter Pool 2B from Crane Creek and spawn for the first time in decades, a clear benefit to the Lake Erie northern pike fishery.

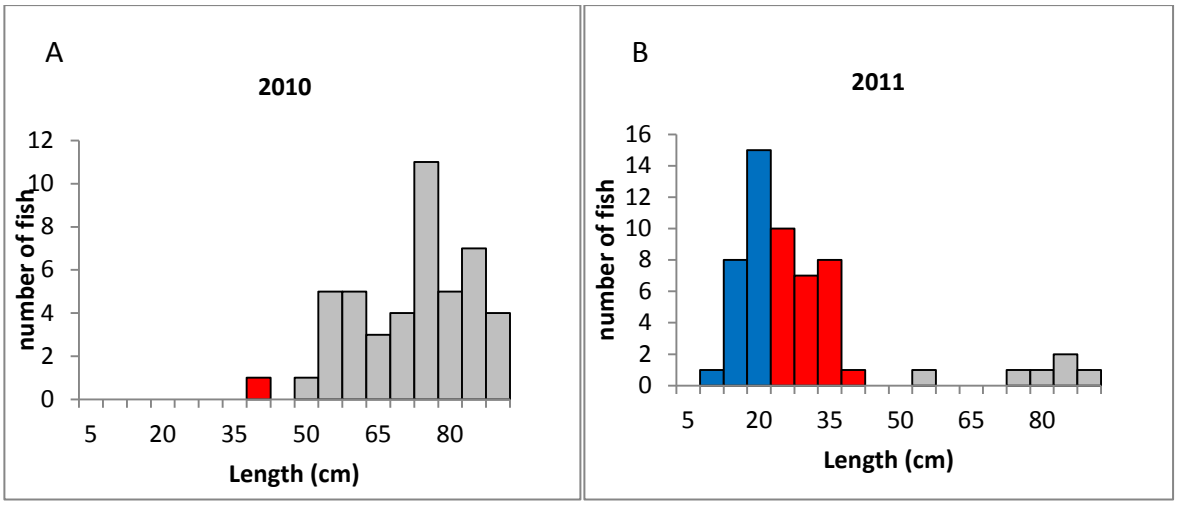

Figure 16 A & B: Age class representation of northern pike in Pool 2B for 2010 and 2011, blue bars are age-0, red bars are juveniles, and gray bars are adults. Age class lengths determined using Trautman (1981).

Figure 17 A & B: A) Age-0 pike caught summer of 2011, B) Immature pike caught in fall 2011.

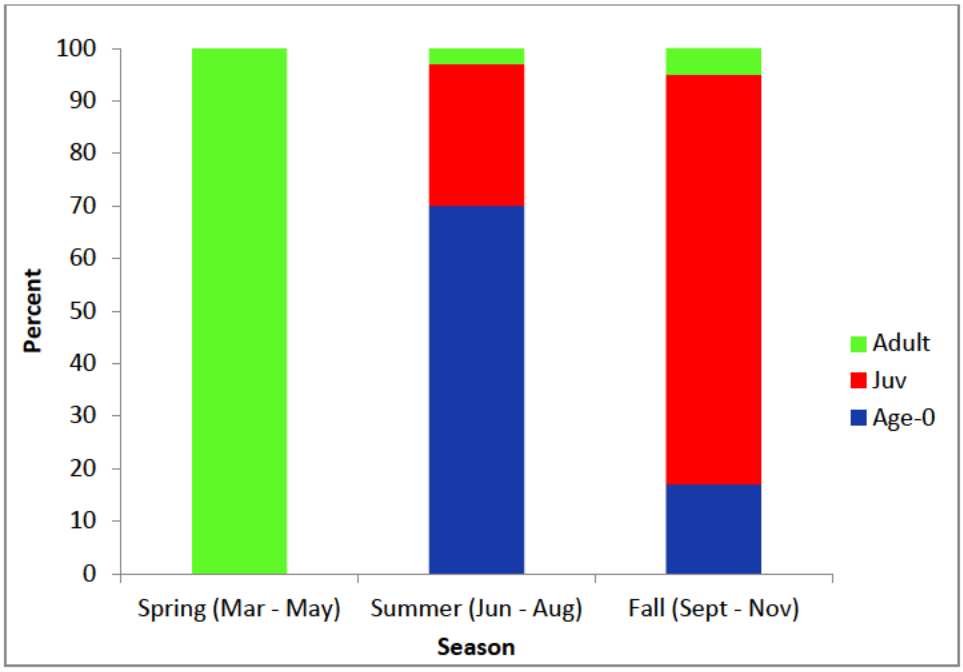

Figure 18: Age class percent of catch of northern pike in Pool 2B during 2011 sampling season.

Avian Community

Background

Diked coastal wetlands, such as those found at the Ottawa National Wildlife Refuge (ONWR), can be beneficial to thousands of migratory birds that use these areas for feeding, resting, and breeding. Land managers are able to use pumps, ditches, and other tools to manage water levels within these wetlands to maintain optimal habitat for different groups of birds (e.g., waterfowl, shorebirds). Maintaining high quality habitat for waterfowl and other migratory birds at ONWR is a priority due to the convergence of two major flyways in this region. This area is of local, regional, and global importance as a hotspot for bird diversity and abundance throughout the year.

However, the intense management of these wetlands for waterfowl habitat has consequences for other bird groups. For example, diked wetlands have lower fish abundances than other non-impounded wetlands, which could negatively impact populations of piscivorous birds (Kowalski *et al.* 2006). By installing the fish passage structure in Pool 2B and allowing fish from Crane Creek to enter and inhabit the wetland, fish diversity and abundance within the pool would be expected to increase and improve the prey base for piscivorous birds—many of which are species of concern in Ohio, such as the common tern and the least bittern. We hypothesized that piscivorous birds would benefit from the structure being opened, while shorebirds could be impacted negatively if higher water levels reduced the availability of suitable habitat (e.g., mud flats, beaches). Variability in water levels and thus water depths is expected to provide habitat to a suite of waterbird and waterfowl species.

Methods

Data collection: In the spring, summer, and fall of 2010 and 2011, we worked with a field crew experienced in bird taxonomy to conduct point-count surveys (5-10 min each) at 10 sites in Crane Creek, Pool 2A, and Pool 2B (Appendix 1). There were 9 survey events in 2010, starting at the end of March and ending in October. In 2011, there were a total of 13 survey events beginning in April and ending in December. Survey efforts were increased during the spring and fall migration periods (i.e., there were two sample events in April, May, October and November). All counts were performed by the same crew within a single day or in two half-days if weather or other conditions disrupted sampling. Surveys were randomized in such a way that individual sites were sampled at different times during the day. Each event produced data on geospatial location of sample, bird species composition, species abundance, distance from observer to birds, and bearing to birds. For analysis, each bird species observed was assigned a type (e.g., waterbird, shorebird) and diet class (e.g., piscivore) based on data presented by the Cornell Laboratory of Ornithology web site and DeGraaf *et al.* (1985). Species groups were chosen based on categories most useful to resource managers and because they were expected to show the most response to wetland restoration efforts: waterfowl (primarily game species; Appendix 4.1), piscivores (fish-eaters; Appendix 4.2), shorebirds (primarily found on mudflats; Appendix 4.3), and waterbirds (primarily gulls, terns, and swans, excludes waterfowl; Appendix 4.4). A complete list of all bird species in 2010 and 2011 can be found in Appendix 4.5. The piscivorous diet class was evaluated separately because the addition of new prey fish species to Pool 2B through the open fish-

passage structure likely would affect fish-eating taxa the most. Nomenclature followed The American Ornithologists' Union 54th supplement (Pyle and DeSante 2014).

Analysis: Species richness and abundance were calculated at the community level and for specific bird groups (e.g., waterfowl, shorebirds, piscivores, waterbirds). Although some species appear in multiple groups, they were not double counted in the annual totals. For example, red-breasted mergansers (*Mergus serrator*) were considered waterfowl during analysis of the waterfowl group and then independently counted as piscivores during other analyses. For the purposes of analysis, the waterfowl group was separated from the waterbird category, and species were classified as waterfowl if they were primarily game taxa. Geospatial locations of observed birds were plotted on aerial photographs. Examination of potential correlations between bird species, bird abundance, water depth, and habitat type are ongoing.

Results & Discussion

We observed a total of 71 species of birds, 59 in 2010 and 47 in 2011 (Appendix 4.5). Of note, four species that are listed as endangered by the state of Ohio (trumpeter swan – *Cygnus buccinator*, common tern – *Sterna hirundo*, cattle egret – *Bubulcus ibis*, and snowy egret – *Egretta thula*) and two species listed as threatened by the state of Ohio (black-crowned night heron – *Nycticorax nycticorax* and least bittern – *Ixobrychus exilis)* were observed. Some endangered species occurred in fairly large numbers. For example, 319 common terns were observed in 2010 and 70 trumpeter swans (*C. buccinators)* were observed in 2011. Nearly 80% of the common terns that were observed were sighted using the expansive habitat in Crane Creek in September 2010. The majority of the trumpeter swans were observed in spring and fall in 2011 and almost entirely in Pool 2B and Crane Creek.

Although variable by season, total waterbird abundance in Crane Creek was very high in fall 2010 (Figure 19). However, seasonal species richness at the same site did not differ between 2010 and 2011 (Figures 20). Temporal variability was observed in the pools, but the small surface area supported fewer birds overall. Pool 2B had higher abundance and species richness of waterbirds than the isolated Pool 2A among all seasons and years. Unlike in 2010, we observed the lowest species richness and total abundance of waterbirds at all sites during the summer of 2011. This shows that the wetlands in post-connection Pool 2B were providing habitat comparable to the outer Crane Creek wetlands, especially during critical periods of bird migration. Additional sampling and analysis should help characterize bird behavior over multiple time scales and help tease out how temperature, wind, precipitation, and annual population variability influence bird use of the reconnected wetland.

For shorebirds, species richness and abundance were lower in 2011 than 2010, among all seasons (Figure 21 and Figure 22). No shorebirds were observed in Pool 2A or 2B in 2011, and the number of shorebirds observed in Crane Creek was low in 2011 (Figure 21). The lower richness and abundance is likely attributable to increased water levels throughout the entire study area in 2011. Pool 2B and Crane Creek were subject to higher annual water levels driven by the lake, while Pool 2A water levels were kept higher for management purposes. Without suitable habitat, shorebirds were not attracted to the area. In 2010, the wide expanses of Crane Creek produced a high abundance of shorebirds (1,083 sightings).

Pool 2B had 307 sightings compared to the 25 sightings in Pool 2A. The difference between years shows the importance that lake levels have on the availability of shorebird habitat (e.g., mudflats).

Piscivore species richness and abundance were variable between years and among sites (Figures 23 and 24). During the fall of both years, more piscivorous birds were observed in Crane Creek than either of the pools (Figure 23). This could be expected due to the abundance of fish found in Crane Creek (see fish section) and large areas of exposed mudflats used by many tern species. In Pool 2B, we only saw a large number of piscivorous birds during the summer of 2010, mostly great blue herons and terns (112 sightings). After the opening of the structure in early 2011, the species richness and abundance of piscivores in the reconnected Pool 2B roughly tracked the patterns observed in Crane Creek.

Waterfowl abundance and species richness also had seasonal variations, but fall 2011 migration produced the most birds in Crane Creek, Pool 2B, and in Pool 2A (Figure 25). Waterfowl abundance values in Pool 2B and Pool 2A were similar during all 2010 seasons, but there was a large increase of waterfowl in both pools (783 and 787 sightings, respectively) in fall of 2011. Seasonal species richness of waterfowl in the reconnected Pool 2B followed a pattern similar to Crane Creek (2011), but Crane Creek generally had more waterfowl species than either of the pools (Figure 26).

Continued survey work is necessary to help explain the variation in population dynamics and usage patterns of birds in Crane Creek, Pool 2A, and Pool 2B. The data from these and future surveys will be used to further describe changes associated with hydrologic reconnection of Pool 2B, with full recognition that there can be large seasonal and inter-annual variation in bird abundance and species richness. However, at this time we can say that connection does not appear to have negatively impacted recreationally-important waterfowl species in the first year following the opening of the structure. As expected, piscivorous species seem to have benefited from the addition of the structure due to the increase in fish available in Pool 2B. On the other hand, shorebird use declined in Pool 2B in 2011 due to high water levels, a direct result of the structure and variability in Lake Erie water levels. It is possible that we will see different impacts on bird abundance and/or species richness in the future as habitat (e.g., mudflat, deep water, vegetation) in Pool 2B changes in response to fluctuating water levels. Further data analysis may consist of reorganizing bird species by feeding guilds and comparing data to similar studies in the region.

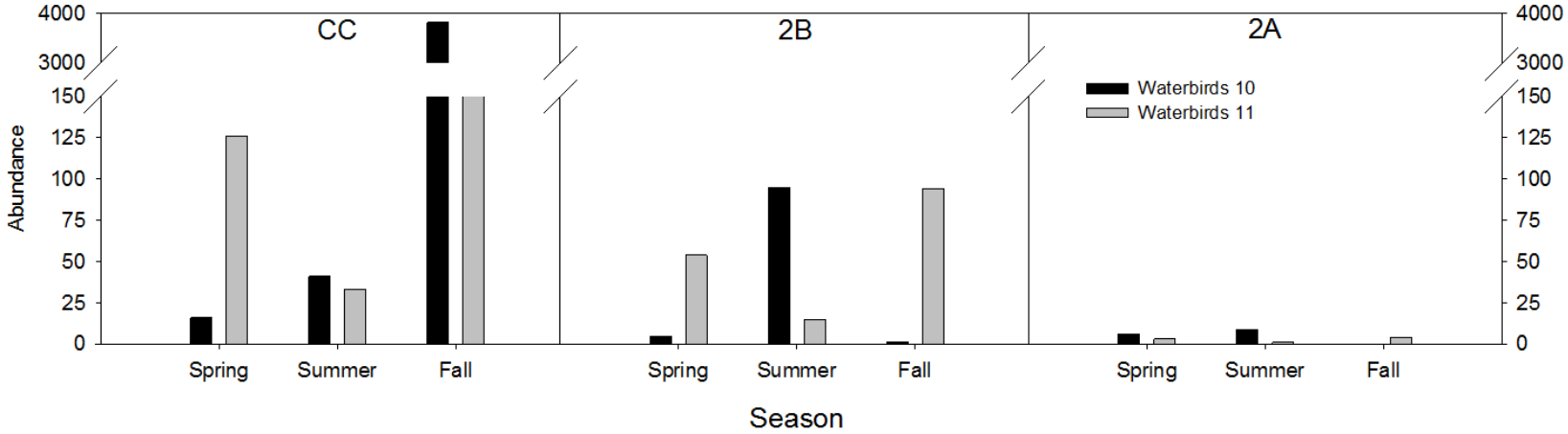

Figure 19: Waterbird abundance by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

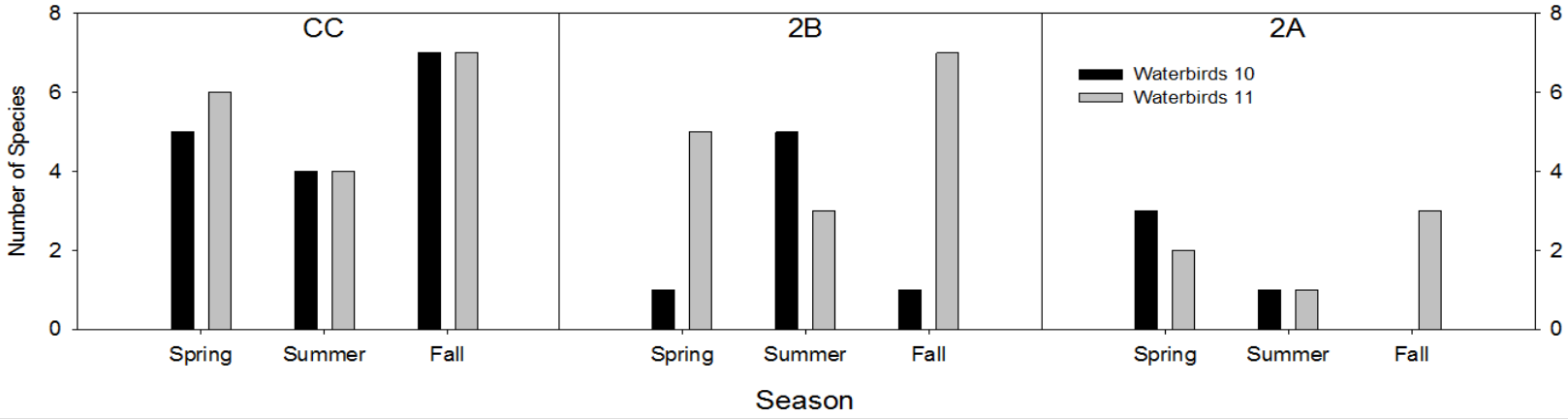

Figure 20: Waterbird species richness by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

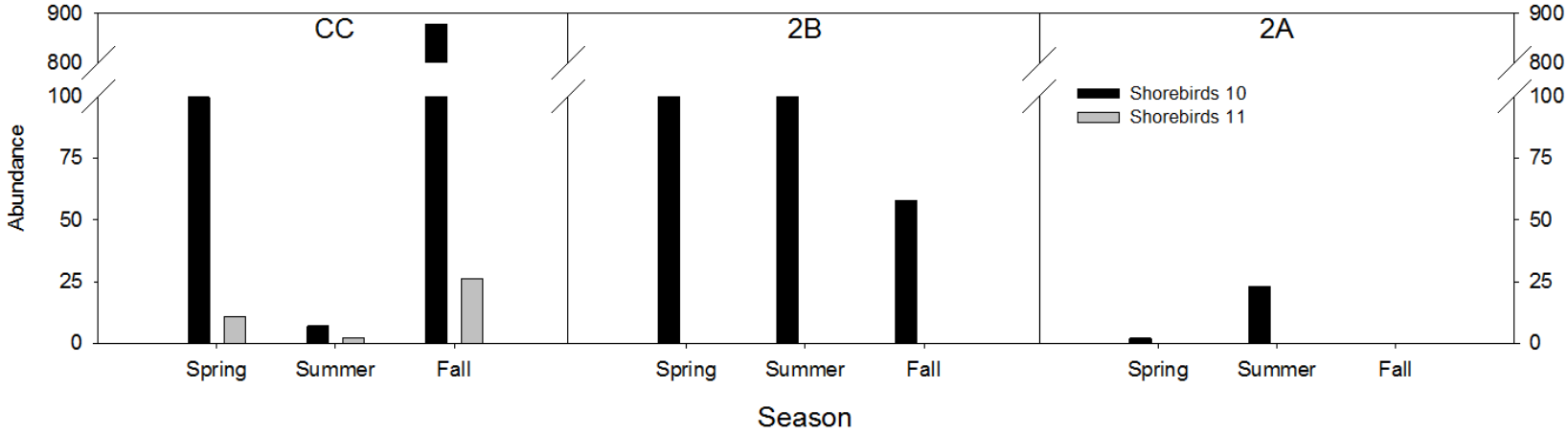

Figure 21: Shorebird abundance by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

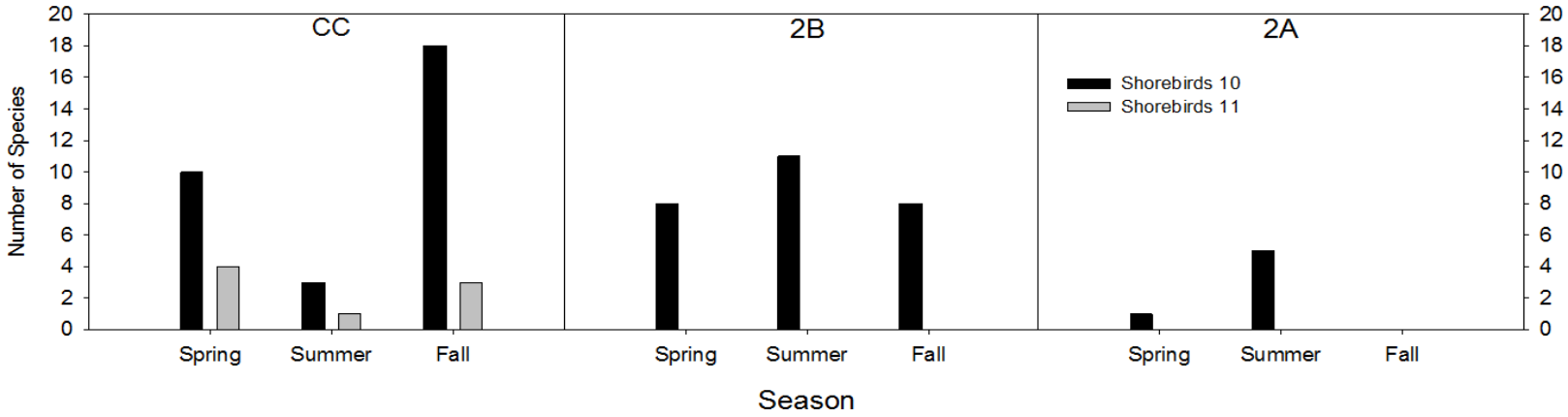

Figure 22: Shorebird species richness by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

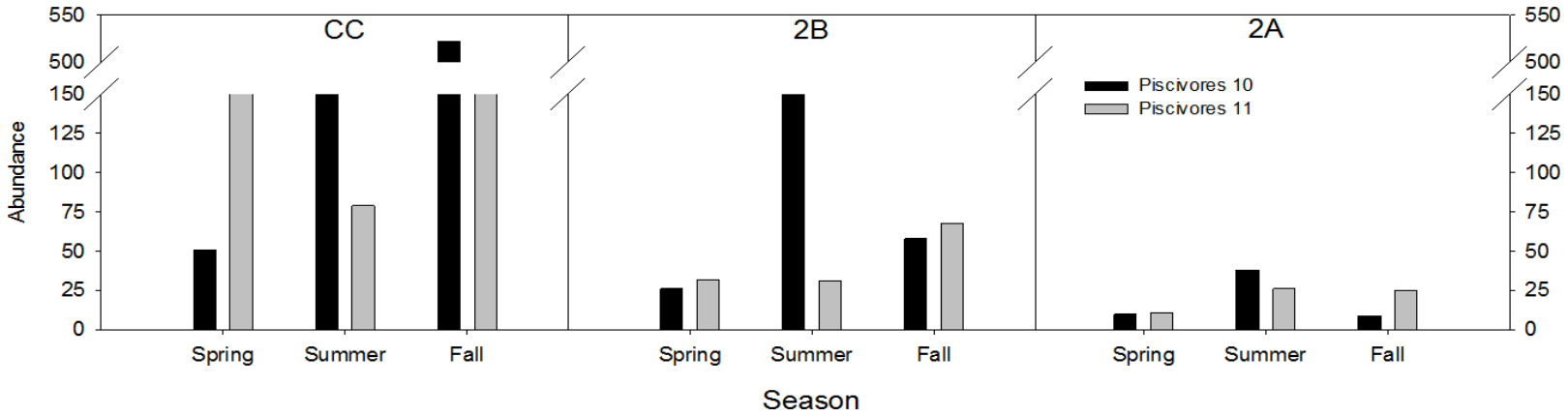

Figure 23: Piscivore abundance by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

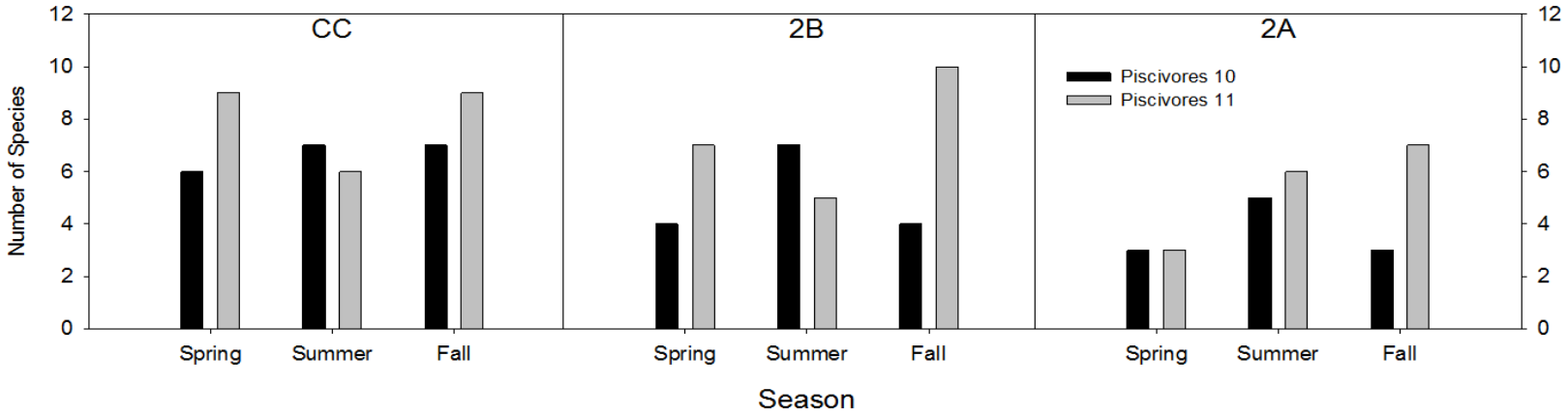

Figure 24: Piscivore species richness by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

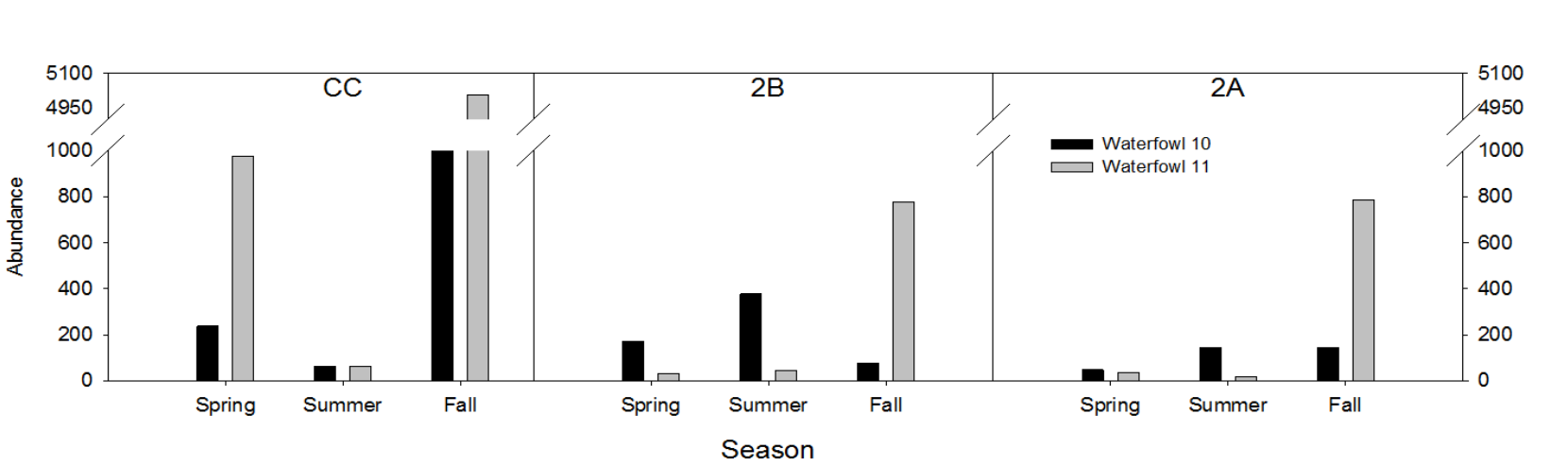

Figure 25: Waterfowl abundance by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

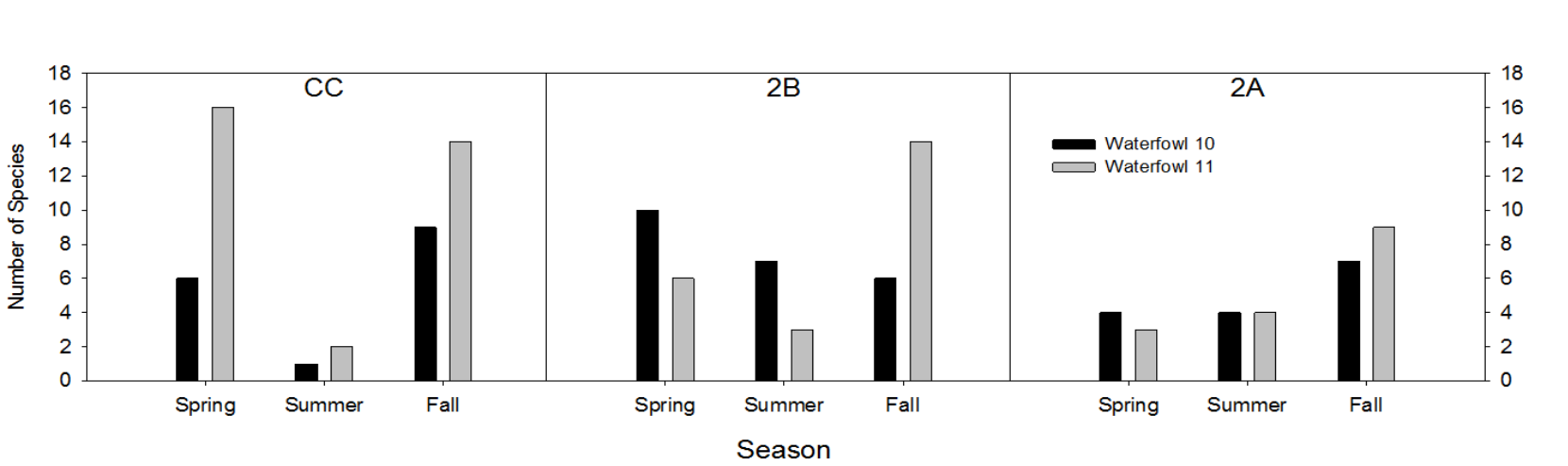

Figure 26: Waterfowl species richness by site and season for 2010 and 2011. Dark bars represent 2010 data, and light bars represent 2011 data.

Vegetative Community

Background

The structure of wetland vegetation communities changes as the underlying hydrology changes. During periods of low water levels, new plants can emerge from the seed bank. These periods when native wetland seedlings can become established are important for maintaining diversity within an area. However, invasive and upland plant species may also establish in wetlands during times of low water. High water levels can flood out these species and promote growth of submerged aquatic vegetation (SAV). Increasing SAV can provide more habitat and food sources for fish and invertebrates, which may increase food sources for a diversity of bird species.

Historically, Pool 2B had been managed as shorebird and waterfowl habitat; water levels within the pool have not reflected those in Crane Creek since the 1970s. With the installment of the reconnecting structure, we hypothesized that the extensive stands of emergent plants would be impacted negatively by the higher water levels and greater water level variations that are driven by the pool's reconnection to Lake Erie.

To quantify the effect of the structure on the vegetative community and to provide information to aid further analyses of other data (e.g., fish assemblages, water quality), we used aerial photographs to create vegetation maps through time. We also quantitatively sampled the species assemblages in the dominant vegetative communities, as indicated by the aerial photographs, to characterize the species composition and dominance within these communities. Taken together, the aerial photographs and quantitative sampling will allow us to examine changes in size and types of vegetative communities and overall species diversity and composition among the sites.

Methods

Data Collection

Aerial photography: Multispectral aerial photographs were collected by the U.S. Fish and Wildlife Service in late August of 2010 and 2011 with a ground resolution of 0.16 meters. Data were rectified by the USFWS and color-corrected to maximize uniformity.

Plant sampling: We used the aerial photos to identify the major vegetation types present in Pool 2A, Pool 2B, and Crane Creek. Within stands of each vegetation type, we haphazardly placed between 10 and 20 quadrats (1 m^2) to measure species richness in August of 2010 and 2011 (Figure 27). The number of quadrats depended on the size and floristic diversity of the stand. Plants within each quadrat were identified to the lowest taxonomic level possible. When identification was not possible in the field, samples were pressed and taken back to the GLSC for expert review. Plants unable to be identified because of maturity or poor condition were not included in our analyses. Nomenclature followed Gleason and Cronquist (2007).

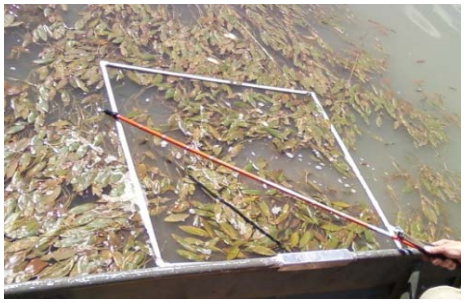

Figure 27: Measuring species richness with a quadrat.

Analysis

Aerial photography: As of January 2012, these images were in the initial stages of analysis. ESRI ArcGIS 10 (ESRI ArcMap; 10.0 Service Pack 2) is being used to delineate the boundaries of major vegetation types in the 3D environment. Labels will be associated with mapped vegetation types and provide the foundation for subsequent analyses of areal changes, spatial distribution, etc. We are planning to use these photos to track changes in dominant vegetation types through time in Pool 2A, Pool 2B, and Crane Creek.

Plant sampling: We calculated species richness and importance values for each dominant vegetation type in each of the three sites. Importance values are a measure of relative frequency and dominance of each taxon in a sampling area. We also calculated the Floristic Quality Assessment Index (FQAI) for each vegetation type within each sample location (Andreas *et al*. 2004). The FQAI was developed to measure the quality of vegetative communities. This is accomplished by assigning every species found in Ohio a coefficient of conservatism (C of C; ranging from 0-10) which represents the ecology of each species and the range (broad or narrow) of environmental characteristics each species requires. Higher C of C values are indicative of plants with narrow ecological tolerances, such as *Myriophyllum sibericum* (Kom.), whereas lower values indicate species with broad tolerances, such as *Sagittaria latifolia* (Willd.). Non-native species have a C of C value of 0. The FQAI value for a site is then calculated by summing the C of C values for all species and dividing by the square root of the total number of species present (Andreas *et al*. 2004).

Results & Discussion

The dominant vegetation types sampled were relatively similar between 2010 and 2011. In 2010, we also sampled areas in Crane Creek that had been managed for *Phragmites* to investigate how management actions such as mowing and spraying of *Phragmites* affected species richness and FQAI scores.

Species richness and FQAI values were generally higher in 2A and 2B than in Crane Creek, even after reconnection. This could reflect the influence of periodic drawdowns associated with management actions since 1973 in the pools. There were no comparably low water levels in Lake Erie during that time period, which would limit seedling establishment in Crane Creek.

As expected, we found decreases in FQAI and species richness in all vegetation types, except SAV, in Pool 2B in 2011. Vegetation in Crane Creek also had lower species richness and FQAI values in 2011. We believe rising lake levels may account for these changes. Higher water levels reduced the surface area of moist soil that supported many of the emergent species we documented in 2B in 2010. In contrast, we saw little overall change in the species richness and FQAI values in Pool 2A, which is likely due to relatively static seasonal and annual water levels in the pool (Figures 28 and 29).

Species richness may also have declined due to clonal spread of many of the dominant species, as opposed to or in concert with the presence of higher water levels in 2011. For example, species richness in the *Polygonum* vegetation type was reduced by 69%, and we can

see that the importance of two aggressively spreading clonal plants *Polygonum amphibum* (L.) and *Nymphaea oderata* (Willd.) increased by 37% and 176%, respectively (Table 4).

The long-term impacts of higher water levels and the increased hydrologic variability and how they relate to the plant communities in Pool 2B are not yet clear. Plant response to water-level fluctuations is often immediate (Wilcox and Nichols 2008), so the relatively minor changes observed in Pool 2B after one growing season are encouraging.

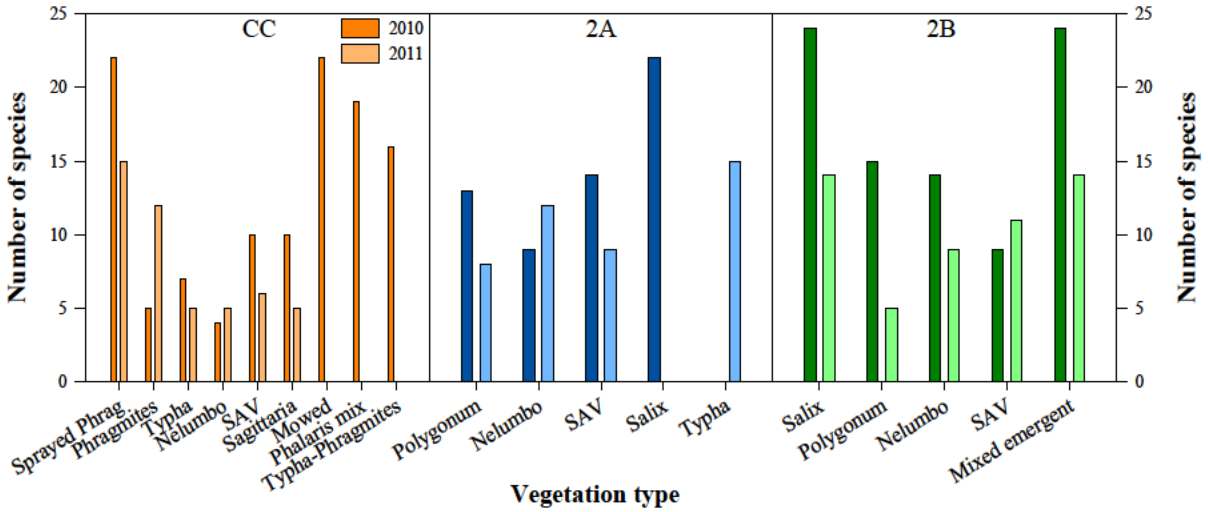

Figure 28: Species richness in 2010 and 2011 by dominant vegetation type and site.

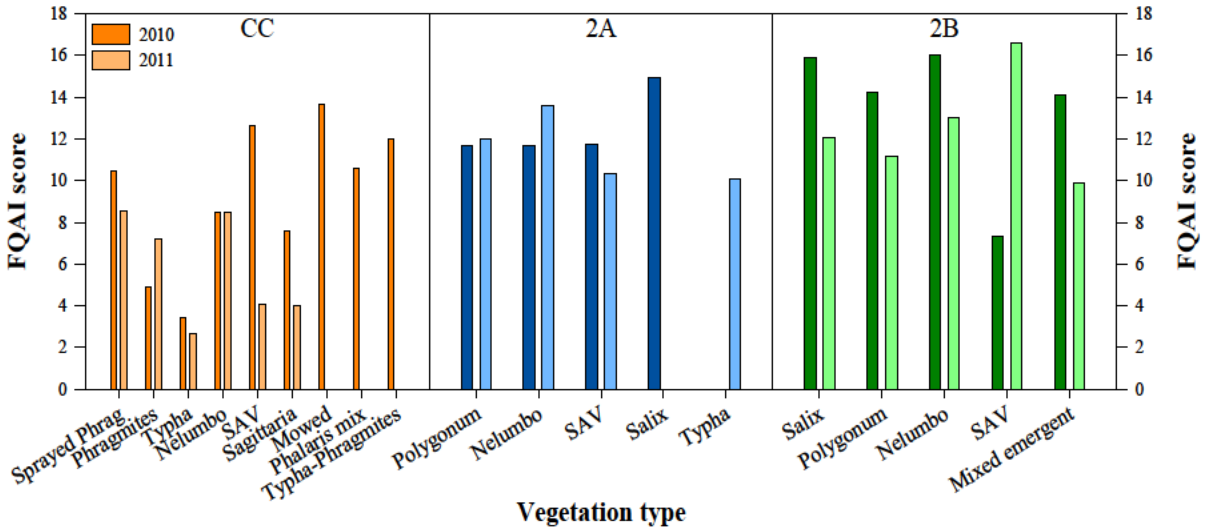

Figure 29: FQAI scores for 2010 and 2011 dominant vegetation types starting from the left: Crane Creek, 2A, and 2B.

Table 4: Importance values for species found in the *Polygonum* vegetation type in Pool 2B in 2010 vs. 2011.

scientific name	common name	C of C	2010	2011
Bidens cernua	nodding beggartick	3	3.71	
Boehmeria cylindrica	smallspike false nettle	4	3.10	
Ceratophyllum demersum	coon's tail	2	13.30	6.15
Eleocharis acicularis	needle spike-rush	5	3.10	
Elodea canadensis	Canadian waterweed	3	15.57	
Lythrum salicaria	purple loosestrife	*	3.10	
Myriophyllum spicatum	Eurasian watermilfoil	*	3.17	
Najas minor	Eurasian water-nymph	*	7.15	
Nelumbo lutea	American lotus	7	3.71	8.59
Nymphaea oderata	American white waterlily	6	11.81	30.50
Polygonum amphibium	water knotweed	4	107.02	142.72
Potamogeton nodosus	long-leaf pondweed	3	7.15	
Ranunculus flabellaris	yellow water-buttercup	8	5.75	
Utricularia vulgaris	common bladderwort	6		12.04
Zosterella dubia	water star-grass	5	3.10	

Note: Unidentified plant specimens in the 2010 data set are not included. However, even without those samples, our results indicate that species richness and FQAI values were higher in 2010 than in 2011. Thus, our results are conservative estimates.

Invertebrate Community

Benthos

Background

In wetlands, invertebrates serve an important role as a food source for fish and waterfowl (French 1988). Zoobenthic communities also play a part in decompositional pathways and the recycling of inorganic nutrients through bioturbation (Matisoff *et al*. 1985). However, little is known about benthic communities within diked wetlands and how reconnecting these wetlands to their coastal counterparts may affect these communities. Benthos in wetlands are influenced by many abiotic (e.g., nutrient and suspended solid concentrations) and biotic (e.g., predation, variation of food sources, and habitat disruption) factors (Krieger and Klarer 1991), many of which change seasonally in wetland systems. Add to these "regular" influences the irregular variability introduced by influxes of creek and lake water and a unique situation arises where the ways in which the benthos responds and adapts to these influences can be studied. The wetland reconnection process provides an opportunity to learn more about how these changes impact a resident invertebrate population.

Methods

Sample collection: To understand the responses of a benthic community in a diked wetland to the wetland's reconnection to Crane Creek, Pools 2A and 2B were sampled for benthic invertebrates in 2010 and 2011. In 2010, two replicate sample sites in these pools were chosen to represent each of the three main vegetation types: open water containing submersed aquatic vegetation (SAV), *Polygonum* stands, and mixed emergent vegetation with *Salix* (Appendix 1). Each sampling location was marked with a GPS point. In 2010, samples were taken monthly from June through November, and in 2011 sampling effort was reduced to collections made in April, July, and September. Due to an increase in water levels that occurred after the opening of the fish passage and which flooded the mixed emergent/*Salix* sites, they were not included in the 2011 sampling period. This reduced the number of sample sites to two in Pool 2A and six in Pool 2B.

The substrate was sampled at each location using a standard 15.24 cm x 15.24 cm x 15.24 cm Ekman dredge with a 1.5 m handle. Grab volume of each sample was visually estimated and recorded (% full) and contents were deposited in a tub for characterization of sediment type, color, and odor. The dredge was rinsed into the tub to ensure no sample remained and the sample was elutriated. The contents of the tub were placed in a 500 μm sieve, the tub was rinsed, and the sample was further elutriated. Once consolidated, the sample was then placed into 0.95 L labeled jars, and the preservative 10% buffered formalin was added to achieve a ratio of 1 part formalin to 1 part sample. The sample jar was inverted a couple of times to ensure thorough mixing. Samples were taken to the GLSC for storage.

In addition to the Ekman samples, dip nets (500 μm mesh) were used to collect material from the substrate and plant community surfaces. Two researchers worked within a 5 meter radius of the sample location point for a total of 5 minutes to effectively collect material typifying the invertebrate community in that vegetation type. The net contents were emptied into a 500 μm sieve bucket and rinsed. Similar to the processing seen with the Ekman samples, the

washed sample was placed in a labeled sample jar, mixed with 10% formalin, inverted, and transported to the GLSC for storage.

Sample processing: As of January 2012, only the 8 samples from June of each collection year (Ekman only) had been processed in the lab. Processing began with samples being drained of formalin under a fume hood and thoroughly rinsed with tap water. Each sample was then rinsed through a series of sieves (2000 µm, 1000 µm, and 500 µm) to separate the macroinvertebrates from the microinvertebrates by separating the coarse (≥2000 µm), medium (1000-2000 µm), and fine (500-1000 µm) material collected by the sampling device. The medium and fine material was stored in sample jars with a 10% Carosafe™ solution for future processing. The contents of the coarse sieve were sorted and all organisms were identified to order. Identification and picking accuracy was verified by a second, more experienced picker. Raw data were recorded on paper datasheets in the lab before being recorded into an Excel spreadsheet to be used in future analysis.

Results & Discussion

A preliminary comparison of the June 2010 and June 2011 samples indicated that the groups represented each year were similar (Appendix 6). However, the Amphipoda, Lepidoptera, and Nematoda were not found in 2011. With additional taxonomic training and time spent in the lab, more of the Ekman and dip net samples should be processed in time to yield results for next year's annual report. These benthic macroinvertebrate samples will aid in creating a better understanding of the environmental changes that occurred between 2010 and 2011 in the vegetation types studied. They also will further characterize differences in composition and abundance between a diked wetland and a reconnected wetland.

Zooplankton

Background

Zooplankton communities in Great Lakes wetlands are not as well-understood as their counterparts in the open waters of the Great Lakes. Some studies have looked at coastal wetlands to explore the impact of marsh habitat fragmentation on zooplankton (Gyekis 2006); zooplankton population dynamics (Krieger and Klarer 1991); zooplankton community composition and dynamics in an urban, highly turbid, and eutrophic coastal wetland (Lougheed and Chow-Fraser 1998); and using zooplankton data to create an index of wetland quality (Lougheed and Chow-Fraser 2002). However, we cannot find any documentation describing the impact of reconnecting a diked wetland to one of the Great Lakes and how this action will affect the resident zooplankton.

Methods

Sample collection: Zooplankton in pools 2A and 2B were sampled using a 63 µm mesh plankton net in conjunction with a bilge pump. The bilge pump was outfitted with an extension tube to draw up water from various depths in the water column and a flexible hose to deliver the water into the net. Water was collected from within each vegetation type for three minutes per sample. The pump rate was measured for calibration checks at the beginning, middle, and end of each sampling day. After each sample was collected, the plankton net was rinsed thoroughly from top to bottom using wetland water sprayed against the outside of the net, with tap water in a squirt bottle used for finer rinsing inside the net once

the majority of the sample was collected in the bottom of the net. The concentrated sample was then rinsed into a 0.95 L labeled jar and ¼ tablet of Alka-Seltzer® was added to narcotize the organisms in the sample. Once the tablet had dissolved, buffered formalin was added to each sample at a ratio of 1 part formalin to 1 part sample and thoroughly mixed by inverting the securely closed jar several times. Two samples were collected within each veg type for purposes of replication. All samples were taken to the GLSC for storage.

Sample processing: Laboratory processing of the samples will commence once staff are fully trained in zooplankton identification. At that time, each sample will be subsampled following an established protocol and organisms will be identified to the lowest reasonable taxonomic level and counted.

Results & Discussion

Although zooplankton identification requires a fairly specialized skill set and is time-consuming to do, the zooplankton samples from Pools 2A and 2B should help present some of the changes in microinvertebrate populations in the plant communities both between years and between pools after the fish passage structure was opened. Despite natural variability in their populations, one would expect to find fairly similar microinvertebrate communities in the pools prior to the opening of the structure. However, with the connection of Pool 2B to Crane Creek, some very significant changes in biomass and species composition could occur as a direct result of grazing pressure by planktivorous fishes, as well as from influxes of water from seiche events and the “washing out” of resident organisms following large rain events. Future processing and data analyses will provide a more informed assessment of the zooplankton communities in Pools 2A and 2B for next year’s annual report.

Mussels

Background

Native freshwater unionids (also referred to as mussels) once were common in the Great Lakes (Herdendorf 1987). Populations have declined precipitously, however, since the introduction of zebra and quagga mussels (i.e., dreissenids) in the 1980s led to intense competition for food (Strayer and Smith 1996). To compound matters, the invasive dreissenids will attach to mussel shells, oftentimes making it impossible for the native mussels to open their shells to feed or move.

While few native mussel beds remain in Lake Erie proper (Gillis and Mackie 1994, Schloesser *et al*. 1996), a diverse mussel community was present in Crane Creek that included mapleleaf (*Quadrula quadrula* Rafinesque, 1820), fragile papershell (*Leptodea fragilis* Rafinesque, 1820), threeridge (*Amblema plicata* Say, 1817), and giant floater (*Pyganodon grandis* Say, 1829; Bowers and de Szalay 2004, Bowers and de Szalay 2007). While non-native mussels have been found on hard substrates within the Crane Creek wetland complex, we have found comparatively low colonization directly on mussels within this community, likely due to the prevalence of soft sediments (Nichols and Wilcox 1997). Another control on non-native mussel populations could be predation by large, molluscivorous fishes such as common carp, freshwater drum, and channel catfish, which are abundant in these wetlands (Bowers and de Szalay 2007). Furthermore, abiotic conditions at the site (e.g., sediment type, water temperature) might limit zebra and quagga mussel productivity (U.S. Geological Survey 1999).

Few mussel communities, like the one documented in Crane Creek, still exist in the Great Lakes (Zanatta *et al*. 2002). Studying the impacts of reconnection is necessary to gain an understanding of how this action will affect mussel populations in Pool 2B.

Methods

Sample collection: A pair of researchers used self-contained underwater breathing apparatus (SCUBA) gear to perform mussel surveys in Pool 2B in the fall of 2011. This was a follow-up survey to the one conducted in 2010, prior to the opening of the fish passage structure. The methods for each survey were very similar, except that the higher water levels in 2011 created more area to be surveyed.

Because mussels tend to form clumped distributions, suitable habitat was identified while in the field and then random samples were collected within that suitable habitat. This practice reduced sampling bias while increasing the likelihood of locating mussels. A 1 m^2 quadrat was placed at the survey location, GPS was used to mark each location, and the area within the quadrat was searched for mussels. To ensure that buried mussels were not overlooked, we dug through the substrate until the hard-pan clay layer or a depth of ~20 cm was reached. Captured individuals were placed in mesh bags that were labeled with the quadrat number. At the conclusion of each quadrat survey, all mussels were identified, measured for length, and placed back in the area from which they were removed. We also noted the presence of dreissenids attached to the mussels. One-hundred quadrats were sampled over the course of four days.

Figure 30: Presence/absence results from the fall 2011 clam survey.

Results and Discussion

We found approximately two dozen members of one species of clam, *Pyganodon grandis*, in Pool 2B during the 2011 survey (Figure 30). This is a very fast-growing clam that has been found in the surrounding Crane Creek wetland complex. It also was found during the 2010 survey, along with eastern floater (*Pyganodon cataracta* Say, 1817). Due to the low water conditions in 2010, most of the clams in Pool 2B died as a result of dewatering or predation from being exposed.

With the connection between Pool 2B and Crane Creek, there is now potential for re-introduction of other mussel species from established Crane Creek populations as fish transport glochidia (i.e., temporarily parasitic microscopic larvae of mussels) on their gills. The glochidia settle out and begin to grow in new areas. Although mussels have a very slow growth rate, we anticipate that they will become large enough to detect during SCUBA surveys over the next few years.

However, just as the structure allows for re-introduction of mussels, it also provides a pathway for dreissenids to colonize Pool 2B. It was noted that most of the clams encountered during the 2011 survey had dreissenids attached to their shells. These were not found in the 2010 survey.

Future Research

The sampling and analysis strategies detailed earlier in this report will continue with GLRI support through 2012 and into 2013. As funding in 2013 and beyond allows, USGS intends to adjust research efforts as needed to support new priorities identified by our partner agencies (e.g., USEPA, Ohio EPA, USFWS, TNC, GLC). Our goal will be to maintain the value of the comprehensive data sets we develop in response to growing needs in new areas.

We will continue to develop relationships with leaders and decision makers in the Areas of Concern (AOC) containing existing and potential coastal wetland habitat restoration projects (e.g., Maumee River, Saginaw River/Bay). For example, engaging the Ohio EPA Remedial Action Plan Coordinator and leadership of Partners for Clean Streams (Maumee River Remedial Action Plan Advisory Committee) in discussions about the restoration efforts at Crane Creek will continue to broaden the impact of our research. Efforts to relate our multi-year data set to the delisting of several beneficial use impairments (e.g., degraded fish and wildlife habitat, eutrophication or undesirable algae) will continue in the Maumee River AOC and be expanded to assist in the delisting of impairments identified in the Saginaw River/Bay AOC at Shiawassee National Wildlife Refuge. This work will support the management and restoration priorities of multiple agencies (e.g., USFWS, TNC, Healing Our Waters, USEPA) and lead to a broader landscape-level understanding of ecosystem restoration efforts in the Great Lakes.

Although not the primary focus of our research, we plan to enhance our sampling and analysis of water chemistry data to understand the retention of phosphorus and other nutrients in hydrologically reconnected wetlands. Our encouraging results so far and the implications that they may have for water quality improvements in AOCs and on the landscape as a whole are leading us in exciting new directions. In addition, we continue to evaluate how our intense sampling can be used to develop a less-intense sustainable monitoring strategy that can be implemented long term with the limited resources that research and management agencies normally have. Long-term monitoring can be valuable to evaluate ecosystem condition and management status at both a site specific scale (e.g., Crane Creek) and a landscape scale (e.g., western basin of Lake Erie), but refined guidance on what that monitoring would look like is needed.

Regular communication of project results with partner agencies (e.g., USFWS, NOAA, TNC, Ducks Unlimited) has led to implementation of this approach in many coastal wetland restoration projects in western Lake Erie and the Shiawassee Flats region of Michigan. We are using this unique opportunity provided by GLRI to monitor intensely the ecosystem response to hydrologic reconnection and then share that information with managers so this approach may be considered in other areas. We will continue to develop collaborations and expand the scope of our work regionally to help broaden our understanding of coastal wetland ecosystems to the landscape level, support a coordinated approach among resource managers, and provide a regional foundation for resource management and restoration decisions.

Finally, our work will continue to explore the impacts of exotic and invasive species on the restoration of ecological functions and how restoration projects involving integrated pest management based invasive species control increases ecosystem resiliency against invasion. For example, the exclusion of mature carp from the reconnected wetland during the spawning season has shown promising results so far. We also will monitor the establishment of *Phragmites australis*, *Butomus umbellatus*, and other invasive plant species in the reconnected wetland and coordinate with other GLRI-funded projects exploring novel strategies for sustainable control.

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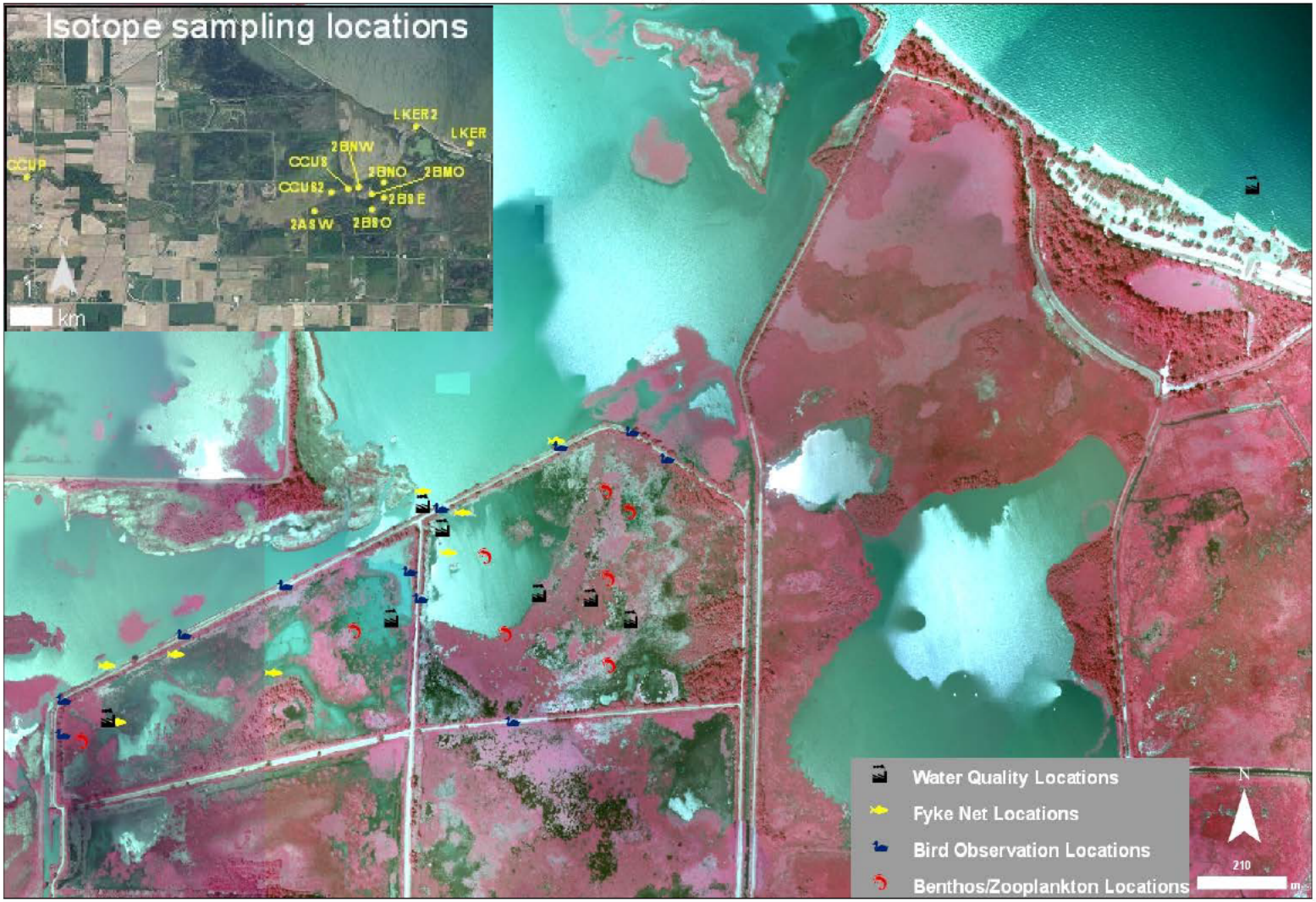
Appendix 1: Map of sampling locations.

2011 ONWR Sampling Locations



Appendix 2: National Water Quality Laboratory (NWQL) Process and Analysis Standard Operating Procedures

Dissolved Organic Carbon: OFR 92-480. Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved organic carbon by uv=promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92-480, 12 p. Method ID: O-1122-92.

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Appendix 3: Fish

Appendix 3.1: Fish species list from Pool 2A, 2B, and Crane Creek in 2010 and 2011. Fish nomenclature follows Trautman (1981).

Fish			Presence/Absence - B = both years, 10 = found only in 2010 , 11 = found only in 2011									Total
			CC			2A			2B			
Family	**Scientific Name**	**Common Name**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**Count**
Amiidae	*Amia calva*	bowfin	B	B	B	B	B	B	B	10	B	**404**
Atherinopsidae	*Labidesthes sicculus*	brook silverside	B	B		B			B			**126**
Catostomidae	*Catostomus commersonii*	white sucker	B	B	B				B		B	**29**
	Hypentelium nigricans	northern hogsucker	B									**1**
	Ictiobus bubalus	smallmouth buffalo			B				B			**2**
	Ictiobus cyprinellus	bigmouth buffalo	B	B	B							**17**
	Moxostoma macrolepidotum	shorthead redhorse			B							**2**
	Minytrema melanops	spotted sucker	B		B				B		B	**14**
		unidentified catostomid	B									**2**
	Carpiodes cyprinus	quillback	B		B							**69**
Centrarchidae	*Ambloplites rupestris*	rock bass	B	B	B				11	10		**7**
	L. cyanellus x L. gibbosus	green sunfish/pseed hybrid	11			B	10	B	10			**12**
	L. cyanellus x L. machrochirus	green sunfish/bluegill hybrid				10	10	11		10		**1**
	Lepomis cyanellus	green sunfish	B	B	B	B	B	B	B	10	11	**2647**
	Lepomis gibbosus	pumpkinseed	B	B	B	B	B	B	B	B	11	**396**
	Lepomis humilis	orange-spotted sunfish	B	B	B	B		B	B	B	11	**746**
	Lepomis machrochirus	bluegill	B	B	B	B	B	B	B		B	**2724**
	Lepomis x spp	sunfish hybrid	10			11						**3**
	L. machrochirus x L. gibbosus	bluegill/pseed hybrid				B		B				**6**
	Lepomis sp.	unidentified sunfish							B	10		**1**
	Micropterus dolomieu	smallmouth bass	B	B	11			11	11	10	11	**21**

Appendix 3.1 cont.

Fish			Presence/Absence - B = both years, 10 = found only in 2010 , 11 = found only in 2011									Total
			CC			2A			2B			
Family	**Scientific Name**	**Common Name**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**Count**
	Micropterus salmoides	largemouth bass	B	B	B	B	B	B	B	B	B	**1612**
	Pomoxis annularis	white crappie	B	B	B	11		B	B		B	**1092**
Centrarchidae	*Pomoxis nigromaculatus*	black crappie	B	B	B	B		B	11	11	11	**1410**
		unidentified centrarchid	B	B	B	B		B	11	10	11	**2206**
Clupeidae	*Dorosoma cepidianum*	gizzard shad	B	B	B				11	11	11	**45431**
Cyprinidae	*Carassius auratus*	goldfish	B	B	B	B	B	B	B	10	B	**573**
	Cyprinus carpio	common carp	B	B	B	B	B	B	B	B	B	**483**
	C. auratus x C. carpio	goldfish x carp hybrid	B									**1**
	Luxilus cornutus	common shiner	B									**4**
	Notemigonus crysoleucas	golden shiner	B		11				11		11	**19**
	Notropis atherinoides	emerald shiner	B	B	11				B	11	11	**172540**
	Notropis heterolepis	blacknose shiner	10		10							
	Notropis volucellus	mimic shiner	B	B					B			**40**
	Notropis hudsonius	spottail shiner	B	B	11				11	11	11	**1522**
	Notropis spiloptera	spotfin shiner	B	B	11				11			**11**
	Notropis stramineus	sand shiner	B	B					11			**54**
	Notropis sp.	unidentified cyprinid	B	B								**266**
	Pimephales notatus	bluntnose minnow	B	B					11	11	11	**149**
	Pimephales promelas	fathead minnow	B	11						11		**16**
	Pimephales sp.	unidentified minnow		B					B			**7**
	Semotilus atromaculatus	creek chub							B			**1**
Cyprinodontidae		banded killifish	10		10							
Esocidae	*Esox lucius*	northern pike	11		11				B	10	B	**83**
Gasterosteidae	*Gasterosteus aculeatus*	threespine stickleback	B									**1**
Gobiidae	*Neogobius melanostomus*	round goby	B	B					11		11	**27**

Appendix 3.1 cont.

Fish			Presence/Absence - B = both years, 10 = found only in 2010 , 11 = found only in 2011									Total
			CC			2A			2B			
Family	**Scientific Name**	**Common Name**	**2**	**3**	**4**	**2**	**3**	**4**	**2**	**3**	**4**	**Count**
Ictaluridae	*Ictalurus melas*	black bullhead	B	B	B	B	B	B	B		B	**5545**
	Ictalurus natalis	yellow bullhead	B	B	B	B	B	B	B	10	B	**343**
	Ictalurus nebulosus	brown bullhead	B	B	B	B	B	B	B		B	**425**
	Ictalurus sp.	bullhead		B					B			**3**
	Ictalurus punctatus	channel catfish	B	B	B				11		B	**421**
	Noturus gyrinus	tadpole madtom	B	B	11	B	B	B	B	B	11	**811**
	Ictalurus sp.	unidentified ictalurid	B									**2**
Lepisosteidae	*Lepisosteus oculatus*	spotted gar	B									**2**
	Lepisosteus osseus	longnose gar	B	B	B				11		11	**132**
Moronidae	*Morone americanus*	white perch	B	B	B				11		11	**306**
	Morone chrysops	white bass	B	B	B				11		11	**359**
	Morone sp.	unidentified Morone	B	B					11			**2526**
Percidae	*Percina caprodes*	logperch	B	11					11			**203**
	Perca flavescens	yellow perch	B	B	B	10			B		11	**46**
	Percina sp.	unidentified percid	B									**1**
Percopsidae	*Percopsis omiscomaycus*	trout-perch	B	B							B	**7**
Petromyzontidae	*Ichthyomyzon unicuspis*	silver lamprey	B	B	B						B	**6**
Salmonidae	*Oncorhynchus mykiss*	rainbow trout									B	**1**
Sciaenidae	*Aplodinotus grunniens*	freshwater drum	B	B	B				11			**120**
Umbridae	*Umbra limi*	central mudminnow	B	B	11	B			B	B	11	**169**

Appendix 4: Birds

Appendix 4.1: Waterfowl species found in 2010 and 2011

Scientific name	Common name	2010	2011
Aix sponsa (L)	wood duck	X	X
Anas acuta (L)	northern pintail	X	X
Anas americana (Gmelin)	American wigeon	X	X
Anas clypeata (L)	northern shoveler	X	X
Anas crecca (L)	green-winged teal	X	X
Anas discors (L)	blue-winged teal	X	X
Anas platyrhynchos (L)	mallard	X	X
Anas rubripes (Brewster)	American black duck	X	X
Anas strepera (L)	gadwall	X	X
Aythya affinis (Eyton)	lesser scaup		X
Aythya americana (Eyton)	redhead		X
Aythya collaris (Donovan)	ring-necked duck		X
Branta canadensis (L)	Canada goose	X	X
Bucephala albeola (L)	bufflehead		X
Fulica americana (Gmelin)	American coot	X	X
Lophodytes cucullatus (L)	hooded merganser		X
Mergus merganser (L)	common merganser	X	X
Mergus serrator (L)	red-breasted merganser		X
Oxyura jamaicensis (Gmelin)	ruddy duck	X	X
Podiceps auritus (L)	horned grebe		X
Podilymbus podiceps (L)	pied-billed grebe	X	X

Appendix 4.2: Piscivorous species found in 2010 and 2011

Scientific name	Common name	2010	2011
Ardea alba (L)	great egret	X	X
Ardea herodias (L)	great blue heron	X	X
Butorides virescens (L)	green heron	X	X
Egretta thula (Molina)	snowy egret[1]	X	X
Haliaeetus leucocephalus (L)	bald eagle	X	X

Hydroprogne caspia (Pallas)	Caspian tern	X	
Ixobrychus exilis (Gmelin)	least bittern[2]	X	
Lophodytes cucullatus (L)	hooded merganser		X
Megaceryle alcyon (L)	belted kingfisher		X
Mergus merganser (L)	common merganser	X	X
Mergus serrator (L)	red-breasted merganser		X
Nycticorax nycticorax (L)	black-crowned night heron[2]		X
Phalacrocorax auritus (Lesson)	double-crested cormorant	X	X
Podiceps auritus (L)	horned grebe		X
Podilymbus podiceps (L)	pied-billed grebe	X	X
Sterna forsteri (Nuttall)	Forster's tern	X	X
Sterna hirundo (L)	common tern[1]	X	X
Tringa melanoleuca (Gmelin)	greater yellowlegs	X	X

[1]Endangered species in Ohio, [2] Threatened species in Ohio

Appendix 4.3: Shorebird species found in 2010 and 2011

Scientific name	Common name	2010	2011
Actitis macularius (L)	spotted sandpiper	X	X
Calidris alba (Pallas)	sanderling	X	
Calidris alpina (L)	dunlin	X	X
Calidris bairdii (Coues)	Baird's sandpiper	X	
Calidris canutus (L)	red knot	X	
Calidris himantopus (Bonaparte)	stilt sandpiper	X	
Calidris melanotos (Vieillot)	pectoral sandpiper	X	
Calidris minutilla (Vieillot)	least sandpiper	X	
Calidris pusilla (L)	semipalmated sandpiper	X	
Charadrius semipalmatus (Bonaparte)	semipalmated plover	X	
Charadrius vociferous (L)	killdeer	X	X
Gallinago delicata (Ord)	Wilson's snipe	X	
Limnodromus griseus (Gmelin)	short-billed dowitcher	X	
Limnodromus scolopaceus (Say)	long-billed dowitcher	X	
Limosa fedoa (L)	marbled godwit	X	
Limosa haemastica (L)	hudsonian godwit	X	
Phalaropus lobatus (L)	red-necked phalarope	X	

Phalaropus tricolor (Vieillot)	Wilson's phalarope	X	
Pluvialis squatarola (L)	black-bellied plover	X	
Tringa flavipes (Gmelin)	lesser yellowlegs	X	X
Tringa melanoleuca (Gmelin)	greater yellowlegs	X	X
Tringa solitaria (Wilson)	solitary sandpiper	X	

Appendix 4.4: Waterbird species found in 2010 and 2011

Scientific name	Common name	2010	2011
Chroicocephalus philadelphia (Ord.)	Bonaparte's gull	X	X
Cygnus buccinator (Richardson)	trumpeter swan[1]	X	X
Cygnus columbianus (Ord)	tundra swan		X
Cygnus olor (Gmelin)	mute swan		X
Hydroprogne caspia (Pallas)	Caspian tern	X	
Larus argentatus (Pontoppidan)	herring gull	X	X
Larus delawarensis (Ord)	ring-billed gull	X	X
Phalacrocorax auritus (Lesson)	double-crested cormorant	X	X
Sterna forsteri (Nuttall)	Forster's tern	X	X
Sterna hirundo (L)	common tern[1]	X	X

[1]Endangered species in Ohio

Appendix 4.5: All avian species found in 2010 and 2011

Scientific name	Common name	201	2011
Actitis macularius (L)	spotted sandpiper	X	X
Agelaius phoeniceus (L)	red-winged blackbird	X	X
Aix sponsa (L)	wood duck	X	X
Anas acuta (L)	northern pintail	X	X
Anas americana (Gmelin)	American wigeon	X	X
Anas clypeata (L)	northern shoveler	X	X
Anas crecca (L)	green-winged teal	X	X
Anas discors (L)	blue-winged teal	X	X
Anas platyrhynchos (L)	mallard	X	X
Anas rubripes (Brewster)	American black duck	X	X

A4: Birds

Scientific name	Common name	201	2011
Anas strepera (L)	gadwall	X	X
Ardea alba (L)	great egret	X	X
Ardea herodias (L)	great blue heron	X	X
Aythya affinis (Eyton)	lesser scaup		X
Aythya americana (Eyton)	redhead		X
Aythya collaris (Donovan)	ring-necked duck		X
Branta canadensis (L)	Canada goose	X	X
Bubulcus ibis (L)	cattle egret[1]	X	X
Bucephala albeola (L)	bufflehead		X
Butorides virescens (L)	green heron	X	X
Calidris alba (Pallas)	sanderling	X	
Calidris alpina (L)	dunlin	X	X
Calidris bairdii (Coues)	Baird's sandpiper	X	
Calidris canutus (L)	red knot	X	
Calidris himantopus (Bonaparte)	stilt sandpiper	X	
Calidris melanotos (Vieillot)	pectoral sandpiper	X	
Calidris minutilla (Vieillot)	least sandpiper	X	
Calidris pusilla (L)	semipalmated sandpiper	X	
Charadrius semipalmatus (Bonaparte)	semipalmated plover	X	
Charadrius vociferous (L)	killdeer	X	X
Chroicocephalus philadelphia (Ord.)	Bonaparte's gull	X	X
Cistothorus palustris (Wilson)	marsh wren	X	X
Cygnus buccinator (Richardson)	trumpeter swan[1]	X	X
Cygnus columbianus (Ord)	tundra swan		X
Cygnus olor (Gmelin)	mute swan		X
Egretta thula (Molina)	snowy egret[1]	X	X
Fulica americana (Gmelin)	American coot	X	X
Gallinago delicata (Ord)	Wilson's snipe	X	
Gallinula chloropus (L)	common moorhen		X

A4: Birds

Scientific name	Common name	201	2011
Haliaeetus leucocephalus (L)	bald eagle	X	X
Hydroprogne caspia (Pallas)	Caspian tern	X	
Ixobrychus exilis (Gmelin)	least bittern[2]	X	
Larus argentatus (Pontoppidan)	herring gull	X	X
Larus delawarensis (Ord)	ring-billed gull	X	X
Limnodromus griseus (Gmelin)	short-billed dowitcher	X	
Limnodromus scolopaceus (Say)	long-billed dowitcher	X	
Limosa fedoa (L)	marbled godwit	X	
Limosa haemastica (L)	hudsonian godwit	X	
Lophodytes cucullatus (L)	hooded merganser		X
Megaceryle alcyon (L)	belted kingfisher		X
Mergus merganser (L)	common merganser	X	X
Mergus serrator (L)	red-breasted merganser		X
Nycticorax nycticorax (L)	black-crowned night heron[2]		X
Oxyura jamaicensis (Gmelin)	ruddy duck	X	X
Phalacrocorax auritus (Lesson)	double-crested cormorant	X	X
Phalaropus lobatus (L)	red-necked phalarope	X	
Phalaropus tricolor (Vieillot)	Wilson's phalarope	X	
Pluvialis squatarola (L)	black-bellied plover	X	
Podiceps auritus (L)	horned grebe		X
Podilymbus podiceps (L)	pied-billed grebe	X	X
Porzana Carolina (L)	sora	X	
Quiscalus quiscula (L)	common grackle	X	
Rallus limicola (Vieillot)	Virginia rail	X	
Spizella arborea (Wilson)	American tree sparrow	X	
Sterna forsteri (Nuttall)	Forster's tern	X	X
Sterna hirundo (L)	common tern[1]	X	X
Tringa flavipes (Gmelin)	lesser yellowlegs	X	X
Tringa melanoleuca (Gmelin)	greater yellowlegs	X	X

A4: Birds

Scientific name	Common name	201	2011
Tringa solitaria (Wilson)	solitary sandpiper	X	
Tyrannus tyrannus (L)	Eastern kingbird	X	X
Zenaida macroura (L)	mourning dove	X	

[1]Endangered species in Ohio, [2] Threatened species in Ohio

Appendix 5: Vegetation

Appendix 5.1: Plant species list

Plant species list from 2010 & 2011. C of C values represent the coefficient of conservatism of each species.

Scientific name	Common name	C of C	2A-10	2B-10	CC-10	2A-11	2B-11	CC-11
Abutilon theophrasti (Medik.)	velvetleaf	*					x	x
Alisma trivial (Pursh)	northern water plantain	6			x			x
Ammannia robusta (Heer & Regel)	grand redstem	7	x					
Asclepias incarnata (L.)	swamp milkweed	4	x					
Asclepias syriaca (L.)	common milkweed	1			x			
Azolla caroliniana (Willd.)	Carolina mosquito fern	*				x	x	
Bidens cernua (L.)	nodding beggartick	3		x	x			x
Bidens connata (Muhl.)	purplestem beggarticks	3			x			
Bidens frondosa (L.)	devil's beggartick	2	x	x	x			
Boehmeria cylindrica (L.)	smallspike false nettle	4		x	x			x
Butomus umbellatus (L.)	flowering rush	*	x		x	x	x	x
Carex lacustris (Willd.)	hairy sedge	5					x	
Ceratophyllum demersum (L.)	coon's tail	2	x	x	x	x	x	x
Cicuta bulbifera (L.)	bulbiliferous water hemlock	3			x		x	
Cirsium arvense (L.)	Canada thistle	*			x			
Convolvulus arvensis (L.)	field-bindweed	*		x	x			
Cyperus diandrus (Torr.)	umbrella flatsedge	7		x				
Cyperus erythrorhizos (Muhl.)	redroot flatsedge	4			x			
Cyperus odoratus (L.)	fragrant flatsedge	4						x
Cyperus strigosus (L.)	false nutsedge	1		x	x			
Echinochloa crus-galli (L., P. Beauv)	barnyard grass	*	x		x			
Echinochloa walteri (Pursh)	rough barnyard grass	6	x	x				
Eleocharis acicularis (L., Roem & Shult.)	needle spike-rush	5	x	x				

Appendix 5.1 cont.

Scientific name	Common name	C of C	2A-10	2B-10	CC-10	2A-11	2B-11	CC-11
Eleocharis palustris (L.) Roem. & Schult.	red-footed spike-rush	4	x	x	x			
Eleocharis ovata (Roth) Roem. & Schult.	blunt spike-rush	9		x				
Elodea canadensis (Michx.)	common waterweed	3	x	x		x	x	
Epilobium coloratum (Biehler)	Eastern willow-herb	1			x			
Euthamia graminifolia (L.) Nutt.	flat-topped goldenrod	2	x					
Fraxinus nigra (Marshall)	black ash	6		x				
Zostrella dubia (Jacq.)	grassleaf mudplantain	5			x	x	x	
Hibiscus moscheutos (L.)	rosemallow	4	x	x	x			x
Hordeum jubatum (L.)	foxtail-tail barley	*			x			
Impatiens capensis (Meerb)	spotted touch-me-not	2		x	x			
Juncus nodosus (L.)	knotted rush	5			x			
Lactuca serriola (L.)	prickly lettuce	*			x			
Leersia oryzoides (L.) Sw.	rice cut-grass	1		x	x		x	x
Lemna minor (L.)	lesser duckweed	3			x			x
Lemna trisulca (L.)	star duckweed	6		x			x	
Lindernia dubia (L.) Pennell	false pimpernel	2	x	x				
Ludwigia palustris (L.) Elliott	common water-purslane	3	x		x			
Lycopus americanus (Muhl.)	American horehound	3						x
Lycopus uniflorus (Michx.)	northern water-horehound	3	x	x	x			x
Lythrum salicaria (L.)	purple loosestrife	*	x	x			x	x
Mentha arvensis (L.)	field mint	2			x			
Mimulus ringens (L.)	Allegheny monkey-flower	4	x		x			
Mitella nuda (L.)	naked mitrewort	??	x					
Myriophyllum sibericum (Kom.)	common watermilfoil	9				x	x	
Myriophyllum spicatum (L.)	European watermilfoil	*	x	x	x	x		x
Najas flexilis (Willd.) Rostk.& W. L. E. Schmidt	Northern water-nymph	5				x	x	

Appendix 5.1 cont.

Scientific name	Common name	C of C	2A-10	2B-10	CC-10	2A-11	2B-11	CC-11
Najas marina (L.)	alkaline water-nymph	8				x	x	
Najas minor (All.)	Eurasian water-nymph	*	x	x				
Nelumbo lutea (Willd.)	American lotus-lily	7	x	x	x	x	x	x
Nymphaea odorata (Aiton)	American white waterlily	6	x	x	x	x	x	x
Onoclea sensibilis (L.)	sensitive fern	2			x			
Penthorum sedoides (L.)	ditch-stonecrop	2	x	x	x			
Phalaris arundinacea (L.)	reed canary grass	0	x	x	x		x	x
Phragmites australis (Cav.) Trin. Ex Steud.	common reed	0	x	x	x	x		x
Polygonum amphibium (L.)	water smartweed	4	x	x	x	x	x	
Polygonum lapathifolium (L.)	dock-leaved smartweed	1			x			
Polygonum pensylvanicum (L.)	Pennsylvania smartweed	0		x	x			
Polygonum punctatum (Elliott)	dotted smartweed	6		x	x			
Populus deltoides (Marshal)	cottonwood	3	x					
Potamogeton crispus (L.)	curly pondweed	*						x
Potamogeton foliosus (Raf.)	leafy pondweed	2	x		x			
Potamogeton nodosus (Poir.)	long-leaf pondweed	3	x	x	x	x	x	x
Potamogeton richardsonii (A. Benn.) Rydb.	Richardson's pondweed	10			x			
Potamogeton zosteriformis (Fernald)	flat-stem pondweed	8	x					
Ranunculus flabellaris (Raf.)	yellow water-crowfoot	8	x	x				
Ranunculus longirostris (Godr.)	white water-crowfoot	5					x	
Rorippa palustris (L.) Besser	common yellow cress	2			x			
Sagittaria latifolia (Willd.)	common arrowhead	1	x	x	x	x		x
Salix cordata (Michx.)	Dune willow	??	x	x				
Salix exigua (Nutt.)	sandbar willow	1	x	x	x			
Salix fragilis (L.)	crack willow	*				x	x	

Appendix 5.1 cont.

Scientific name	Common name	C of C	2A -10	2B-10	CC -10	2A-11	2B-11	CC-11
Saururus cernuus (L.)	lizard's-tail	8			x			
Scirpus fluviatilis (Torr.) A. Gray	river bulrush	5		x	x			x
Scirpus validus (Vahl)	softstem bulrush	2			x	x		x
Scutellaria galericulata (L.)	marsh skullcap	6		x	x			
Scutellaria lateriflora (L.)	mad-dog skullcap	3		x				
Sium suave (Walter)	water-parsnip	6			x			
Solanum dulcamara (L.)	bittersweet	*		x				
Sonchus arvensis (L.)	perennial sow-thistle	*		x	x			
Sparganium eurycarpum (Engelm.)	giant bur-reed	4					x	x
Spirodela polyrhiza (L.) Schleid.	common duckmeat	5		x	x	x	x	
Potamogeton pectinatus (L.)	sago pondweed	2	x	x	x	x	x	x
Typha angustifolia (L.)	narrow-leafed cattail	*		x	x	x	x	x
Typha latifolia (L.)	common cattail	1		x				
Typha x glauca (Godr.)	hybrid cattail	*				x		
Utricularia vulgaris (L.)	common bladderwort	6				x	x	
Vallisneria americana (Michx.)	American eelgrass	8			x		x	
Verbena hastata (L.)	common vervain	4	x					
Vitis riparia (Michx.)	riverbank grape	3		x	x		x	
Zosterella dubia (Jacq.)	water star-grass	5		x				
Species richness			36	46	56	22	28	26

Appendix 5.2: Plant species found only in 2010

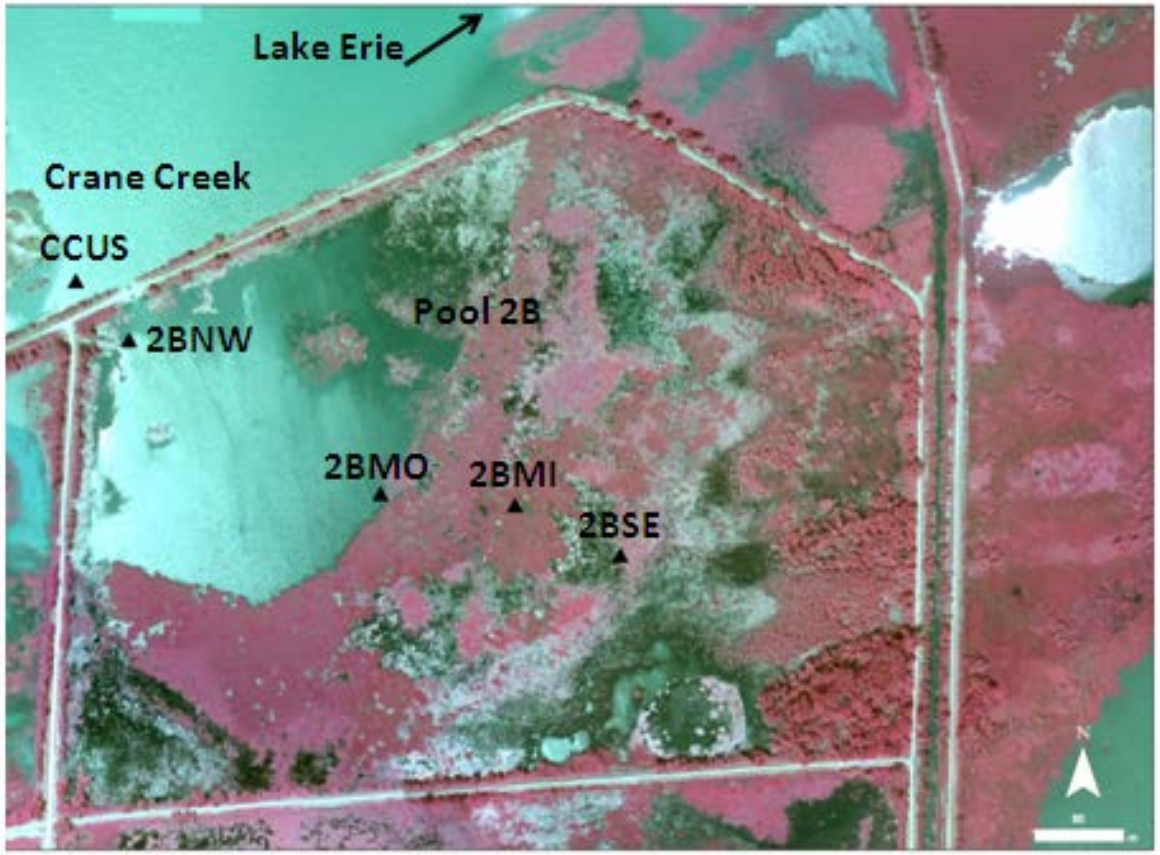
Scientific name	Common name	Scientific name	Common name
Asclepias incarnata (L.)	swamp milkweed	*Mimulus ringens* (L.)	Allegheny monkey-flower
Asclepias syriaca (L.)	common milkweed	*Najas minor* (L.)	Eurasian water-nymph
Ammannia robusta (Heer & Regel)	grand redstem	*Mitella nuda* (L.)	naked miterwort
Bidens connata (L.)	purplestem beggarticks	*Penthorum sedoides* (L.)	ditch-stonecrop
Bidens frondosa (L.)	devil's beggartick	*Panicum flexile* (Gatt.) Scribn.	wiry witch-grass
Cirsium arvense (L.)	Canada thistle	*Polygonum lapathifolium* (L.)	dock-leaved smartweed
Convolvulus arvensis (L.)	field-bindweed	*Polygonum pensylvanicum* (L.)	pinkweed
Cyperus diandrus (Torr.)	umbrella flatsedge	*Polygonum punctatum* (Elliott)	dotted smartweed
Cyperus erythrorhizos (Muhl.)	redroot flatsedge	*Populus deltoides* (Marshal)	eastern cottonwood
Cyperus strigosus (L.)	strawcolored flatsedge	*Potamogeton foliosus* (Raf.)	leafy pondweed
Echinochloa crusgalli (L.) P. Beauv	barnyard grass	*Potamogeton richardsonii* (A.Benn.)	Richardson's pondweed
Echinochloa walteri (Push)	rough barnyard grass	*Potamogeton zosteriformis* (Fernald)	flat-stemmed pondweed
Eleocharis acicularis (L.) Roem & Schult.	needle spike-rush	*Ranunculus flabellaris* (Raf.)	yellow water-buttercup
Eleocharis erythropoda (L.)	red-footed spike-rush	*Rorippa palustris* (L.) Besser	yellow cress
Eleocharis ovata (Roth) Toem. & Schult.	ovate spike-rush	*Salix cordata* (Michx.)	heartleaf willow
Euthamia graminifolia (L.)Nutt.	flat-topped goldenrod	*Salix exigua* (Nutt.)	sandbar willow
Epilobium coloratum (Biehler)	purple-leaved willow-herb	*Saururus cernuus* (L.)	lizard's-tail
Fraxinus nigra (Marshall)	black ash	*Scutellaria galericulata* (L.)	marsh skullcap
Hordeum jubatum (L.)	squirrel-tail barley	*Scutellaria lateriflora* (L.)	mad-dog skullcap
Impatiens capensis (Meerb)	spotted touch-me-not	*Sium suave* (Walter)	water-parsnip
Juncus nodosus (L.)	knotted rush	*Solanum dulcamara* (L.)	bittersweet nightshade
Lactuca serriola (L.)	prickly lettuce	*Sonchus arvensis* (L.)	field sow-thistle
Lindernia dubia (L.) Pennell	false pimpernel	*Typha latifolia* (L.)	broad-leaved cattail
Ludwigia palustris (L.) Elliott	water-purslane	*Verbena hastata* (L.)	blue vervain
Mentha arvensis (L.)	field mint	*Zosterella dubia* (Jacq.)	water star-grass

Appendix 5.3: Plant species found only in 2011

Scientific name	Common name
Abutilon theophrasti (Medik.)	velvetleaf
Azolla caroliniana (Willd.)	Carolina mosquito fern
Carex lacustris (Willd.)	hairy sedge
Cyperus odoratus (L.)	fragrant flatsedge
Lycopus americanus (Muhl.)	American horehound
Myriophyllum sibericum (Kom.)	shortspike watermilfoil
Najas flexilis (Willd.) Rostk. & W. L. E. Schmidt	nodding waternymph
Najas marina (L.)	spiny naiad
Potamogeton crispus (L.)	curly pondweed
Ranunculus longirostris (Godr.)	longbeak buttercup
Salix fragilis (L.)	crack willow
Sparganium eurycarpum (Engelm.)	broadleaf bur-reed
Typha X glauca (Godr.)	hybrid cattail
Utricularia vulgaris (L.)	common bladderwort

Appendix 6: Benthos. Presence/Absence of invertebrate groups in vegetation types of Pool 2A & Pool 2B for 2010 and 2011.

	2B OW		2A OW		2B Pol Nel		2A Pol Nel	
Family List	2010	2011	2010	2011	2010	2011	2010	2011
Amphipoda	X	X			X	X	X	
Anisoptera	X				X	X	X	
Bivalvia								
Cnidaria							X	
Coleoptera	X		X		X	X	X	
Decapoda					X	X	X	
Diptera	X	X	X	X	X	X		X
Ephemeroptera	X	X			X			X
Gastropoda	X	X			X	X		
Hemiptera	X	X	X		X		X	X
Hirudinea	X				X		X	
Isopoda								
Lepidoptera	X				X			
Megaloptera								
Nematoda	X							
Nemertea					X			
Oligochaeta	X	X	X	X	X	X	X	X
Plecoptera								
Trichoptera	X	X	X		X	X		
Turbellaria								
Zygoptera	X	X	X		X			X

X = presence; OW = open water; Pol Nel = Polygonum or Nelumbo area

Appendix 7: Water quality sampling locations. The Lake Erie site (LKER) is in Lake Erie near the Crane Creek outlet.