Implementing the Great Lakes Coastal Wetland Monitoring Program

Final Report

October 1, 2015 – September 30, 2021

Prepared for:
U.S. EPA GLNPO (G-17J) 77 W. Jackson Blvd. Chicago, IL 60604-3590
Contract/WA/Grant No./Project Identifier:
GL- 00E01567

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INTRODUCTION

Monitoring the biota and water quality of Great Lakes coastal wetlands began as a project funded under the Great Lakes Restoration Initiative on September 10, 2010. The project had the primary objective of implementing a standardized basin-wide coastal wetland monitoring program. Our first five years of sampling (2011-2015) set the baseline for future sampling years and showed the power of the datasets that can be used to inform decision-makers on coastal wetland conservation and restoration priorities throughout the Great Lakes basin. During round 1, we 1) developed a database management system; 2) developed a standardized sample design with rotating panels of wetland sites to be sampled across years, accompanied by sampling protocols, Quality Assurance Project Plans (QAPPs), and other methods documents; and 3) developed background documents on the indicators.

We have now completed the second phase of this work. The status of the work has been changed from a project to a sampling program, and have finished sampling the wetlands again for the second time. During this second round (2016-2020), we have investigated sampling adjustments to ensure that water level fluctuations are taken into account and began assessing effects of these large water level changes on metrics and indicators. We also continued to support on-the-ground restoration projects by providing data and the interpretation of those data.

Summary of Round 1 of sampling:

Our first round of sampling, in the project phase, began with the development of our Quality Assurance Project Plan, developing the site selection mechanism, selecting our sites, extensively training all field crew members, and finally beginning wetland sampling. After a few method adjustments, we updated our QAPP and have kept it updated, although relatively minor changes have had to be made since that first year. Crews sampled 176 sites that first year and roughly 200 sites per year each of the next 4 years. Data were entered into an on-line web-interface database specifically designed to hold the data.

Our yearly sampling schedule proceeds in this manner. During the winter, PIs and crew chiefs meet to discuss issues, update each other on progress, and ensure that everyone is staying on track for QA/QC. Sites are selected using the site selection system by March, and field crew training happens in March – June, depending on biotic type. Amphibian sampling typically begins in late March/early April with bird sampling beginning in April or May, and finally vegetation, fish, macroinvertebrate, and water quality sampling begins in June. Phenology is followed across the basin, so that the most southerly sites are sampled earlier than more northerly sites. In the fall and early winter, data are entered into the database, unknown fish and plants are identified, and macroinvertebrates are identified. The goal is to have all data entered and QC'd by March. Metrics and IBIs are calculated in late March in preparation for the spring report to US EPA GLNPO.

A full summary of round 1 of sampling was submitted to US EPA and is available at http://www.greatlakeswetlands.org/Reports-Publications.vbhtml.

PROGRAM ORGANIZATION

Figure 1 shows our organization for the 2016-2021 period. Our project management team has not changed but there have been other changes. We have a new technical lead at GLNPO, Matt Pawlowski. Dr. Greg Grabas of Environment and Climate Change Canada has been promoted and daily management of the ECCC team is by Joe Fiorino, a long-time team member. The ECCC team collaborates with University of Windsor to sample sites on the Canadian side of Lake Ontario. Dr. Doug Wilcox has retired and was succeeded by Dr. Katherine Amatangelo, who worked alongside him for several years.

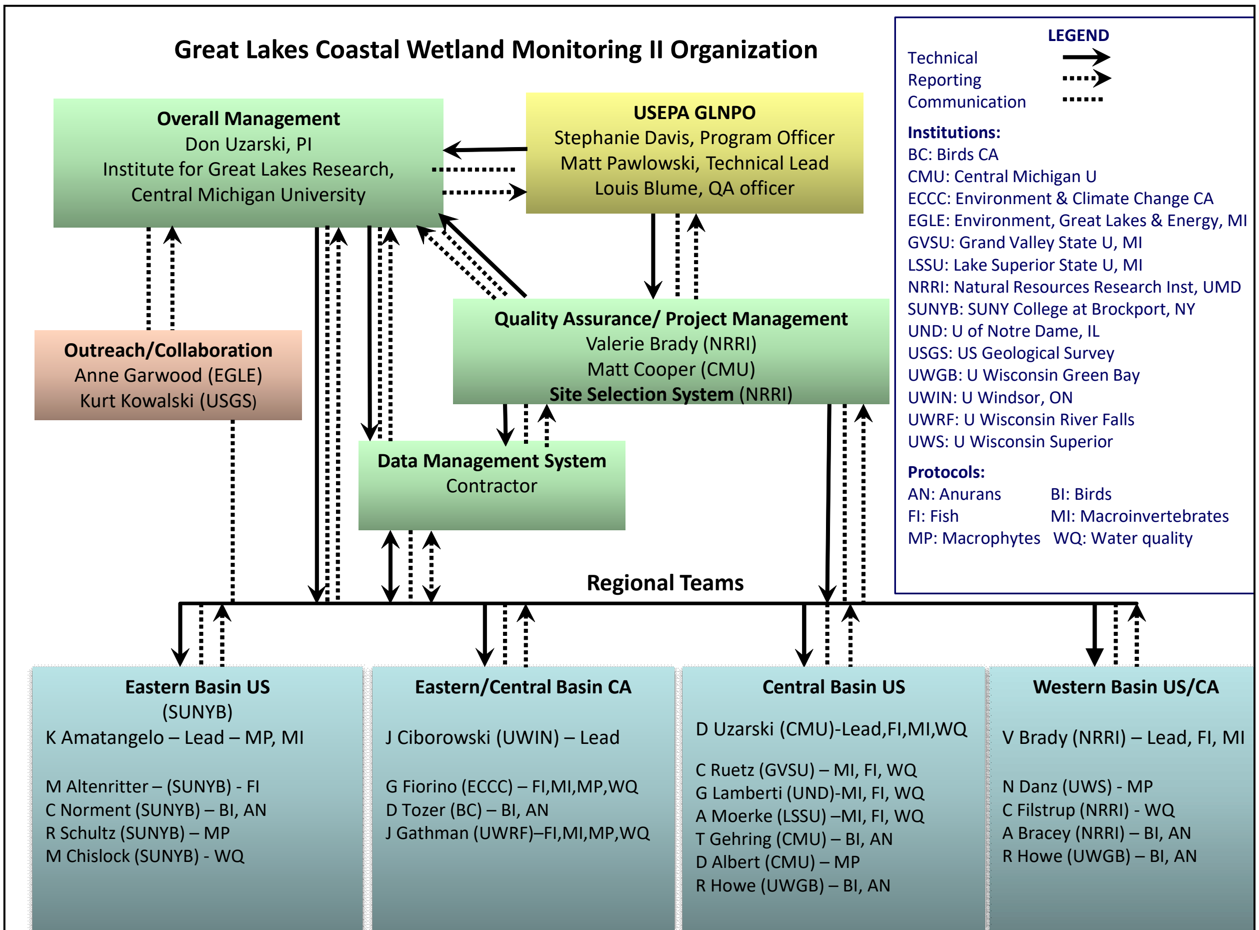

Figure 1. Organizational chart for the program showing lines of technical direction, reporting, and communication separately.

PROGRAM TIMELINE

The program timeline is shown in Table 1.

Table 1. Timeline of tasks and deliverables for the Great Lakes Coastal Wetland Monitoring Program.

	2016				2017				2018				2019				2020				2021			
Tasks	**W**	**Sp**	**Su**	**F**	**W**	**Sp**	**Su**	**F**	**W**	**Sp**	**Su**	**F**	**W**	**Sp**	**Su**	**F**	**W**	**Sp**	**Su**	**F**	**W**	**Sp**	**Su**	**F**
Funding received																								
PI meeting	X				X				X				X				X				X			
Site selection system updated	X				X				X				X				X							
Site selection for summer		X			X				X				X				X							
Sampling permits acquired		X				X				X				X				X						
Data entry system updated	X	X	X	X																				
Field crew training		X	X			X	X			X	X			X	X			X	X					
Wetland sampling		X	X			X	X			X	X			X	X			X	X					
Mid-season QA/QC evaluations			X				X				X				X				X					
Sample processing & QC				X	X			X	X			X	X			X	X			X	X			
Data QC & upload to GLNPO					X	X			X	X			X	X			X	X		X	X	X		
Report to GLNPO		X		X		X		X		X		X		X		X		X		X		X		X

Table 2. GLRI Action Plan II of Measure of Progress. Wetlands were sampled during the summer.

GLRI Action Plan II of Measure of Progress		Project Status* (October 2016 – September 2020)	
		Number	Percent
4.1.3	Number of Great Lakes coastal wetlands assessed for biotic condition	978	100%
* (Not Started; Started; Paused; 25% Completed; 50% Completed; 75% Completed; 95% Completed; and 100% Completed)			

SITE SELECTION

We have now completed our 5-year sampling scheme twice (round 1: 2011-2015; round 2: 2016-2020). This section outlines how sites were selected for sampling overall and for each year of the 5-yr sampling round. Besides regular site sampling, we also sampled sites of special interest for restoration or protection (which we term "benchmark sites"). These sites may have been sampled more than once in the five-year sampling rotation, and may not have been on the original sampling list. The dramatic change in Great Lakes water levels have also affected what wetlands we were able to sample for which biota.

Original data on Great Lakes coastal wetland locations

The GIS coverage used was a product of the Great Lakes Coastal Wetlands Consortium (GLCWC) and was downloaded from http://www.glc.org/wetlands/data/inventory/glcwc_cwi_polygon.zip on December 6, 2010. See http://www.glc.org/wetlands/inventory.html for details.

Site Selection Tool, completed in 2011, minor updates in subsequent years

Background
In 2011, a web-based database application was developed to facilitate site identification, stratified random site selection, and field crew coordination. This database is housed at NRRI and backed up routinely. It is also password-protected. Using this database, potential wetland polygons from the GLCWC GIS coverage were reviewed by PIs and those that were greater than four hectares, had herbaceous vegetation, had (or appeared to have) a lake connection

navigable by fish, and were influenced by lake water levels were placed into the site selection random sampling rotation (Table 3). That is, these 1014 wetlands became our wetland sampling universe, with minor modifications for benchmark sites, as previously described. See the QAPP for a thorough description of site selection criteria. Note that the actual number of sampleable wetlands fluctuated year-to-year with lake level, continued human activity and safe access for crews. The total number of sampleable wetlands was between 900 and 1000 in any given year; we sampled roughly 200 of these (one fifth) per year.

Table 3. Counts, areas, and proportions of the 1014 Great Lakes coastal wetlands deemed sampleable in 2011 following Great Lakes Coastal Wetland Consortium protocols based on review of aerial photography. Area in hectares.

Country	Site count	Site percent	Site area	Area percent
Canada	386	38%	35,126	25%
US	628	62%	105,250	75%
Totals	**1014**		**140,376**	

This wetland coverage shows more wetlands in the US than in Canada, with an even greater percent of wetland area in the US (Table 3). We speculate that this is partly due to poor representation of Georgian Bay (Lake Huron) wetlands in the sampleable wetland database. This area is also losing wetlands rapidly due to a combination of glacial rebound and topography that limits the potential for coastal wetlands to migrate up and downslope during periods of changing water levels. Another component of this US/CA discrepancy is the lack of coastal wetlands along the Canadian shoreline of Lake Superior due to the rugged topography and geology. A final possibility is unequal loss of wetlands between the two countries, but this has not been investigated.

Strata

Geomorphic classes

Geomorphic classes (riverine, barrier-protected, and lacustrine) were identified for each site in the original coastal wetland GIS coverage. Many wetlands inevitably combine aspects of multiple classes, with an exposed coastal region transitioning into protected backwaters bisected by riverine elements. Wetlands were classified according to their predominant geomorphology. Note that we typically do not revisit or change the class originally assigned to a wetland during our 2011 initial site review process.

Regions

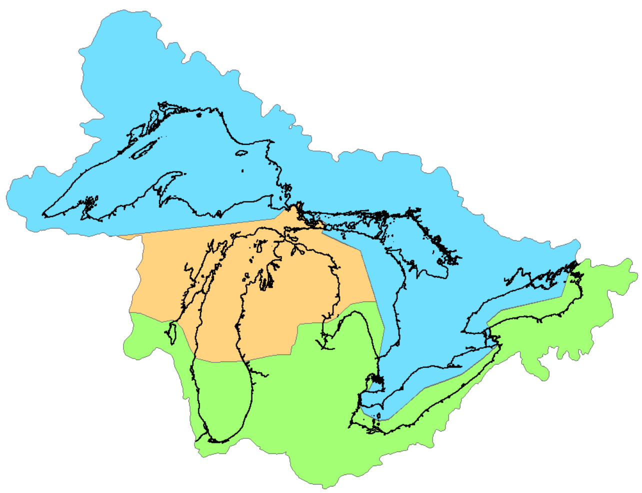

Figure 2. Divisions of lakes into regions. Note that stratification is by region *and* lake, so northern Lake Erie is not in the same region as Lake Superior, etc.

Existing ecoregions (Omernik 1987, Bailey and Cushwa 1981, CEC 1997) were examined for stratification of sites. None were found that stratified the Great Lakes' shoreline in a manner that captured a useful cross section of the physiographic gradients in the basin. To achieve the intended stratification of physiographic conditions, a simple regionalization dividing each lake into northern and southern components, with Lake Huron being split into three parts and Lake Superior being treated as a single region, was adopted (Figure 2). The north-south splitting of Lake Michigan is common to all major ecoregions systems (Omernik / Bailey / CEC).

Panelization

Randomization

To create our stratified random wetland site sampling design, the first step was the assignment of selected sites from each of the project's 30 strata (10 regions x 3 geomorphic wetland types) to a random year or panel in the five-year rotating panel. Because the number of sites in some strata was quite low (in a few cases less than 5, more in the 5-20 range), simple random assignment would not produce the desired even distribution of sites within each strata over time. Instead, it was necessary to assign the first fifth of the sites within a stratum, defined by their pre-defined random ordering, to one year, and the next fifth to another year, etc. All sites were assigned to panels in 2011, prior to the first round of sampling.

In 2012, sites previously assigned to panels for sampling were assigned to sub-panels for re-sampling. The project's sampling design required that 10% of sites were re-sampled the year after they were sampled based on their main panel designation to help determine interannual variability and the effects of changing water levels. This design required five primary panels, *A-E*, one for each year of a five-year rotation, and ten sub-panels, *a-j,* for the 10% resample sites. If 10% of each panel's sites were simply randomly assigned to sub-panels in order *a-j*, sub-panel *j* would have a low count relative to other sub-panels. To avoid this, the order of sub-panels was randomized for each panel during site-to-sub-panel assignment, as can be seen in the random distribution of the '20' and '21' values in Table 4.

For the first five-year cycle, sub-panel *a* was re-sampled in each following year, so the 20 sites in sub-panel *a* of panel *A* were candidates for re-sampling in 2012. The 20 sites in sub-panel *a* of panel *B* were candidates for re-sampling in 2013, and so on. In 2016, panel *A* was sampled for the second time, so the 21 sites in sub-panel *a* of panel *E* became the re-sample sites. The total panel and sub-panel rotation covers 50 years.

Table 4. Sub-panel re-sampling, showing year of re-sampling for sub-panels *a-c*.

	Subpanel										
Panel	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**TOTAL**
A: 2011 2016 2021	20/2012	21/2017	21/2022	20	21	20	21	21	21	21	207
B: 2012 2017 2022	20/2013	20/2018	20/2023	21	20	21	21	20	21	21	205
C: 2013 2018 2023	21/2014	21/2019	21/2024	21	21	20	21	21	21	21	209
D: 2014 2019 2024	22/2015	21/2020	21/2025	21	21	21	21	21	21	21	211
E: 2015 2020 2025	21/2016	20/2021	21/2026	21	21	21	20	21	21	21	208

Workflow states

Each site was assigned a particular 'workflow' status for the year(s) it was to be sampled. During the field season, sites selected for sampling in the current year moved through a series of sampling states in a logical order, as shown in Table 5. The *data_level* field was used for checking that all data were received and the data's QC status. Users set the workflow state for sites in the web tool, although some states could also be updated by querying the various data entry databases. In 2020 we ran into the problem of being unable to sample some sites because of the global pandemic, Covid-19. The site status code "could not sample" was added as a workflow state in the site selection list for crews to have more options to indicate problems sampling sites. "Could not access" was used to indicate when a crew cannot safely get to a site for some reason (including Covid-19 access restrictions on, e.g., tribal lands), while "could not sample" was used to indicate the inability to sample a site even though they could get to it (e.g., water was too deep for their sampling gear).

Team assignment

With sites assigned to years and randomly ordered within years, specific sites were then assigned to specific teams. Sites were assigned to teams initially based on expected zones of logistic practicality, and the interface described in the 'Site Status' section was used to exchange sites between teams for efficiency and to better assure that distribution of effort matched each team's sampling capacity.

Field maps

Multi-page PDF maps were generated for each site for field crews each year. The first page depicted the site using aerial imagery and a road overlay with the wetland site polygon boundary. The image also showed the location of the waypoint provided for navigation to the site via GPS. The second page indicated the site location on a road map at local and regional scales. The remaining pages listed information from the database for the site, including site informational tags, team assignments, and the history of comments made about the site, , including information from previous field crew visits intended to help future crews find boat launches and learn about any hazards a site poses.

Table 5. Workflow states for sites listed in the Site Status table within the web-based site selection system housed at NRRI. This system tracked site status for all taxonomic groups and teams for all sites to be sampled in any given year. Values have the following meanings: -1: site will not generate data, 0: site may or may not generate data, 1: site should generate data, 2: data received, 3: data QC'd.

Name	Description	Data_level
too many	Too far down randomly-ordered list, beyond sampling capacity for crews.	-1
not sampling BM	Benchmark site that will not be sampled by a particular crew.	-1
listed	Place holder status; indicates status update needed.	0
web reject	Rejected based on regional knowledge or aerial imagery in web tool.	-1
will visit	Indicates site assignment to a team with intent to sample.	0
could not access	Proved impossible to access.	-1
could not sample	Added for 2020; indicates inability of crew to sample for some reason other than safety or lack of an appropriate wetland.	-1
visit reject	Visited in field, and rejected (no lake influence, etc.).	-1
will sample	Interim status indicating field visit confirmed sampleability, but sampling has not yet occurred.	1
sampled	Sampled, field work done.	1
entered	Data entered into database system.	2
checked	Data in database system QC-checked.	3

Browse map

The *browse map* feature allowed the user to see sites in context with other sites, overlaid on either Google Maps or Bing Maps road or aerial imagery. Boat ramp locations were also shown when available. The *browse map* provided tools for measuring linear distance and area. When a site was selected, the tool displayed information about the site, the tags and comments applied to it, the original GLCWC data, links for the next and previous site (see *Shoreline ordering* and *Filter sites*), and a link to edit the site in the site editor.

TRAINING

All personnel responsible for sampling invertebrates, fish, macrophytes, birds, amphibians, and water quality received training and were certified prior to sampling in 2011. During that first year, teams of experienced trainers held training workshops at several locations across the Great Lakes basin to ensure that all PIs and crews were trained in Coastal Wetland Monitoring methods. For this second round, because PIs and crew chiefs were very experienced, field crew training was handled by each PI at each regional location. If there was significant crew turnover, new crew members had the option to either train with an experienced crew or have the experienced trainers return for their crew training. All crew members had to pass all training tests each year and PIs conducted mid-season QC. Trainers and QC managers were always be available via phone and email to answer any questions that arose during training sessions or during the field season.

The following is a synopsis of the training conducted by PIs each spring prior to the field season. In general, each PI or field crew chief trained all field personnel on meeting the data quality objectives for each element of the project. This included reviewing the most current version of the QAPP, covering site verification procedures, providing hands-on training for each sampling protocol, and reviewing record-keeping and archiving requirements, data auditing procedures, and certification exams for each sampling protocol. All field crew members were required to pass all training certifications before they were allowed to work unsupervised. Those who did not pass all training aspects were only allowed to work under the supervision of a crew leader who had passed all training certifications.

Training for bird and anuran field crews included tests on anuran calls, bird vocalizations, and bird visual identification. These tests were based on an online system established at the University of Wisconsin, Green Bay – see http://www.birdercertification.org/GreatLakesCoastal. In addition, individuals were tested for proficiency in completing field sheets, and audio testing was done to ensure their hearing was within the normal ranges. Field training was also completed to ensure guidelines in the QAPP were followed: rules for site verification, safety issues including caution regarding insects (e.g., tick-borne diseases), GPS and compass use, and record keeping.

Fish, macroinvertebrate, and water quality crews were trained on field and laboratory protocols. Field training included selecting appropriate sampling points within each site, setting fyke nets, identifying fish, sampling and sorting invertebrates, and collecting water quality and habitat covariate data. Laboratory training included preparing water samples, titrating for alkalinity, and filtering for chlorophyll. Other training included GPS use, safety and boating issues, field sheet completion, and GPS and records uploading. All crew members were required to be certified in each respective protocol prior to working independently.

Training for fish and invertebrate crews also included specific instructions for sampling in deep water. These techniques were trialed in 2019 and found to work to allow sampling in at least somewhat deeper water than we had sampling before the very high water levels in the Great Lakes. Specifically, to sample invertebrates in depths greater than 1 m, D-frame dip net handles were extended and sampling was allowed from inside the boat by moving around the boat and by allowing the boat to swing around one of its anchors. To set fyke nets in deeper water, the boat could be used to set the cod end of the net and the frame could be set underwater, using rock bag anchors to weight the cod end.

Vegetation crew training also included both field and laboratory components. Crews were trained in field sheet completion, transect and point location within sites, and sampling, GPS use, and plant curation. Plant identification was tested following phenology through the first part of the field season. All crew members were required to be certified in all required aspects of sampling before starting in the field unless supervised.

Training on data entry and data QC was provided by Valerie Brady and Terry Brown through a series of conference calls/webinars during the late summer, fall, and winter of 2011. All co-PIs and crew leaders responsible for data entry participated in these training sessions and each regional laboratory successfully uploaded data each year. Additional training on data entry, data uploading, and data QC was provided in 2016 with the implementation of the updated version of the data entry/data archiving system by Todd Redder at LimnoTech. Training on data entry and QC continued via webinar as needed for new program staff and was done in both 2017 and 2018 as new staff joined the program.

Certification

To be certified in a given protocol, individuals had to pass a practical exam. Certification exams were conducted in the field in most cases, either during training workshops or during site visits early in the season. When necessary, exams were supplemented with photographs (for fish and vegetation) or audio recordings (for bird and anuran calls). Passing a given exam certified the individual to perform the respective sampling protocol(s). Since not every individual was responsible for conducting every sampling protocol, crew members were only tested on the protocols for which they were responsible. Personnel who were not certified (e.g., part-time technicians, new students, volunteers) were not allowed to work independently or to do any taxonomic identification except under the direct supervision of certified staff members. Certification criteria were listed in the project QAPP. For some criteria, demonstrated proficiency during field training workshops or during site visits was considered adequate for certification. Training and certification records for all participants were collected by regional team leaders and copied to Drs. Brady, Cooper (QC managers), and Uzarski (lead PI). Note that the training and certification procedures explained here are separate from the QA/QC evaluations explained in the following section. However, failure to meet project QA/QC standards required participants to be re-trained and re-certified.

Documentation and Record

All site selection and sampling decisions and comments were archived in the site selection system (see "site selection"). These included comments and revisions made during the QC oversight process.

Regional team leaders archived copies of the testing and certification records of all field crew members. Summaries of these records were also archived with the lead PI (Uzarski), and the QA managers (Brady and Cooper).

Web-based Data Entry System

The CWMP used a web-based data management system (DMS) that was originally developed by NRRI in 2011 to hold field and laboratory data, and then redeveloped by LimnoTech during 2015-16. The LimnoTech system, which was brought online on April 26, 2016, used Microsoft's Active Server Pages .NET (ASP.NET) web application framework running on a Windows 2012 Server and hosted on a virtual machine at Central Michigan University (CMU). The open source PostgreSQL Relational Database Management System (RDMS) with PostGIS spatial extensions was used to provide storage for all CWMP data on the same Windows 2012 server that hosted the web application.

The CWMP database included collections of related tables for each major taxonomic group, including macrophytic vegetation, fish, macroinvertebrates, anurans and birds. Separate data entry/editing forms were created for data entry based on database table schema information that was stored in a separate PostgreSQL schema. Data entry/editing forms were password-protected and could be accessed only by users that had "Project Researcher" or "Admin" credentials associated with their CWMP user account and permissions for specific taxa group(s).

Specific features of note for the CWMP data management system included:

- Automated processes for individual users to request and confirm accounts;
- An account management page where a limited group of users with administrative privileges could approve and delete user accounts and change account settings as needed;
- Numerous validation rules employed to prevent incorrect or duplicate data entry on the various data entry/editing forms;
- Custom form elements to mirror field sheets (e.g. the vegetation transects data grid), which made data entry more efficient and minimized data entry errors;

- Domain-specific “helper” utilities, such as generation of fish length records based on fish count records;
- Dual-entry inconsistency highlighting for anuran and bird groups using dual-entry for quality assurance;
- Tools for adding new taxa records or editing existing taxa records for the various taxonomic groups; and
- GPS waypoint file (*.gpx) uploading utilities and waypoint processing to support matching of geographic (latitude/longitude) coordinates to sampling points.

The CWMP data management system also provided separate webpages that allowed researchers to download “raw” data for the various taxonomic groups as well as execute and download custom queries that were useful for supporting dataset review and QA/QC evaluations as data entry proceeded during, and following, each field season. Users from state management agencies were able to access the separate download pages for raw data and custom queries. Such organizations include GLNPO and its subcontractors and EGLE. Index of Biological Integrity (IBI) metrics were included as a download option based on static scores that reflect data collection through the 2020 field season.

Raw data downloads were available in both Microsoft (MS) Excel spreadsheet and MS Access database formats, while custom query results were available in spreadsheet format only. All available data/query export and download options were automatically regenerated every night, and users had the option of either downloading the last automated export or generating a new export that provided a snapshot of the database at the time the request was made (the former option was much faster). Datasets for the major taxonomic groups must be downloaded individually; however, a comprehensive export of all pertinent data tables was generated in a single MS Access database file and provided to GLNPO on a bi-annual schedule in the fall and spring each year.

In addition to providing CWMP researchers with data entry and download access, the CWMP data management team provided ongoing technical support and guidance to GLNPO to support its internal management and application of the QA/QC’d monitoring datasets. GLNPO, with support from subcontractors, maintained a separate, offline version of the CWMP monitoring database within the Microsoft Access relational database framework. In addition to serving as an offline version of the database, this version provided additional querying and reporting options to support GLNPO’s specific objectives and needs under GLRI. CWMP data management support staff generated and provided to GLNPO and its contractors a “snapshot” of the master CWMP PostgreSQL database as a Microsoft Access database twice per year, corresponding to a spring and fall release schedule. This database release was then used by GLNPO and its contractors to update the master version of the Microsoft Access database used to support custom querying and reporting of the monitoring datasets.

A full backup of the CWMP PostgreSQL database was created each night at 3:00 AM Eastern time using a scheduled backup with the PostgreSQL Backup software application. Nightly database backups were automatically uploaded to a dedicated folder on LimnoTech's Sharefile system where they were maintained on a 30-day rolling basis. In the event of significant database corruption or other failure, a backup version could be restored within an hour with minimal data loss. The server that housed the DMS was also configured to use CMU's Veeam Backup Solution. This backup solution provided end-to-end encryption including data at rest. Incremental backups were performed nightly and stored at secure locations (on premise and offsite). Nightly backup email reports were generated and sent to appropriate CMU IT staff for monitoring purposes. Incremental backups were kept indefinitely and restores could be performed for whole systems, volumes, folders and individual files.

RESULTS

Sites Sampled

The sites sampled in this five-year sampling round are shown in Figure 3. Benchmark sites are sites that were not on the site list, were special interest sites that were too far down the site list and risked not being sampled by all crews, or were sites that were considered a reference of some type and were being sampled more frequently. Sites that were not on the site list typically were too small, disconnected from lake influence, or were not a wetland, and thus did not fit the protocol. These sites were added back to the sampling list by request of researchers, agencies, or others who had specific interest in the sites. Many of these sites were scheduled for restoration, and the groups responsible for restoration needed pre- or post-restoration data against which to determine restoration success.

We ended up with approximately 85 sites for which at least some of their sampling was designated as "benchmark." Of these sites, 37 were to evaluate restoration efforts and 11 served as reference sites for their area or for nearby restoration sites. The rest were more intensive monitoring sites at which the extra data help provide long-term context and better ecological understanding of coastal wetlands. Almost all benchmark sites were in the US.
A total of 176 wetlands were sampled in 2011, with 206 sampled in 2012, 201 in 2013, 216 in 2014, and 211 in 2015 our 5th and final summer of sampling for the first project round. Overall, 1010 Great Lakes coastal wetland sampling events were conducted in the first round of sampling (2011-2015; Table 5), and we have now nearly completed sampling these wetlands a second time for the second complete round of coastal wetland assessment, 2016-2020. Note that this total number is not the same as the number of unique wetlands sampled because of temporal re-sampling events and benchmark sites that are sampled in more than one year. For the second round of sampling, we sampled 192 wetlands in 2016, 209 wetlands in 2017, 192 wetlands in 2018, 211 wetlands in 2019, and 174 wetlands in 2020 (fewer wetlands sampled due to the global pandemic).

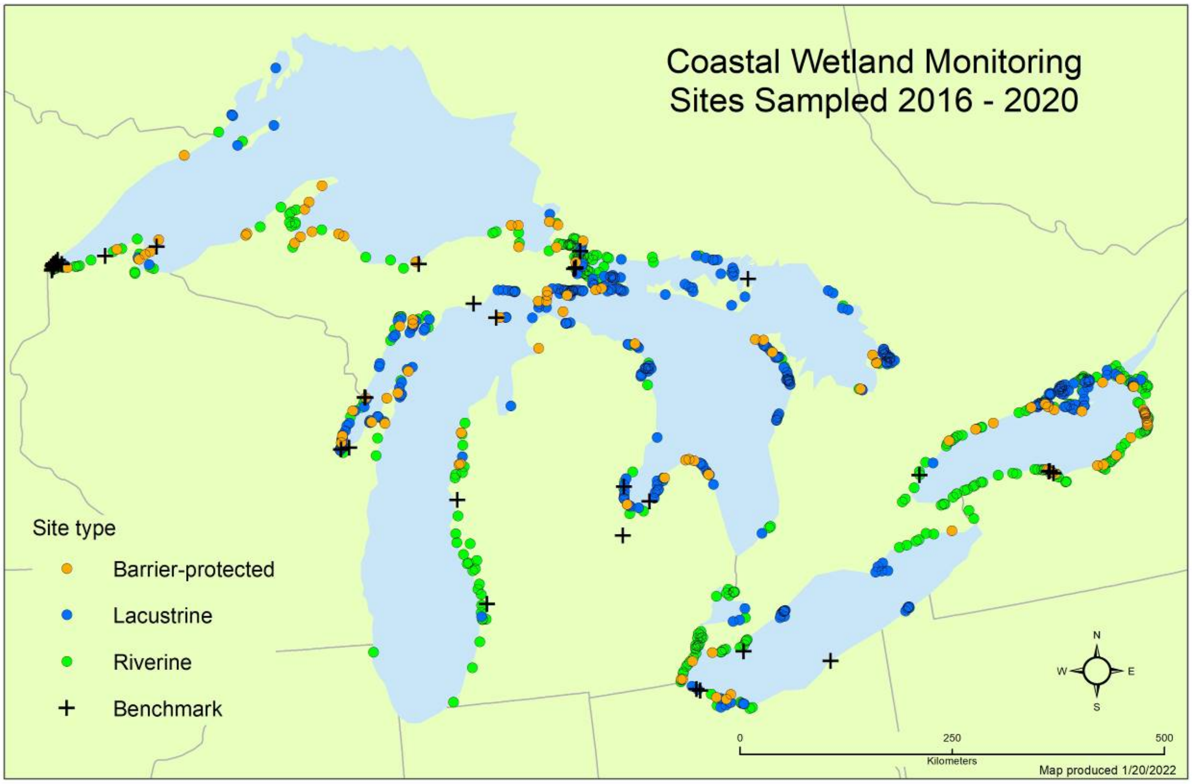

Figure 3. Locations of the Great Lakes coastal wetlands sampled from 2016-2020, color-coded by site type. See text for description of site types.

In all years, more wetlands were sampled on the US side due to the uneven distribution of wetlands between the two countries. The wetlands on the US side also tended to be larger (see area percentages, Table 6). When compared to the total number of wetlands targeted to be sampled by this project (Table 3), we achieved our goal of sampling 20% of US wetlands per year, both by count and by area. However, each year 60-65% of total sites sampled were US coastal wetlands, with 75-80% of the wetland area sampled on the US side. Overall, we have sampled most of the large, surface-connected Great Lakes coastal emergent wetlands by count and by area. A few wetlands could not be sampled due to a lack of safe access or a lack of permission to cross private lands.

Table 6. Counts, areas, and proportions of Great Lakes coastal wetlands sampled in Round 1 (2011 – 2015) and Round 2 (2016 – 2020) sampling by the Coastal Wetland Monitoring Program. Percentages are of overall total sampled each year. Area in ha.

Country	Site count	Site %	Site area	Area %
Canada				
Round 1: 2011 - 2015				
2011	50	28%	3,303	13%
2012	82	40%	7,917	27%
2013	71	35%	7,125	27%
2014	72	33%	6,781	20%
2015	77	36%	10,011	27%
CA total Round 1	**352**	**35%**	**35,137**	**23%**
Round 2: 2016 - 2020				
2016	63	33%	4,336	15%
2017	70	33%	7,801	20%
2018	67	35%	3,356	18%
2019	76	36%	7,746	20%
2020	55	32%	8,603	23%
CA total Round 2	**331**	**34%**	**31,843**	**18%**
United States				
Round 1 (2011 – 2015)				
2011	126	72%	22,008	87%
2012	124	60%	21,845	73%
2013	130	65%	18,939	73%
2014	144	67%	26,836	80%
2015	134	64%	26,681	73%
US total Round 1	**658**	**65%**	**116,309**	**77%**
Round 2: 2016 – 2020				
2016	129	67%	24,446	85%
2017	139	67%	30,703	80%
2018	125	65%	17,715	82%
2019	135	64%	30,281	80%
2020	119	69%	29,325	77%
US total Round 2	**647**	**66%**	**132,470**	**82%**
Overall Totals Round 1	**1010**		**151,446**	
Overall Totals Round 2	**978**		**164,312**	

Teams were able to sample more sites in 2014 due to higher lake levels on Lakes Michigan and Huron, which allowed crews to access sites and areas that had been dry or inaccessible in previous years. By 2015 water depths in some coastal wetlands had become so deep that crews had difficulty finding areas shallow enough to set fish nets in zones typically sampled for fish (cattail, bulrush, SAV, floating leaf, etc.). In 2017 Lake Ontario levels reached highs not seen in many decades. Water levels were again near historic highs in 2019 and 2020 and crews continued to report sampling challenges due to the high water, with coastal wetlands flooded out and only beginning to migrate upslope into areas that remain covered by terrestrial vegetation (shrubs, trees, etc.) or being blocked in this upslope migration by human land use or shoreline hardening. This highlights the difficulty of precisely determining the number of sampleable Great Lakes coastal wetlands in any given year, and the challenges crews face with rising and falling water levels.

Because of the Covid-19 global pandemic and because of continued high water, about 25 fewer sites than usual were sampled during summer 2020. The pandemic created the unusual situation of some field crews not being allowed to cross state borders or travel to areas deemed to be a high risk for Covid-19 spread. Moreover, no field crews were allowed to cross the US-Canada border in summer 2020. In a more typical year, several field crews routinely move back and forth across the US-Canada border to sample sites that are nearer to them than the closest national crew. Despite site trades among US and Canadian teams, some sites could not be sampled in 2020 because no team could get there due to logistics or safety.

Biotic Communities and Conditions

We can now compile good statistics on Great Lakes coastal wetland biota because we have sampled nearly 100% of the medium and large coastal wetlands that have a surface water connection to the Great Lakes and are hydrologically influenced by lake levels.

Wetlands contained 24 to 29 bird species on average; some sampled benchmark sites had only a few bird species, but richness at high quality sites was as great as 64 bird species (Table 7). There are many fewer anuran (calling amphibian) species to be found in Great Lakes coastal wetlands (8 total), and wetlands averaged about 4 species per wetland, with some benchmark wetlands containing no calling anurans (Table 7). However, there were wetlands where all 8 calling anuran species were heard over the three sampling dates.

Bird and anuran data in Great Lakes coastal wetlands by lake (Table 8) shows that wetlands on most lakes averaged around 25 bird species. The greatest number of bird species at a wetland occurred on Lake Huron, with Lake Michigan not far behind. These data include the benchmark sites, many of which are in need of or undergoing restoration, so the minimum number of species can be quite low.

Table 7. Bird and anuran species in wetlands; summary statistics by country. Data from 2016 through 2020 (all of Round 2 sampling).

Country	Site count	Mean	Max	Min	St. Dev.
Birds					
Can.	275	28.5	64	11	10.7
U.S.	574	24.3	58	6	9.8
Anurans					
Can.	212	4.8	8	1	1.7
U.S.	521	4.2	8	1	1.3

Tara Hohman (M.Sc. 2019) in collaboration with all of the anuran and bird PIs analyzed the program's entire bird dataset and reported new findings of wetland bird community changes at broad scales in relation to changing water levels throughout the entire Great Lakes basin. Tara's results indicate that water extent and interspersion increased in coastal wetlands across the Great Lakes between low (2013) and high (2018) lake-level years, although variation in the magnitude of change occurred within and among lakes. Increases in water extent and interspersion resulted in a general increase in marsh-obligate and marsh-facultative bird species richness. Species like American Bittern, Common Gallinule, American Coot, Sora, Virginia Rail, and Pied-Billed Grebe were significantly more abundant during high water years. Lakes Huron and Michigan showed the greatest increase in water extent and interspersion among the five Great Lakes, while Lake Michigan showed the greatest increase in marsh-obligate bird species richness. These results reinforce the idea that effective management, restoration, and assessment of wetlands must account for fluctuations in lake levels. Although high lake levels generally provide the most favorable conditions for wetland bird species, variation in lake levels and bird species assemblages create ecosystems that are both spatially and temporally dynamic. The team published Tara's results in the *Journal of Great Lakes Research* available here [https://doi.org/10.1016/j.jglr.2021.01.006].

All of the bird and anuran PIs in collaboration with a large team of scientists from National Audubon and Audubon Great Lakes analyzed the program's entire bird dataset from the U.S. portion of the Great Lakes and developed a spatial prioritization to identify the most important U.S. Great Lakes coastal wetlands for 14 marsh bird species. We modeled occurrence and relative abundance of each species using boosted regression trees, a machine learning algorithm, to relate standardized monitoring data to ten remotely-sensed environmental covariates. We then used Zonation conservation planning software to rank every wetland cell based on its importance for the suite of marsh bird species. Evaluation of the drivers of marsh bird occurrence and abundance revealed that open water, herbaceous wetland, latitude, longitude, and impervious surface were the most important predictors across focal species. The high-priority wetlands for marsh birds (defined as grid cells ranked in the top 20%) occurred along the shores of eastern Lake Ontario, western Lake Erie/St. Clair, Saginaw Bay, Green Bay, northern lakes Michigan and Huron, and western Lake Superior. Overall, less than half (42%) of high priority coastal wetlands across the Great Lakes basin are currently under some level of protection, with Lake Ontario priority wetlands being the least protected (25%). Our findings represent an opportunity to improve coastal wetland conservation in a region where wetland loss and degradation continue to threaten marsh bird populations and the integrity of one of the world's largest freshwater ecosystems. The team published these findings in *Biological Conservation* available here [https://doi.org/10.1016/j.biocon.2020.108708].

Calling anuran species counts show less variability among lakes simply because fewer of these species occur in the Great Lakes. Wetlands averaged about four calling anuran species regardless of lake (Table 8). Similarly, there was little variability by lake in maximum or minimum numbers of species. At some benchmark sites, and occasionally during unusually cold spring weather, only a single species was detected.

Table 8. Bird and anuran species found in Great Lakes coastal wetlands by lake. Mean, maximum, and minimum number of species per wetland for wetlands sampled from 2016 through 2020 (all of Round 2 sampling).

	Birds				Anurans			
Lake	**Sites**	**Mean**	**Max**	**Min**	**Sites**	**Mean**	**Max**	**Min**
Erie	115	28.6	52	10	112	3.9	7	1
Huron	248	25.0	64	7	204	4.4	7	1
Michigan	158	26.3	58	6	148	4.1	7	1
Ontario	218	24.8	54	7	185	4.9	8	1
Superior	110	24.2	46	9	84	4.2	8	1

An average of 9 to 12 fish species were collected in Canadian and US Great Lakes coastal wetlands, respectively (Table 9). Again, these data include sites in need of restoration, and some had very few species. On the other hand, the wetlands with the highest richness had as many as 19 (CA) or 27 (US) fish species. The average number of non-native fish species per wetland was approximately one, though some wetlands had as many as 4 (US). An encouraging sign is that there were wetlands in which no non-native fish species were caught in fyke nets, although some non-native fish are adept at net avoidance (e.g., common carp).

Table 9. Total fish species in wetlands, and non-native species; summary statistics by country for sites sampled from 2016 through 2020 (all of Round 2 sampling).

Country	Sites	Mean	Max	Min	St. Dev.
Overall					
Can.	161	9.5	19	3	3.7
U.S.	309	11.7	27	2	4.4
Non-natives					
Can.	161	0.7	3	0	0.8
U.S.	309	0.8	4	0	0.8

From 2016-2020, we collected no non-native fish in 44% of Great Lakes coastal wetlands sampled, and we caught only one non-native fish species in 40% of Great Lakes coastal wetlands (Figure 5). We caught more than one non-native fish species in far fewer wetlands. It is important to note that the sampling effort at sites was limited to one night using passive capture nets, so these numbers are likely quite conservative, and wetlands where we did not catch non-native fish may actually harbor them.

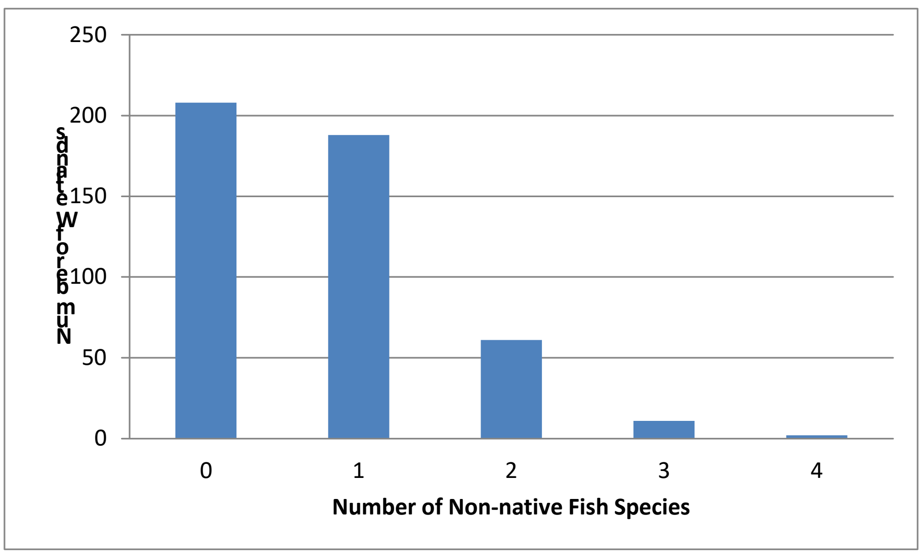

Figure 5. Number of Great Lakes coastal wetlands containing non-native fish species. Data from 2016 through 2020.

Total fish species did not differ greatly by lake, averaging 2-13 species per wetland (Table 10). Lake Michigan wetlands had the highest maximum number of species (27), with the other lakes all having similar maximums of 20-22 species. Because sites in need of restoration were included, some of these sites had very few fish species, as low as two. Wetlands in lakes Huron and Ontario averaged the lowest mean number of non-native fish species captured (about 0.6

non-native species per wetland) and Lake Erie wetlands had the highest, averaging 1.1 non-native fish species per wetland. Having very few or no non-native fish is a positive sign and all lakes had some wetlands in which we caught no non-native fish. This result does not necessarily mean that these wetlands are free of non-natives, unfortunately. Our single-night net sets do not catch all fish species in wetlands, and some species are quite adept at avoiding passive capture gear. For example, common carp can avoid fyke nets. There are well-documented biases associated with each type of fish sampling gear. For example, active sampling gears (e.g., electrofishing) are better at capturing large active fish, but perform poorly at capturing smaller fish, forage fish, and young fish that were sampled well by our passive gear.

Table 10. Fish total species and non-native species found in Great Lakes coastal wetlands by lake. Mean, maximum, and minimum number of species per wetland. Data from 2016 through 2020 (all of Round 2 sampling).

		Fish (Total)			**Non-native**		
Lake	**Sites**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
Erie	67	10.0	21	3	1.1	3	0
Huron	164	11.5	22	3	0.6	3	0
Michigan	77	11.7	27	4	0.8	4	0
Ontario	103	9.5	20	2	0.7	3	0
Superior	59	12.2	22	3	0.8	4	0

The average number of macroinvertebrate taxa (taxa richness) per site was about 37 (Table 11), but some wetlands had more than twice this number. Sites scheduled for restoration and other taxonomically poor wetlands had fewer taxa. On a more positive note, the average number of non-native invertebrate taxa found in coastal wetlands was less than 1, with a maximum of no more than 5 taxa (Table 11). Note that our one-time sampling may not be capturing all of the non-native taxa at wetland sites. In addition, some non-native macroinvertebrates are quite cryptic, resembling native taxa, and may not yet be recognized as invading the Great Lakes.

There was little variability among lakes in the mean number of macroinvertebrate taxa per wetland, with averages ranging from 33-40 taxa with lakes Ontario and Erie having lower averages than the upper lakes (Table 12). The maximum number of invertebrate taxa was highest in Lake Michigan wetlands (86) with the most invertebrate-rich wetlands in the other lakes having a maximum of 57-66 taxa. Wetlands with the fewest taxa were sites in need of restoration. Patterns were likely being driven by differences in habitat complexity, which may be due in part to the loss of wetland habitats on lakes Erie and Ontario from diking (Erie) and water level control (Ontario). This has been documented in numerous peer-reviewed publications.

Table 11. Total macroinvertebrate taxa in Great Lakes coastal wetlands, and non-native species; summary statistics by country. Data from 2016 through 2020 (all of Round 2 sampling).

Country	Sites	Mean	Max	Min	St. Dev.
Overall					
Can.	183	37.2	61	18	9.9
U.S.	365	36.8	86	12	11.7
Non-natives					
Can.	183	0.6	4	0	0.8
U.S.	365	0.7	5	0	1.0

There was little variability among lakes in non-native taxa occurrence, although lakes Erie and Huron had wetlands with 4-5 non-native taxa (Table 12). In each lake there were some wetlands in which we found no non-native macroinvertebrates. As noted above, however, this does not necessarily mean that these sites do not contain non-native macroinvertebrates.

Table 12. Macroinvertebrate total taxa and non-native species found in Great Lakes coastal wetlands by lake. Mean, maximum, and minimum number of taxa per wetland. Data from 2016 through 2020 (all of Round 2 sampling).

		Macroinvertebrates (Total)			Non-native		
Lake	**Sites**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
Erie	72	34.5	57	17	0.9	4	0
Huron	183	38.8	66	12	0.6	5	0
Michigan	99	39.9	86	14	0.8	3	0
Ontario	123	32.8	57	16	0.7	3	0
Superior	70	38.6	60	19	0.3	2	0

We did not find any non-native aquatic macroinvertebrates in 55% of Great Lakes coastal wetlands sampled in the past 5 years (Figure 6), but in a handful of wetlands we found as many as 4-5 non-native invertebrate taxa.

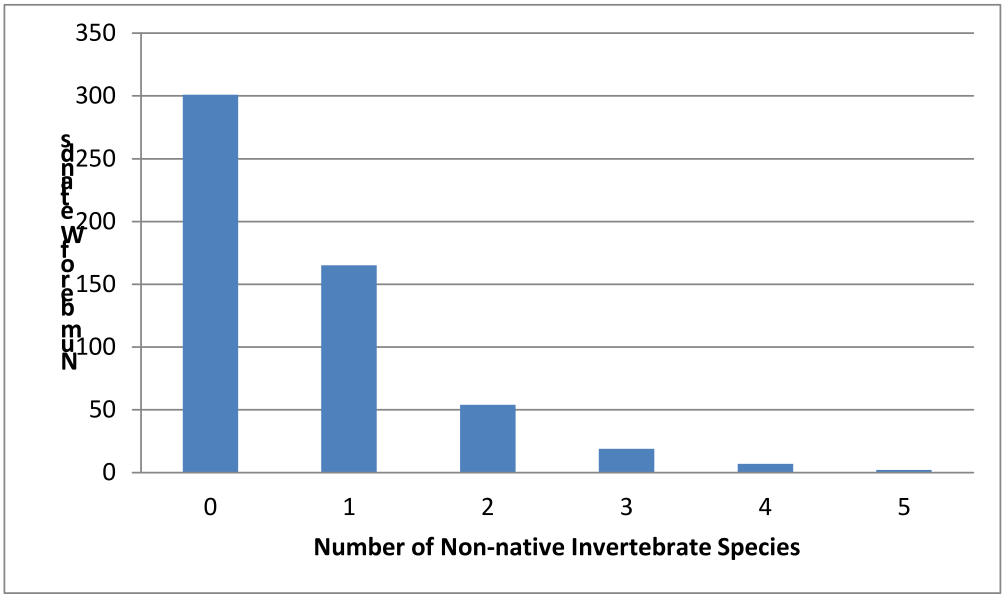

Figure 6. Number of Great Lakes coastal wetlands containing non-native invertebrate species. Data from 2016 through 2020.

We realized that we were finding some non-native, invasive species in significantly more locations around the Great Lakes than was being reported on nonindigenous species tracking websites such as the USGS's Nonindigenous Aquatic Species (NAS) website (http://nas.er.usgs.gov/). Locations of aquatic macroinvertebrates were particularly under-reported. The best example of the difference was locations reported for the faucet snail, *Bithynia tentaculata*. The USGS website had only a handful of Great Lakes coastal locations reported for this snail before we sent them our findings of dozens of locations containing this snail across the entire Great Lakes area. The faucet snail is of particular interest to USFWS and others because it carries parasites that can cause disease and die-offs of waterfowl.

One reason that we were able to increase the geographic range and total number of known locations occupied by faucet snails is the limited number of ecological surveys occurring in the Great Lakes coastal zone. Furthermore, those surveys that do exist tend to be at a much smaller scale than ours and sample wetlands using methods that do not detect invasive species with the precision of our program.

We produced or collaborated on two publication about the Bithynia invasion of Great Lakes coastal areas. The most recent, focused on the factors that may have contributed to this invasion, was recently published in the journal *Biological Invasions* (Schock *et al.* 2019).

We also provided USGS with locations of other non-native macroinvertebrates and fish. The invasive macrophyte information had previously been provided to websites that track these locations, and reported to groups working on early detection and eradication.

On average, there were approximately 35 macrophyte species per wetland (Table 13) with a maximum number of 70 species at exceptionally diverse sites. Some sites were quite depauperate in plant taxa (some having none), particularly in highly impacted areas that were no longer wetlands but were sampled because they were designated for restoration, and because of high water levels along higher energy coastlines.

Non-native vegetation was commonly found in Great Lakes coastal wetlands. We updated our plant taxa lists to ensure that we were correctly coding all non-native macrophyte taxa, even those that are not currently considered invasive. This update changed the numbers of non-native species for many wetlands because in the past we had focused more on the non-natives that are invasive and are problematic in wetlands.

Coastal wetlands averaged 4-5 non-native species (Table 13). Some wetlands contained as many as 21 non-native macrophyte species, but there were wetlands in which no non-native plant species were found. It is unlikely that our sampling strategy missed significant non-native plants invading a wetland. However, small patches of cryptic or small-stature non-natives could have been missed. Invasive species are a particularly important issue for restoration work. Restoration groups often struggle to keep restored wetland sites from becoming dominated by invasive plant species.

Table 13. Total macrophyte species and non-native macrophytes in Great Lakes coastal wetlands; summary statistics by country. Data from 2016 through 2020 (all of Round 2 sampling).

Country	Site count	Mean	Max	Min	St. Dev.
Overall					
Can.	188	34.0	71	6	14.6
U.S.	370	36.4	79	0	15.4
Non-native					
Can.	188	4.9	13	0	2.7
U.S.	370	4.2	21	0	2.9

Lake Erie wetlands had the lowest mean number of macrophyte species (21, Table 14). The other lakes' wetlands had higher mean numbers of species (35-40, Table 14). Maximum species richness in Lake Erie wetlands was also lower than wetlands on the other Great Lakes. Average numbers of non-native species were highest in Lake Ontario and lowest in Lake Superior wetlands (Table 14). Lake Superior had the lowest maximum number of non-native macrophytes in a wetland (7) and Lake Huron had the highest maximum number with 21. There were wetlands on lakes Huron, Michigan, and Superior where we did not detect invasive plants.

Table 14. Macrophyte total species and non-native species found in Great Lakes coastal wetlands by lake. Mean, maximum, and minimum number of species per wetland. Data from 2016 through 2020 (all of Round 2 sampling).

		Macrophytes (Total)			**Non-native**		
Lake	**Sites**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
Erie	74	21.5	53	6	5.1	10	1
Huron	181	38.2	79	3	3.3	21	0
Michigan	93	40.0	76	6	4.6	11	0
Ontario	140	36.9	79	8	6.6	16	2
Superior	70	35.3	64	0	1.9	7	0

Our macrophyte data have reinforced our understanding of the numbers of coastal wetlands that contain non-native plant species (Figure 7). Only 7% of 556 sampled wetlands lacked non-native species, leaving 93% with at least one. Sites were most commonly invaded by up to 7 non-native plant species and 13% of sites contained 8 or more non-native species. Detection of non-native species was more likely for plants than for organisms that were difficult to collect such as fish and other mobile fauna, but we may still have missed small patches of non-natives in some wetlands.

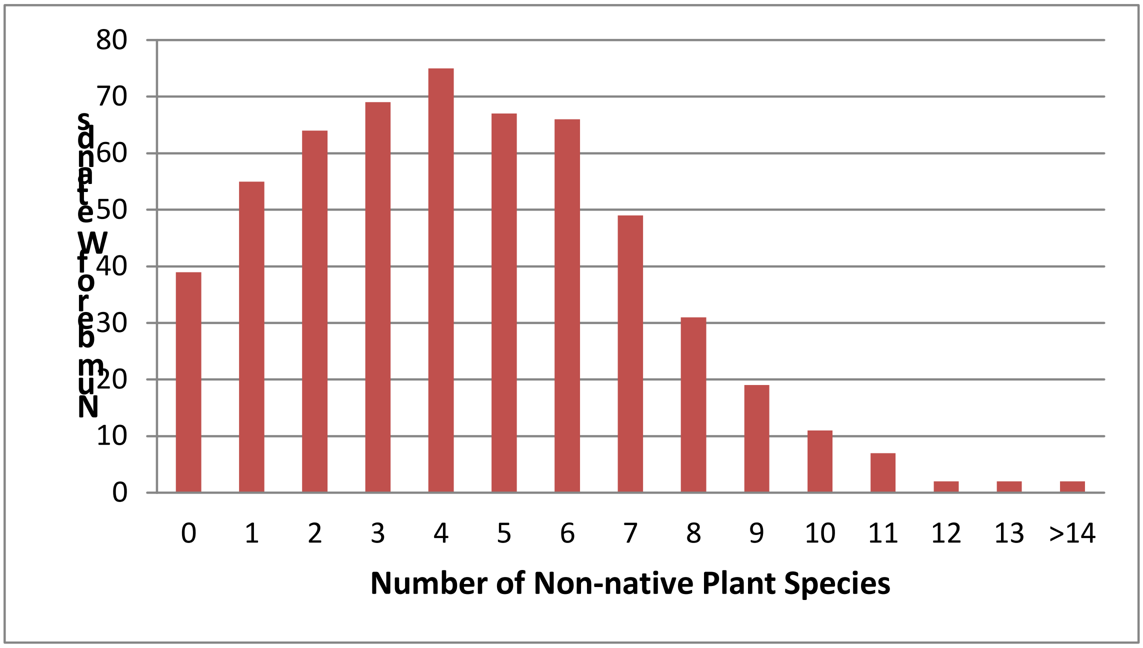

Figure 7. Number of Great Lakes coastal wetlands containing invasive plant species based on 2016 through 2020 data.

Wetland Condition

Metrics and IBIs for were calculated to evaluate coastal wetland condition using a variety of biota (wetland vegetation, aquatic macroinvertebrates, fish, birds, and anurans [calling amphibians]). We focused on assessing wetland condition based on the biota, rather than on water quality and habitat measures, to ensure that we actually know how each biotic group is faring in each wetland and each Great Lake.

Macrophytic vegetation has been used for many years as an indicator of wetland condition (note that we did not include algal species). One very common and well-recognized indicator is the Floristic Quality Index (FQI); this evaluates the quality of a plant community using all of the plants at a site. Each species has a Coefficient of Conservatism (C) score based on the level of disturbance that characterizes each plant species' habitat. A species found in only undisturbed, high quality sites has a high C score (maximum 10), while a weedy species has a low C score (minimum 0). In addition, we gave invasive and non-native species a rank of 0. These C scores were determined for various areas of the country by plant experts; we used the published C values for the midwest. The FQI is an average of all of the C scores of the species growing at a site, divided by the square root of the number of species. The CWM wetland vegetation index is based largely on C scores for wetland species.

The map (Figure 8) shows the distribution of Great Lakes coastal wetland vegetation index scores across the basin. Note that there are long stretches of Great Lakes coastline that do not have coastal wetlands due to topography and geology. Sites with low FQI scores were concentrated in the southern Great Lakes where there were large amounts of both agriculture and urban development, and where water levels are more tightly regulated (e.g., Lake Ontario), while sites with high FQI scores were concentrated in the northern Great Lakes. Even in the north, an urban area like Duluth, MN had high quality wetlands in protected sites and lower quality degraded wetlands in the lower reaches of estuaries (drowned river mouths) where there were legacy effects from the pre-Clean Water Act era, along with nutrient enrichment or heavy siltation from industrial development and/or sewage effluent. Benchmark sites in need of restoration also had lower condition scores.

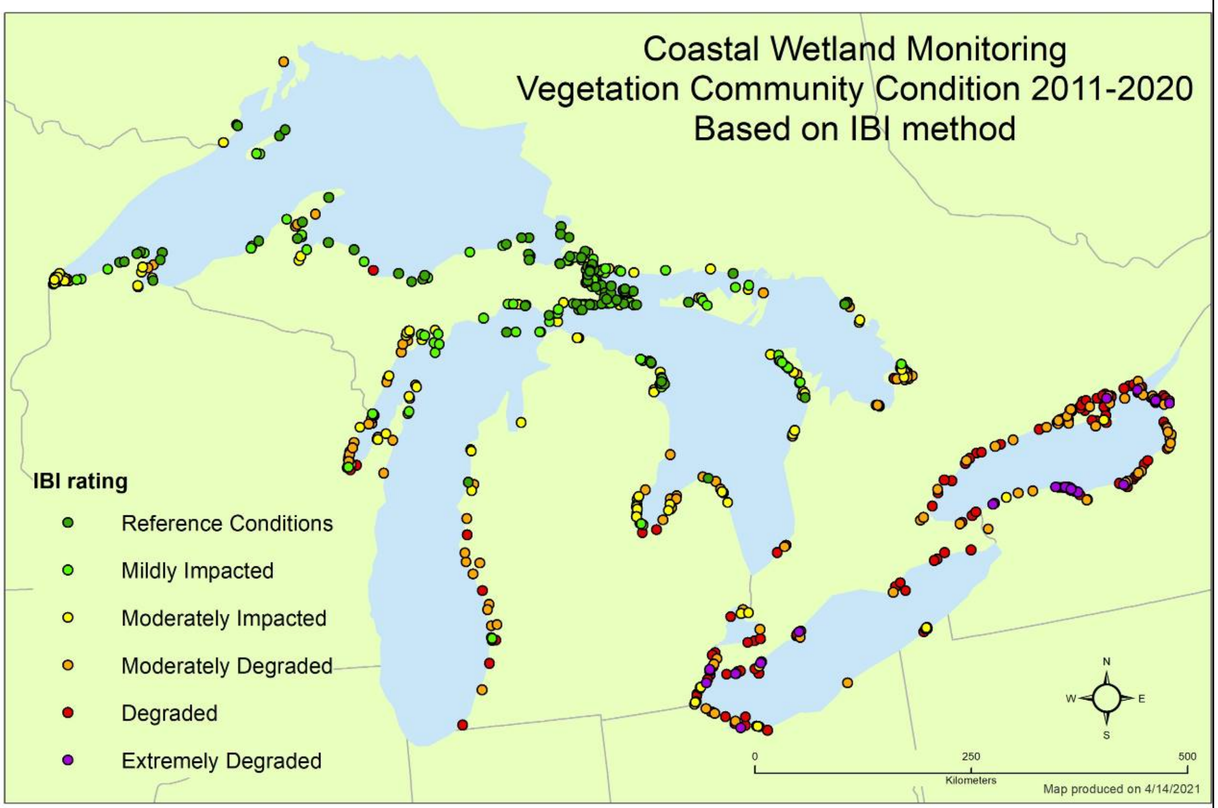

Figure 8. Condition of coastal wetland vegetation at sites across the Great Lakes. Circle color indicates vegetation community quality. The indicator is labeled “draft” while this indicator is investigated for robustness against varying water levels and latitude. Based primarily on data collected between 2016 and 2020, with 2011-2015 data used for sites only sampled in those years.

This IBI was updated and adjusted multiple times since the start of the project, accounting for the shift in condition scores for some sites. The first adjustment was necessary to reflect changes in the taxonomic treatment of many marsh plants in the 2012 Michigan Flora and Flora of North America. The non-native species list was also reviewed and updated.

The wetland macrophyte IBI's values were almost certainly affected by the high water levels of 2017-2020. The macrophyte experts have noted that in many wetlands there were fewer species than there were several years ago.

Another of the IBIs developed by the Great Lakes Coastal Wetlands Consortium uses the aquatic macroinvertebrates found in several of the most common vegetation types in Great Lakes coastal wetlands: sparse bulrush (*Schoenoplectus*), dense bulrush (*Schoenoplectus*), and wet meadow (multi-species) zones. We calculated these IBIs for sites sampled since 2011 that contain these habitat zones (Figure 9). In 2019 we had a major shift in the taxonomy of some invertebrates (primarily snails and mollusks) used in the calculation of some indicator metrics due to taxonomic updates and revisions. Thus, the invertebrate IBI map (Figure 9) in this report should not be compared to the maps shown in previous reports. However, this IBI was calculated for all sites with appropriate zones and invertebrate data for all years.

The lack of sites on lakes Erie and Ontario and southern Lake Michigan in Figure 9 was due to either a lack of wetlands (southern Lake Michigan) or because the wetlands in these areas did not contain any of the three specific vegetation types that GLCWC used to develop and test the invertebrate IBI. Many areas contained dense cattail stands (e.g., southern Green Bay, much of Lake Ontario) for which we do not yet have a published macroinvertebrate IBI.

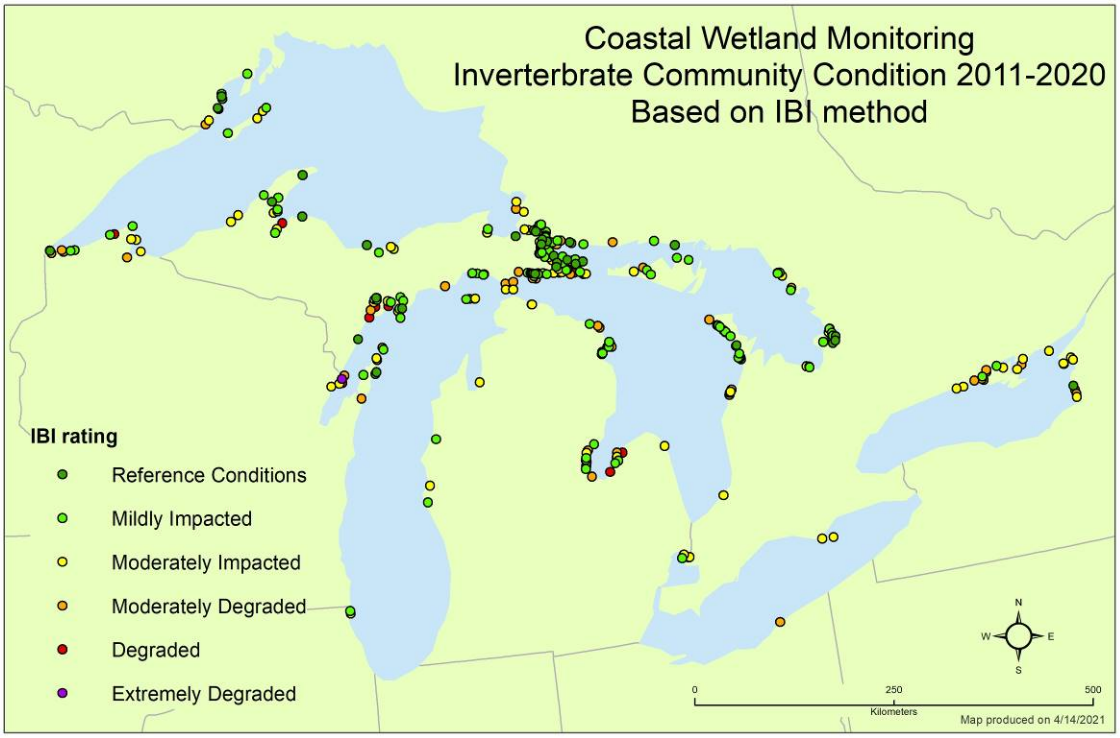

Figure 9. Condition of coastal wetland macroinvertebrate communties at sites with bulrush or wet meadow zones. Based primarily on data collected between 2016 through 2020 with data from 2011-2015 used for sites that were only sampled in those years.

In this 5-year round, we updated and improved our fish IBI calculations for wetland sites containing bulrush, cattail, lily, or SAV zones (Figure 10). Because of the prevalence of these vegetation types in wetlands throughout the Great Lakes basin, this indicator was able to be calculated for more sites than was the macroinvertebrate indicator. Because these are updated and adjusted indicators, the map image in this report should not be compared to fish IBI map images in previous reports. However, all sites reporting fish data from zones applicable to the new fish IBIs are shown here, regardless of the year they were sampled.

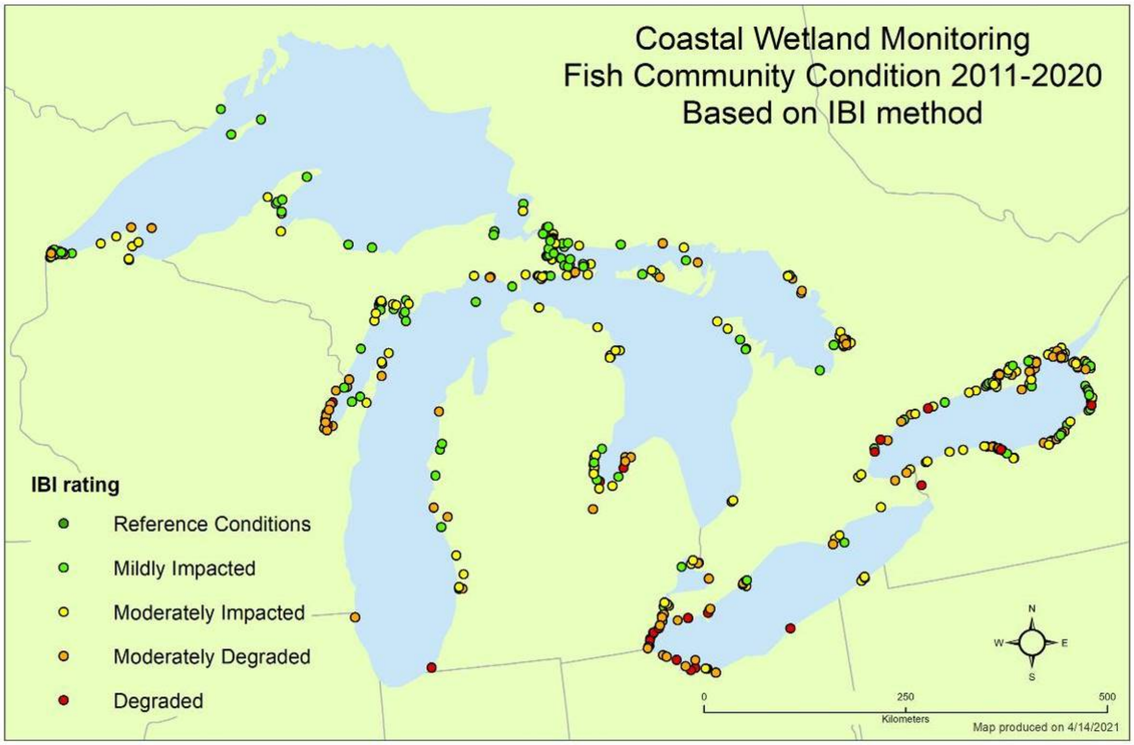

Figure 10. Condition of coastal wetland fish communties at sites with bulrush, cattail, lily, or submerged aquatic vegetation zones. Based primarily on data collected between 2016 through 2020 with 2011-2015 data used for sites that were only sampled in those years.

To develop the new fish IBI, fish community metrics were evaluated against numerous indices of anthropogenic disturbance derived from measurements of water quality and surrounding land cover. Disturbance indices included individual land cover and water quality variables, principal components combining land cover and water quality variables, a previously published landscape-based index (SumRel; Danz *et al*. 2005), and a rank-based index combining land cover and water quality variables (SumRank; Uzarski *et al*. 2005). Multiple disturbance indices were used to ensure that IBI metrics captured various dimensions of human disturbances.

We divided fish, water quality, and land cover data (2011-2015 data) into separate "development" and "testing" sets for metric identification/calibration and final IBI testing, respectively. Metric identification and IBI development generally followed previously established methods (e.g., Karr *et al*. 1981, USEPA 2002, Lyons 2012) in which 1) a large set of candidate metrics was calculated; 2) metrics were tested for response to anthropogenic disturbance or habitat quality; 3) metrics were screened for responses to anomalous catches of certain taxa, for adequate range of responses, and for highly redundant metrics; 4) scoring schemes were devised for each of the final metrics; 5) the final set of metrics was optimized to improve the fit of the IBI to anthropogenic disturbance gradients; and 6) the final IBI was validated against an independent data set.

Final IBIs were composed of 10-11 fish assemblage metrics for each of four vegetation types (bulrush [*Schoenoplectus* spp.], cattail [*Typha* spp.], water lily [*Brassenia, Nuphar, Nymphaea* spp.], and submersed aquatic vegetation [SAV, primarily *Myriophyllum* or *Ceratophyllum* spp.]). Scores of all IBIs correlated well with values of anthropogenic disturbance indices using the development and testing data sets. Correlations of IBIs to disturbance scores were also consistent among each of the five years. A manuscript describing development and testing of this IBI was published (Cooper *et al.* 2018).

Bird indicators were calculated using the same approach described in previous years and publications (Howe *et al.* 2007a, Howe *et al.* 2007b, Gnass Giese *et al.* 2015, Jung *et al.* 2020). In short, we applied a two-stage process: 1) quantify the responses of selected bird species to an *a priori* reference gradient based on a multivariate measure of disturbance or stress (the "human footprint"), and 2) use these parameterized biotic responses (BR functions) to iteratively assess the condition of wetlands according to the species present (or absent) in each wetland. The result for a given wetland site, called the Index of Ecological Condition (IEC), was scaled from 0 (worst condition) to 10 (best condition) in the context of all sites evaluated.

We refined the IEC method in two notable ways. Specifically, we used an improved reference gradient developed by Elliott *et al.* (in prep) and restricted the analysis to a suite of marsh-obligate or disturbance-associated species. Jung *et al*. (2020) applied a similar approach in their recent application of the IEC in coastal wetlands of Lake Erie and Lake Michigan.

We quantified BR functions for 15 species or species groups (Table 15) that use non-woody coastal wetlands for nesting or foraging and are sensitive to the environmental reference gradient described above. Eight of these taxa consisted of two or more ecologically similar species, and a ninth group combined three rare species (Northern Harrier, Black-crowned Night-Heron, and Wilson's Snipe) that were not frequent enough to yield meaningful species-specific BR functions. One species, European Starling, is a non-native bird that uses wetlands occasionally in human-disturbed landscapes.

Table 15. Species and species groups used for calculation of Index of Ecological Condition (IEC) metrics.

#	Taxon	Species
1	BITTERN	American Bittern (*Botaurus lentiginosus*) and Least Bittern (*Ixobrychus exilis*)
2	TERNS	Black Tern (*Chlidonias niger*), Common Tern (*Sterna hirundo*), and Forster's Tern (*Sterna forsteri*)
3	COYE	Common Yellowthroat (*Sterna forsteri*)
4	DABxMAL	Dabbling (marsh) ducks (*Anas* spp., *Mareca* spp., *Aix sponsa*), excluding Mallard (*Anas platyrhynchos*)
5	EAOS	Bald Eagle (*Haliaeetus leucocephalus*) and Osprey (*Pandion haliaetus*)
6	EUST	European Starling (*Sturnus vulgaris*)
7	GBH_GE	Great Blue Heron (*Ardea herodias*) and Great Egret (*Ardea alba*)
8	WREN	Marsh Wren (*Cistothorus* palustris) and Sedge Wren (*Cistothorus stellaris*)
9	MOOT	Common Gallinule (*Gallinula galeata*) and American Coot (*Fulica americana*)
10	PBGR	Pied-billed Grebe (*Podilymbus podiceps*)
11	RWBL	Red-winged Blackbird (*Agelaius phoeniceus*)
12	SACR	Sandhill Crane (*Grus canadensis*)
13	RAIL	Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*) , King Rail (*Rallus elegans*), and Yellow Rail (*Coturnicops noveboracensis*)
14	SWSP	Swamp Sparrow (*Melospiza georgiana*)
15	RARE	Rare/seldon recorded marsh obligates: Wilson's Snipe (*Gallinago delicata*), Northern Harrier (*Circus hudsonius*), Black-crowned Night Heron (*Nycticorax nycticorax*)

Geographic ranges of bird taxa used in our analyses extend across the Great Lakes basin, yet local abundances of these taxa were not evenly distributed. For example, large herons (Great Blue Heron and Great Egret) were much more frequent in the southern and eastern Great Lakes than in Lake Superior. Sedge Wrens were more frequent in the northern lakes. Combining species into multi-species groups (e.g., Sedge Wren + Marsh Wren = WREN; Least Bittern + American Bittern = BITTERN) mitigated the effects of some geographic patterns because at least one of the combined species could be expected in any given Great Lakes region. These combined groups enabled us to validly compare IEC estimates across the basin.

Despite our efforts to develop basin-wide IEC estimates, regional differences were still evident in the distributions of our selected taxa. We used Dufrene and Legendre’s (1997) indicator analysis to compare frequencies and abundances of the 15 taxa among 4 geographic regions: Lake Ontario (LO); Lake Erie and southern lakes Huron and Michigan (LEsHM); northern lakes

Huron and Michigan (nLHM); and Lake Superior (LS). All but one taxon (EAOS = Bald Eagle/Osprey) showed a statistically significant affinity to one or more of these regions. For example, BITTERN, WREN, and DABxMAL (dabbling ducks excluding mallards) were far more frequent in LO; EUST (starling) and GBH_GE (Great Blue Heron and Great Egret) were far more frequent in LEsHM; TERNS, SACR (Sandhill Crane), RAIL, and RARE were far more frequent in nLHM; and COYE (Common Yellowthroat) were significantly more frequent in LS (and nLHM).

In order to compare IEC values without the confounding effects of geographic differences in bird distributions, we applied a second approach. All 15 taxa were well represented in LEsHM and nLHM so we included the full list of species and species groups for these regions. However, we removed 2 seldom-encountered taxa (TERNS and SACR [Sandhill Crane]) from LO and 5 taxa (TERNS, DABxMAL, GBH_GE, MOOT [Gallinule and Coot], and PBGR [Pied-billed Grebe]) from the regional IEC analysis for LS. Results provided a regional IEC that used the same analytical framework but did not "penalize" geographic regions for taxa that were at the margins of their geographic distribution in the Great Lakes basin.

Our results produced two alternative types of IEC values: 1) a basin-wide index (IECgl) that used data from all 15 taxa and BR functions calculated from data representing all wetlands, and 2) a regional index (IECr) that used subsets of species for LS (10 taxa) and LO (13 taxa) and BR functions calculated within the respective regions (Figure 11). Unlike the reference gradient (Cenv), the two alternative IEC values showed generally flatter or more skewed distributions, reflecting different patterns than those exhibited by the reference gradient. Note that high IEC values occur in all regions, suggesting that quality coastal wetlands (for birds) were widely distributed across the Great Lakes.

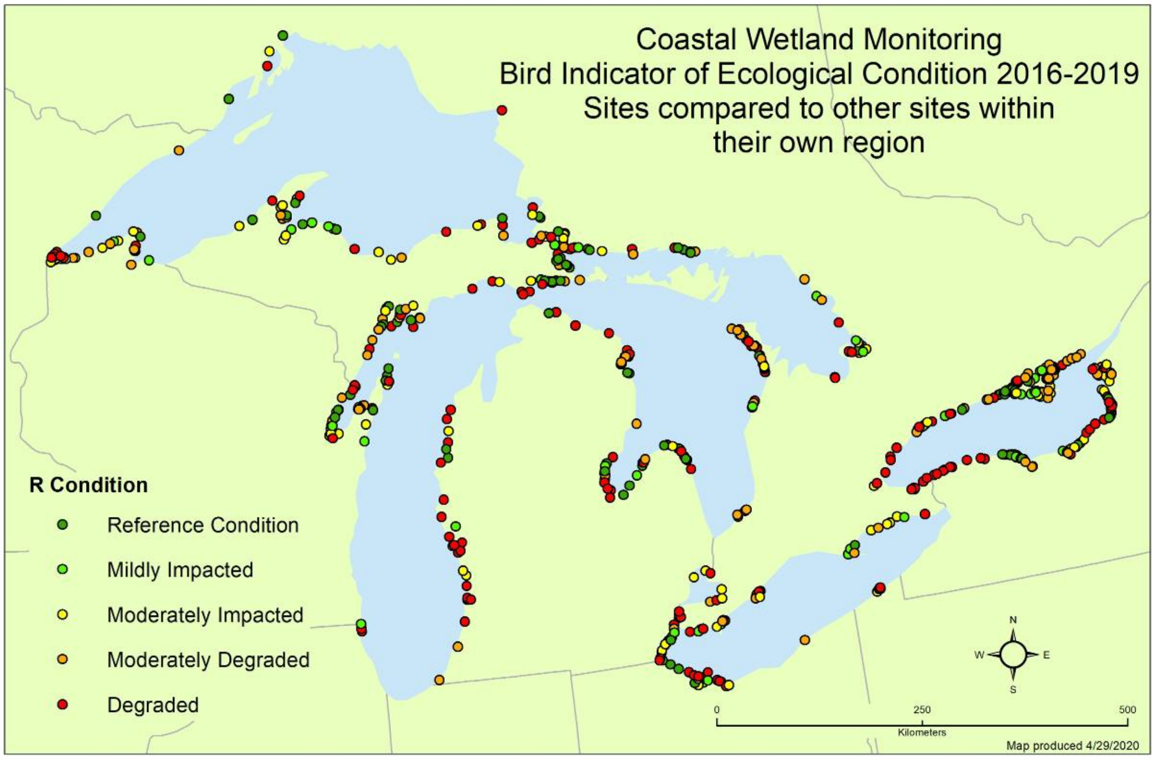

Figure 11. Condition of coastal wetland bird communties with wetlands compared regionally (see text for regions). This indicator is based on the IEC method using data collected primarily between 2016 and 2019.

The most striking difference in the basin-wide vs. regional IEC values was the consistently higher values of IECr for Lake Superior, where excluded taxa (for IECr) were virtually absent in the regional sampling area. IECr values also were consistently higher than IECgl for Lake Erie (Figure 11).

Comparisons of IEC values over time suggest that changing water levels in Lakes Michigan, Huron, and Erie influence bird assemblages and the resulting ecological indicator metrics. Lowest IECr values invariably occurred during low water-level years of 2011-2014. Highest IEC values generally occurred during 2015-2019, but interesting local patterns are evident. Declining IEC values in Lake Michigan during 2018 and 2019 may be due to water levels being too high for optimal wetland bird habitat; indeed, some of the wetlands in Lake Michigan during 2019 were completely flooded and unavailable for wetland bird surveys. Temporal comparisons of IEC values also revealed a lower variability of IEC values for Lake Ontario and Lake Superior, perhaps reflecting the different hydrologic regime affecting coastal wetlands in these lakes.

Recognizing that future work will be needed to expand and fortify our assessment of coastal wetlands, we submit the following general conclusions:

- High quality coastal wetlands exist in all 5 Great Lakes (Figure 11). Local concentrations of prime wetlands occurred in areas such as southern Lake Superior, Green Bay, Saginaw Bay, Sleeping Bear Dunes region of eastern Lake Michigan, Georgian Bay, western Lake Erie, northeastern Lake Ontario, etc., but opportunities for wetland protection and restoration were present across the Great Lakes coastal zone.
- Even in areas with concentrations of quality wetlands, a range of wetland conditions was evident. In other words, both degraded and high quality wetlands occurred in most of the wetland "hot spots," again suggesting that restoration opportunities were widespread.
- Significant variation in wetland condition has occurred during the course of this investigation (2011-2019). Some of this variation can be attributed to historic changes in lake levels, which need to be taken into account when assessing the ecological condition of a given wetland site.
- Regional variations in biotic assemblages are unavoidable at the scale of the entire Great Lakes coastal zone, even if general taxa representing multiple species are used for indicator development. Biogeographic variation is likely relevant to the development of environmental indicators for other taxonomic groups besides birds.
- Wetland bird assemblages clearly were sensitive to local (wetland area), landscape (e.g., percent developed land within 2 km) and watershed level environmental variables. Some bird taxa were more sensitive than others, and the nature of the bird-environment relationship was often non-linear and certainly not identical among taxa. The Index of Ecological Condition (IEC) approach was able to account for these different types of responses. The resulting IEC values did not simply reflect the environmental variables, however. The value of this approach was the additional information that species were able to uniquely provide about the condition of Great Lakes coastal wetlands.

Coastal Wetland Monitoring field teams documented 13 species of anurans (2 toads and 11 frogs) since 2011, but 4 of these (northern [Blanchard's] cricket frog, *Acris crepitans*; Fowler's toad, *Anaxyrus fowleri*; mink frog, *Lithobates septentrionalis*; and pickerel frog, *Lithobates palustris*) were seldom observed and provided inadequate numbers for analysis. Cope's gray treefrog (*Dryophytes chrysoscelis*) and eastern gray treefrog (*Dryophytes versicolor*) are sibling species that were difficult to differentiate in the field, so we combined records into a single taxon. We also did not separate geographically distinct species of chorus frogs, *Pseudacris*. IEC calculations for anurans therefore were based on 8 taxa (gray treefrogs plus American toad, *Anaxyrus americanus*; bullfrog, *Lithobates catesbeianus*; northern leopard frog, *Lithobates* *pipiens*; green frog, *Lithobates clamitans*; wood frog, *Lithobates sylvaticus*; chorus frogs, *Pseudacris* spp., and spring peeper, *Pseudacris crucifer*).

Anuran IEC values were calculated for 1922 point counts at 687 coastal wetlands (Figure 12). Highest IEC values were obtained for wetlands in Lake Michigan during high water years (Table 16), although very high IEC values also were found in Lakes Superior, Huron and Michigan during low water years. Lake Erie, as with birds, yielded the lowest anuran IEC values on average. For two of the lakes (Superior and Huron), IEC values were higher on average during low water years than during high water years. A general linear model using the Gamma family of objects (because IEC values were left skewed) showed a significant difference among lakes (F test, $p < 0.001$) and a significant interaction between lake and year group ($p = 0.0016$). Year group (2011-2014 vs. 2015-2017) itself was not a statistically significant factor for anurans ($p = 0.20$).

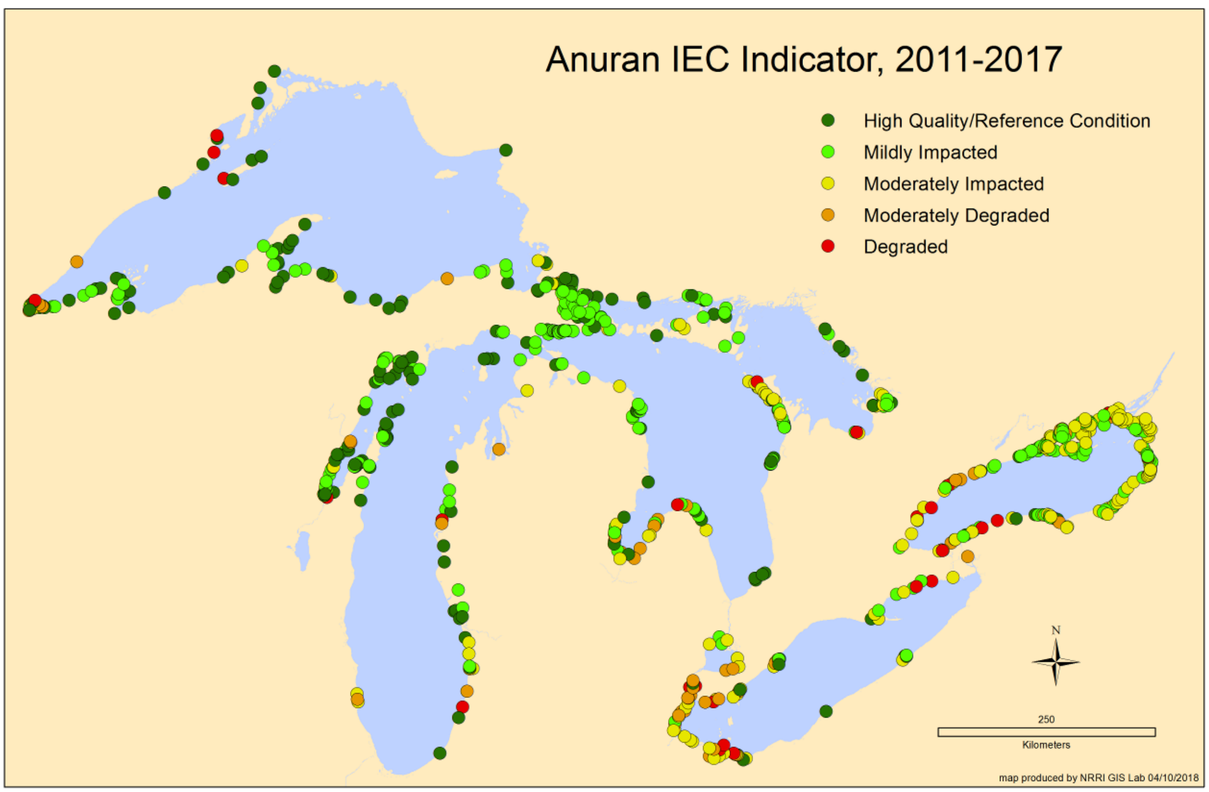

Figure 17. Condition of coastal wetland calling anuran communties. This indicator is based on the IEC method using data from 2011 through 2017.

Mean anuran species richness was highest in Lake Ontario during both low water ($\overline{x}$ = 4.12, SE = 0.10) and high water years ($\overline{x}$ = 4.65, SE = 0.13), while lowest mean species richness was recorded in Lake Erie (low water $\overline{x}$ = 2.66, SE = 0.11; high water $\overline{x}$ = 3.34, SE = 0.10). Lake

Superior (low water $\overline{x}$ = 3.14, SE = 0.11; high water $\overline{x}$ = 3.72, SE = 0.13), Lake Michigan (low water $\overline{x}$ = 3.53, SE = 0.10; high water $\overline{x}$ = 3.85, SE = 0.12), and Lake Huron (low water $\overline{x}$ = 3.69, SE = 0.07; high water $\overline{x}$ = 3.93, SE = 0.09) exhibited intermediate values of species richness. Overall, most points yielded between 2 and 4 anuran species (Figure 13).

Table 16. Mean Index of Ecological Condition (IEC) for anurans at 687 coastal wetlands in the Great Lakes (n = 868 point counts or their averages; standard errors in parentheses). Sites are divided into years with lowest water levels (2011-2014) and years with highest water levels (2015-2017). If multiple point counts were conducted at a wetland during either period (2011-2014 or 2015-2017), the average IEC was used to avoid pseudo-replication.

Lake	2011-2014	2015-2017
Superior	7.81 (0.27)	7.61 (0.30)
Michigan	7.70 (0.29)	8.09 (0.19)
Huron	7.71 (0.14)	7.24 (0.17)
Erie	3.94 (0.28)	4.68 (0.21)
Ontario	5.94 (0.13)	6.20 (0.16)

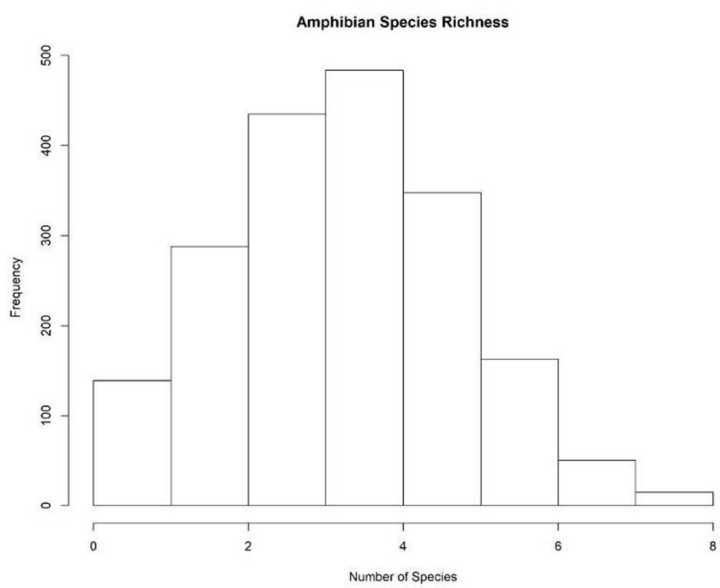

Figure 13. Distribution of anuran species richness at coastal wetland sample points from 2011-2017. Number of species refers to the total number of species recorded during three visits to the point during a given year.

Finally, we developed a disturbance gradient (SumRank) indicator (Harrison et al. 2019). This indicator was based on landscape stressor data, local stressor data seen at the site itself, and water quality data collected from each aquatic plant morphotype (Figure 14).

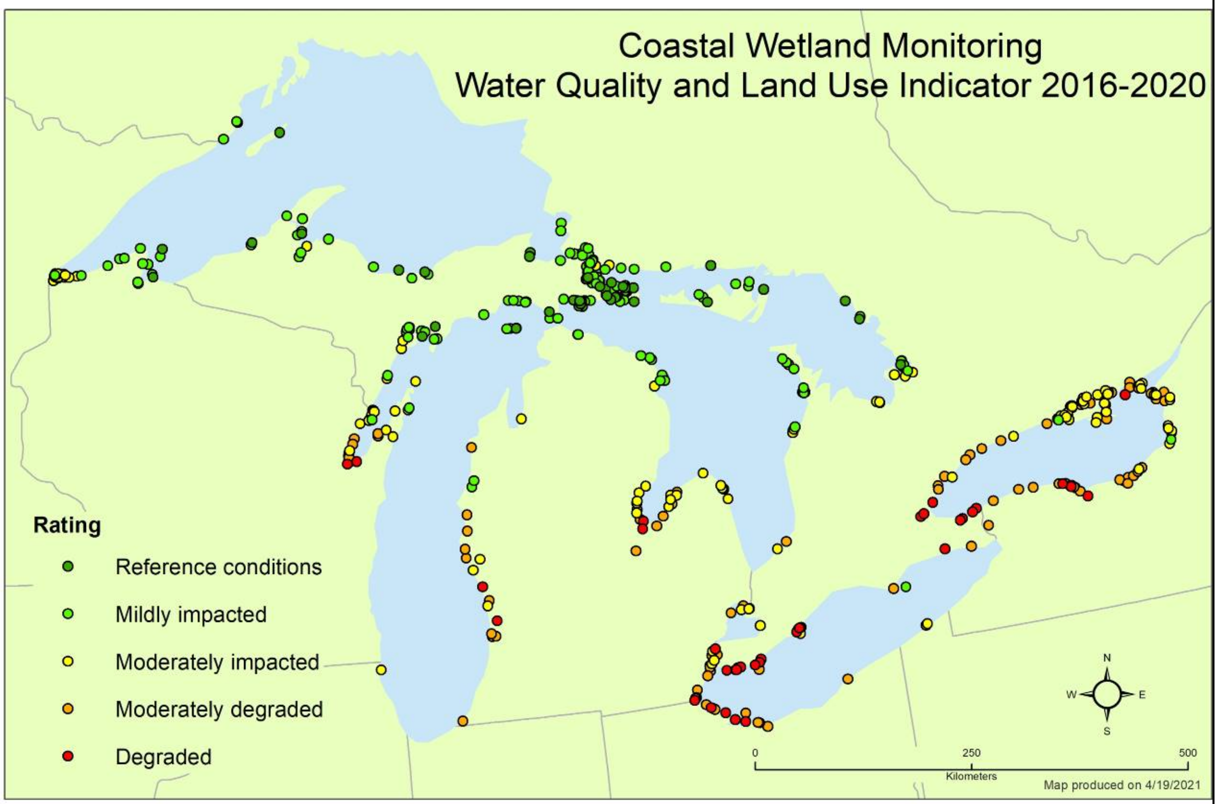

Figure 14. Disturbance gradient (SumRank) indicator. This indicator was based on landscape stressor data, site-based stressor data, and site water quality data. This was based on data collected from 2016 through 2020.

PUBLIC ACCESS WEBSITE

The Coastal Wetlands Monitoring Program (CWMP) website provides efficient access to program information and summary results for coastal managers, agency personnel, and the interested public (Figure 15). As previously noted, the CWMP website was redeveloped and upgraded by LimnoTech and transitioned from an NRRI server to a permanent web hosting environment at Central Michigan University in spring 2016. The official launch of the new CWMP website occurred on April 26, 2016, including the public components of the website and data management tools for CWMP principal investigators and collaborators. Since that time, coastal managers and agency personnel have used the website's account management system to request and obtain accounts that provide access to the wetland site mapping tool, which includes reporting of Index of Biotic Integrity (IBI) scores. CWMP researchers also obtained user accounts that provide access to data upload, entry, editing, download, and mapping tools. LimnoTech provided ongoing maintenance and support for the website, including modifying and enhancing the site as required to meet CWMP and GLNPO needs, as well as other end user needs.

Figure 20. Front page of the Great Lakes Coastal Wetland Monitoring public website, www.greatlakeswetlands.org.

The CWMP website provides a suite of interrelated webpages and associated tools that allow varying levels of access to results generated by the CWMP, depending on the user's data needs and affiliation. Webpages available on the site allow potential users to request an account and for site administrators to approve and manage access levels for individual accounts. Specific levels of access for the website are as follows:

- **Public** – this level of access does not require a user account and includes access to a basic version of the wetland mapping tool, as well as links to CWMP documents and contact information;
- **Site Metrics ("Level 1")** – provides access to index of biological integrity (IBI) scores by wetland site via the coastal wetland mapping tool;
- **Agency/Manager (basic) ("Level 2")** - access to IBI scores and full species lists by wetland site via mapping tool;
- **CWMP Scientists ("Level 4")** - access to data entry/editing tools (+ Level 3 capabilities); and
- **Admin** - access to all information and data included on the website plus administrative tools. A small team of CWMP principal investigators have been given "Admin" access and will handle approval of account requests and assignment of an access level (1-4).

The following sub-sections briefly describe the general site pages available to all users ("Public" level) and the coastal wetland mapping tool features available to "Level 1" and "Level 2" users. User requests for CWMP datasets are handled through a formal process which involves the requestor submitting a letter detailing the request and providing assurances regarding maintaining the publication rights of the CWMP team.

Coastal Wetland Mapping Tool

The enhanced CWMP website provides a new and updated version of the coastal wetland site mapping tool described in previous reports (http://www.greatlakeswetlands.org/Map). The basic version of the mapping tool, which is available at the "Public" access level, provides the following features and capabilities (Figure 16):

- Map navigation tools (panning, general zooming, zooming to a specific site etc.);
- Basemap layer control (selection of aerial vs. "ocean" basemaps);
- Display of centroids and polygons representing coastal wetlands that were sampled by the CWMP;
- Capability to style/symbolize wetland centroids based on: 1) geomorphic type (default view; Figure 16), or 2) year sampled (Figure 17); and
- Reporting of basic site attributes (site name, geomorphic type, latitude, longitude, and sampling years) and general monitoring observations for the site (e.g., hydrology, habitat, disturbances).

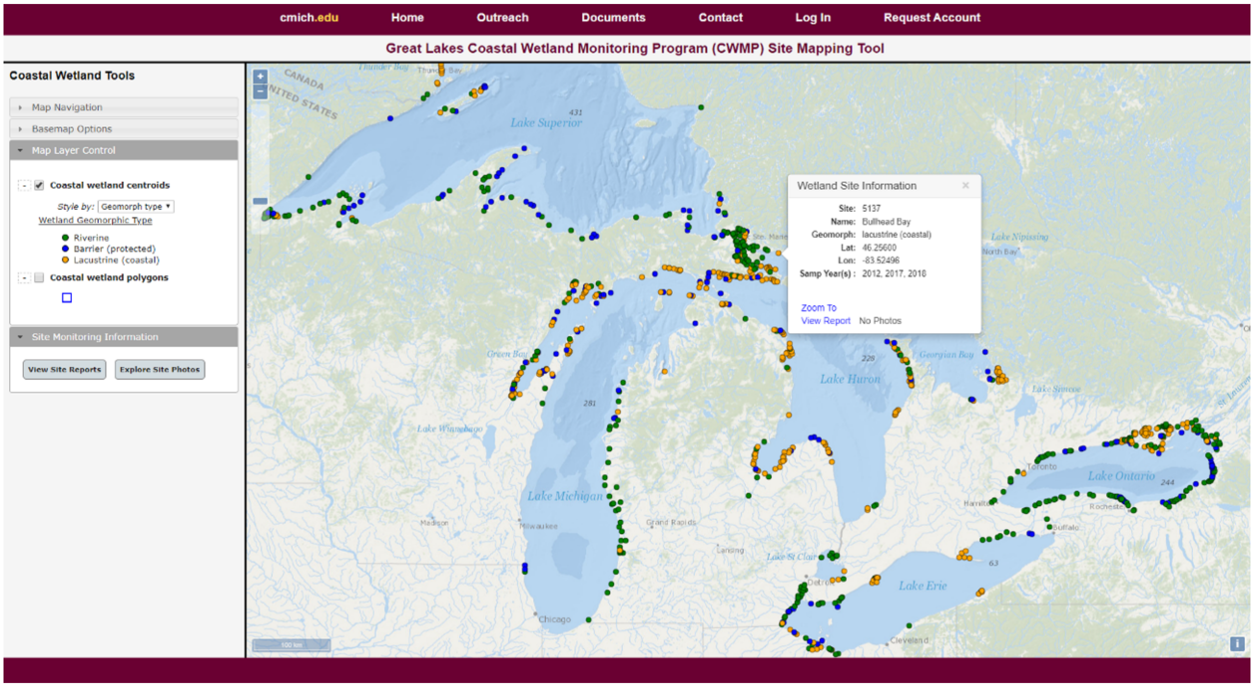

Figure 16. Coastal Wetland Mapping Tool – Public Version (geomorphic type view).

In addition to the features made available at the "Public" access level, users with "Level 1" (*Site Metrics*) access to the website can obtain information regarding IBI scores for vegetation, invertebrates, and fish; *Index of Ecological Condition* (IEC) scores for anurans and birds; and a *Water Quality and Land Use Index*, which functions as a Disturbance Gradient and was previously called "SumRank."

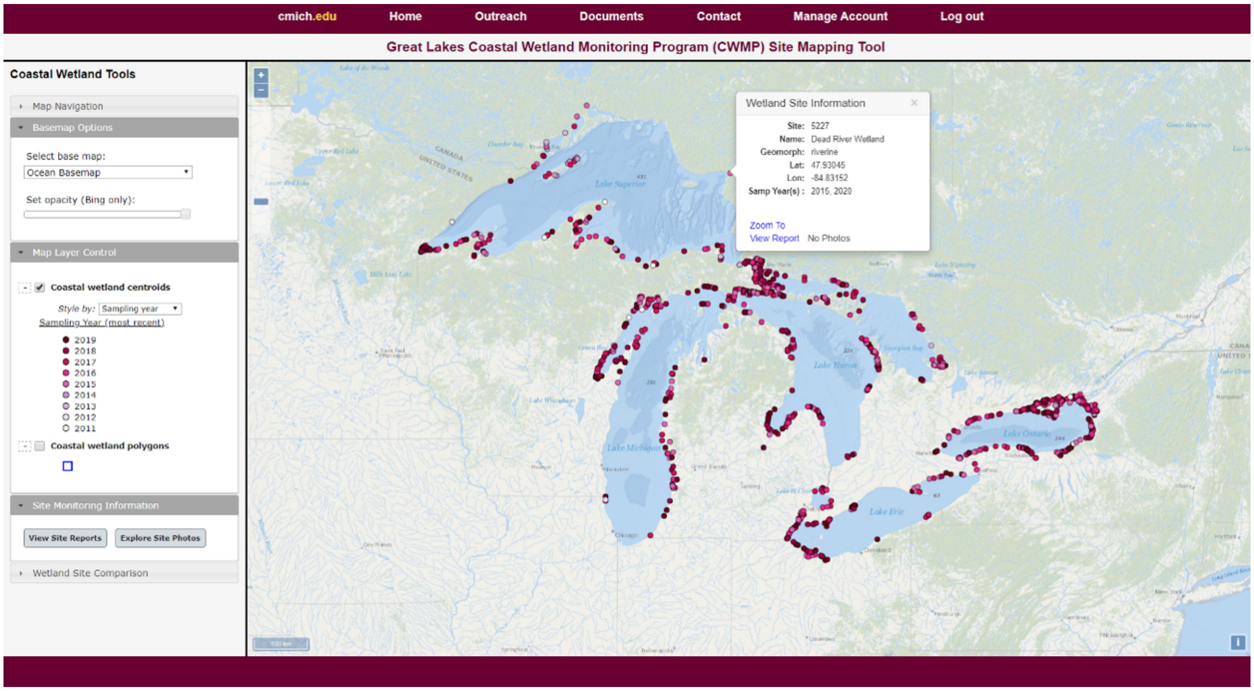

Figure 17. Coastal Wetland Mapping Tool – Public Version (sampling year view)

Wetland centroids can be symbolized based on IBI scores for a specific biological community, as well as based on geomorphic type and year sampled. For example, vegetation IBI scores calculated for individual sites can be displayed by selecting the "Vegetation IBI" option available in the "Style by:" pull-down menu (Figure 18). In addition, the actual IBI scores can be viewed by clicking on an individual wetland centroid.

Users with "Level 2" (Agency/Manager (basic)) access to the website are provided with the same visualization options described above for the "Public" and "Level 1" access levels, but also have the capability of viewing a complete listing of species observed at individual wetland sites. Species lists can be generated by clicking on the "Species List" link provided at the bottom of the "pop-up" summary of site attributes (Figure 19), and the information can then be viewed and copied and pasted to another document, if desired.

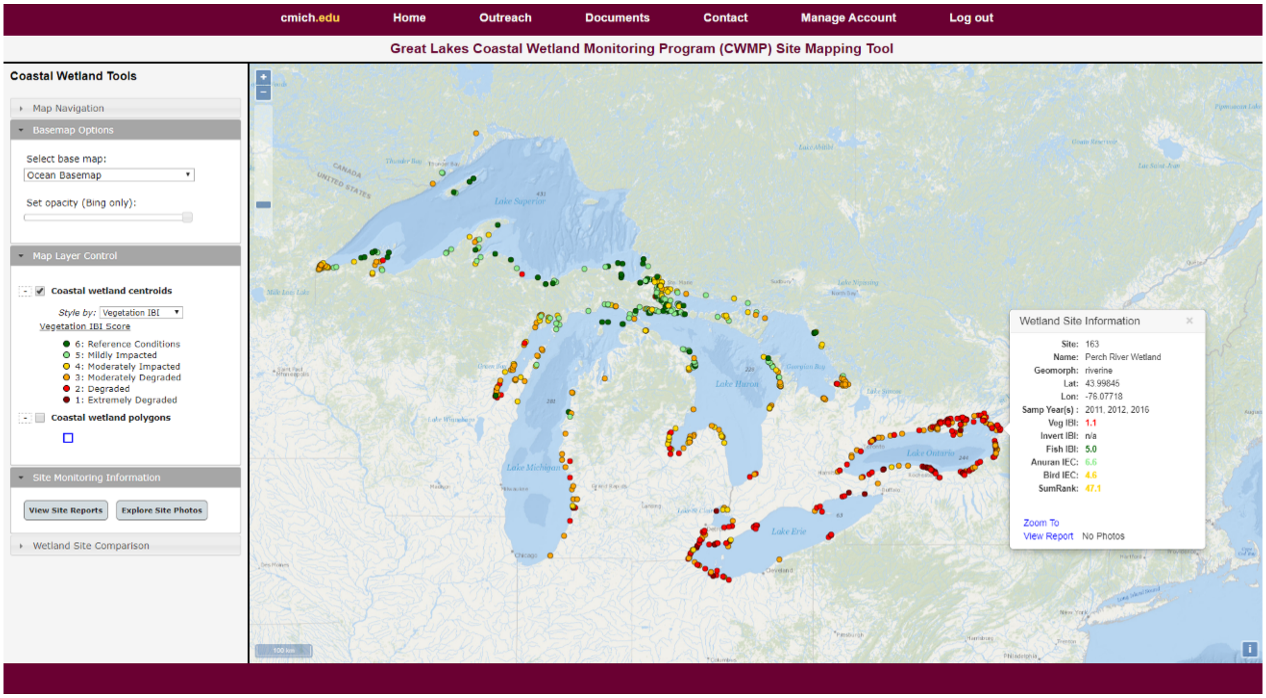

Figure 18. Coastal Wetland Mapping Tool with IBI scores displayed.

"Level 1" and "Level 2" users may also access the following tools that are available in the site mapping tool:

- **Wetland Site Report** – a tool that provides monitoring design information, monitoring observations, and the entire matrix of IBI/IEC/Water Quality and Land Use Index scores on an individual site basis.
- **Wetland Site Photos** – a photo viewer that allows users to review CWMP-approved digital photos taken during site sampling events.
- **Wetland Site Comparison** – a tool that allows users to select a geographic area of interest on the map and then generate a matrix comparing characteristics and IBI/IEC/ Water Quality and Land Use Index scores across the selected sites.

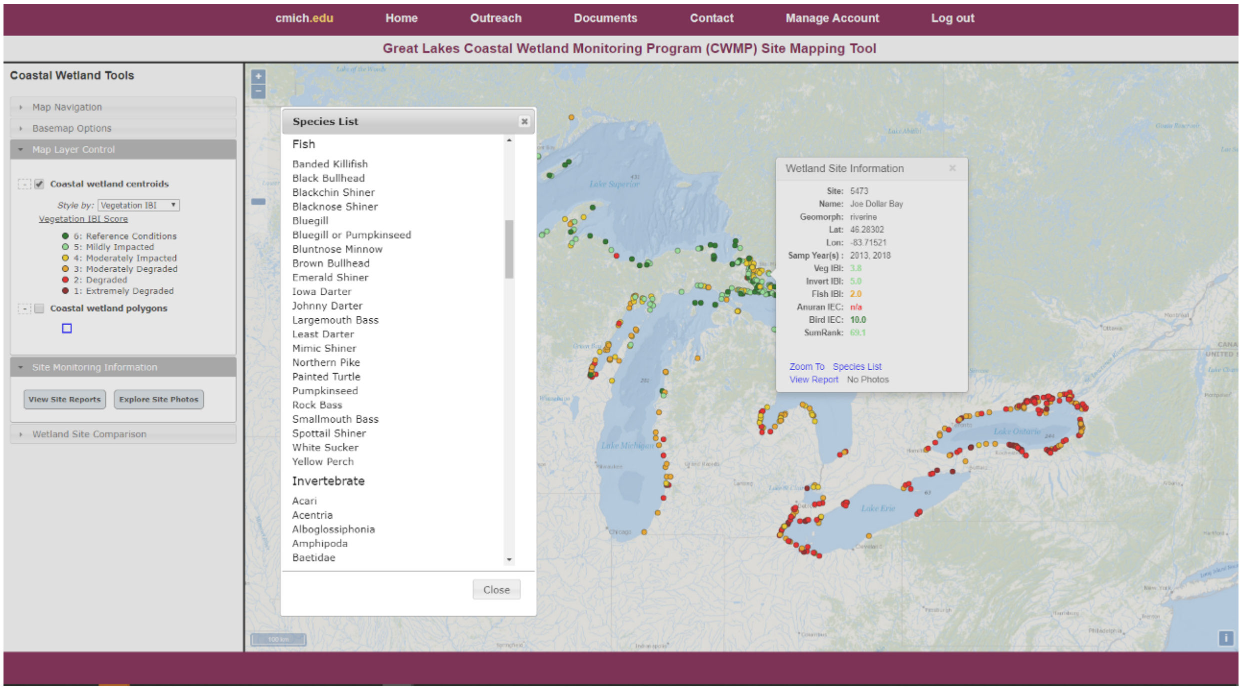

Figure 19. Coastal Wetland Mapping Tool with wetland macrophyte IBI scores and species lists displayed.

Outreach to Managers

In late summer 2016 the Michigan DEQ hosted two full-day information and outreach meetings in Traverse City, MI and Bay City, MI, in order to introduce and promote use of the GLCWM program results through the new GIS-based website and database. The Traverse City meeting was held on August 29, 2016 and was attended by approximately 17 target users from conservation organizations, watershed groups, CISMAs, local government, and state agencies. The Bay City meeting was held on August 31, 2016 and was attended in person by approximately 25 target users primarily from state agencies, CISMAs, and conservation organizations, and had three attendees via webinar from state and federal agencies.

Overall we received very positive responses to these meetings, and the survey responses highlighted some different perspectives. The two meetings were very different, with participants from differing backgrounds, which was reflected in the survey responses. Some of the main comments, both in the survey responses and at the meetings, revolved around interpretation of the information by users accessing the website who were not involved in the program. In particular, many people commented that after seeing the presentations about the monitoring techniques, as well as some of the presentation discussion of how things such as water levels or local issues can affect the samples, they had a better understanding of how to interpret the results and of the limitations of this information. Many people were supportive of website improvements to provide more of this information to users online, and they were excited to hear about the Coastal Wetlands Decision Support Tool (link).

Since these meetings, we have had many of the participants and their colleagues register for access accounts on the website, at appropriate access levels. We have also had some interest in additional future meetings or webinars on the project, results, and how to access the information through the website.

A documentary was created about our monitoring program and the importance of Great Lakes Coastal Wetlands. This one-hour documentary aired on 275 PBS stations in 46 states, the Virgin Islands, and Washington D.C. beginning in July of 2020. It can be viewed at https://www.pbs.org/video/linking-land-and-lakes-hdo22u/

ASSESSMENT AND OVERSIGHT

The Quality Assurance Project Plan (QAPP) for this program was originally written, signed by all co-PIs, and approved by USEPA in the spring of 2011, prior to beginning any fieldwork. Throughout the first round of the project (2011-2015) five revisions were made to the QAPP. These revisions were necessary to improve methodology, better clarify protocols, and ensure the safety of all personnel. After each revision, all co-PIs and US EPA reviewed and signed the updated document prior to commencing fieldwork. The final QAPP revision for round 1 of the project was signed in March 2015. This 2015 revision (QAPP_r5) served as the basis for the second round of monitoring (2016-2020).

For the second 5-year sampling rotation, no substantial methodological or quality assurance/quality control changes were necessary. The QAPP_r5 document was reviewed by project PIs prior to our February 19, 2016 project meeting. The only changes that were required to QAPP_r5 related to the data management system. Specifically, an update was added noting how the data management system developed by LimnoTech and housed at Central Michigan University was being backed up. Project PIs signed the updated QAPP (QAPP_CWMII_v1) at the February 19, 2016 meeting. This QAPP was reviewed and approved by all project co-PIs at our February 10, 2017 meeting and at our February 22, 2018 meeting. In thoroughly reviewing the QAPP and SOPs in early 2018, crews found inconsistencies between the QAPP and SOPs, requiring a handful of minor corrections and clarifications. PIs signed off on these changes at the 2018 PI meeting in Michigan in February. These fixes were incorporated into the QAPP in 2018 and PIs again signed off on the QAPP at the March 1, 2019, meeting in Michigan. The updated QAPP (QAPP_CWMII_rev 1) and SOPs were submitted to EPA in April of 2019.

Major QA/QC elements of this program included:

- Training of all laboratory staff responsible for macroinvertebrate sample processing: This training was conducted by experienced technicians at each regional lab and was overseen by the respective co-PI or resident macroinvertebrate expert. Those labs without such an expert sent their new staff to the closest collaborating lab for training (e.g., LSSU sent a lead technician to NRRI or CMU for training). Macroinvertebrate IDers communicated with each other via their own email list and assisted each other with difficult identifications and other questions that arose.

- Training of all fish, macroinvertebrate, vegetation, bird, anuran and water quality field crew members followed the QAPP and SOPs. This included passing tests for procedural competence as well as identification tests for fish, vegetation, birds, and anurans. Training certification documents were archived with the lead PI and QA managers.

- GPS testing: Every GPS unit used during the field season was tested for accuracy and its ability to upload data to a computer. Field staff collected a series of points at locations that could be recognized on a Google Earth image (e.g., sidewalk intersections) then uploaded the points to Google Earth and viewed the points for accuracy. Precision was calculated by using the measurement tool in Google Earth. Results of these tests were archived and referenced to each GPS receiver by serial number.

- Review of sites rejected after initial site visits: In cases where a site was rejected during a site visit, the reason for rejection was documented by the field crew in the site selection database. The project QA managers (Brady and Cooper) then reviewed these records to ensure consistency among crews. Occasionally, field crew leaders contacted Uzarski, Brady, or Cooper by cell phone when deciding whether to reject a site. The frequency of these consultations increased in 2018 and 2019 as high water levels made sampling particularly challenging.

- Collection and archiving of all training/certification documents and mid-season QA/QC forms from regional labs: These documents were PDF'd and will be retained as a permanent record.

- Maintenance, calibration, and documentation for all field meters: All field meters were calibrated and maintained according to manufacturer recommendations. Calibration/maintenance records were archived at each institution.

- Collection of duplicate field samples: Precision and accuracy of many field-collected variables was evaluated with duplicate samples. Duplicate water quality samples were collected at approximately every 10th vegetation zone sampled.

- QC checks for all data entered into the data management system (DMS): Every data point that was entered into the DMS was checked to verify consistency between the primary record (e.g., field data sheet) and the database. QC was completed for all data by the spring semi-annual report submission each year.

- Linking of GPS points with field database: Inevitably, some errors occurred when crew members type in GPS waypoint names and numbers. All non-linking points between these two databases were assessed and corrected in 2014, which took a hundred or more person-hours. We then implemented a more automated way to link GPS waypoints with data. In addition, crews paid more attention to waypoint name/number accuracy and the lat/longs for critical locations were typed directly into the data management system. These three actions greatly reduced number of GPS waypoints that could be linked to data in the DMS system.

- Mid-season QC checks: These were completed by PIs for each of the field crews to ensure that there were no sampling issues that developed after training and while crews were sampling on their own.

- Creation/maintenance of specimen reference collections: Reference collections for macroinvertebrates, fish, and plants were either created or were maintained and updated by each regional team. Macroinvertebrate reference collections, in particular, were developed or expanded as these samples were processed. Vegetation reference collections were often kept in collaboration with local herbaria.

- Data Quality Objectives (DQO) for laboratory analyses: Participating water quality laboratories generated estimates of precision, bias, accuracy, representativeness, completeness, comparability, and sensitivity for all water quality analyses.

Communication among Personnel

Regional team leaders and co-PIs maintained close communication throughout this entire monitoring program. PIs and many crew leaders attended annual in-person program meetings each winter in Michigan through 2020. Nearly all program members virtually attended an all-hands Zoom program organizational meeting on February 12, 2021. Holding the meeting virtually meant that field and laboratory technicians and graduate students could attend without worrying about having a travel budget. At these meetings, PIs discussed issues pertaining to the upcoming field season including (in 2020 and 2021) how we would deal with Covid 19 issues and border closures, dealing with high Great Lakes water levels, QC issues and fixes, manuscript topics, and report products. Individual taxonomic teams held their meetings virtually within a week of the overall program meeting. Regional team leaders and co-PIs held many conference calls and e-mail discussions regarding fieldwork, taxonomic changes, data analysis, indicator refinement, and publications.

Typically, most PIs spend the first week of field season in the field with their crews to ensure that all protocols are being followed according to the standards set forth in the QAPP and SOPs and to certify or re-certify crew members. That changed in 2020, depending on the field crew and PI, due to Covid-19. However, most crews had returning and experienced personal and the PIs were in contact and did training and provided advice via phone calls and webinars. Under all circumstances, PIs kept in close contact with crews via cell phone, text, and email, and the leadership team was always available via cell phone and text to answer crew questions.

Overall

The quality management system developed for this program was fully implemented and PIs and their respective staff members followed established protocols very closely, relying on the QAPP and SOPs as guiding documents. QA managers were also encouraged by each crew's continued willingness to contact their supervisors or, in many cases, the project management team with questions.

Despite the somewhat dangerous nature of this work, injury rates were very low. We are very proud of what our field crews accomplished safely throughout the program but especially in 2020 despite a global pandemic and having to navigate continually changing guidance from the CDC and each individual university and state. Crews sampled safely, accurately, and without spreading Covid-19. This exemplary safety record was due to the leadership and safety consciousness of PIs, field crew leaders and field teams. PIs are grateful for the willingness of their crews to work long hours day after day, to successfully sample under often adverse conditions (including a global pandemic), and to conduct that sampling in accordance with strict QA procedures.

LEVERAGED BENEFITS OF PROJECT

This program generated a number of spin-off projects and served as a platform for many graduate and undergraduate thesis topics. In addition, project PIs collaborated with many other groups to assist them in getting data for areas that were or will be restored or that are under consideration for protection. Finally, the program supported (fully or partially) many jobs (jobs created/retained). All of these are detailed below.

Spin-off Projects (cumulative)

Modeling distribution of *Phragmites* and *Typha* in response to climate change (2021-2023):
The Canadian Wildlife Service requested and received permission for the Meteorological

Services of Canada to use *Phragmites australis subsp. australis* and *Typha spp.* data from CWMP between years 2011 and 2019 for Lakes Ontario, Huron, and Erie to model the distribution of *Phragmites* and *Typha* through time in response to key physical variables (e.g. water levels) under carbon emission scenarios. These models are integral to a climate change vulnerability assessment for 20 Great Lakes coastal wetland sites and will improve the understanding of climate-related impacts on these important ecosystems across the basin. The results of the vulnerability assessment will be used to inform resilience strategies and mitigation actions for coastal wetlands under climate change.

Restoration of Allouez Bay, Superior, WI (2020-2025): Great Lakes Audubon and the Wisconsin Department of Natural Resources put together a collaborative team to assess the restoration potential of Allouez Bay, an extensive lacustrine coastal wetland complex located in Superior, WI. This wetland has been sampled as a benchmark site by CWMP since 2011 to collect extra data on this important wetland. These data will provide critical baseline information about the quality of the site which will be used to guide restoration efforts by distinguishing between quality and degraded habitats within the wetland site. These data will be compiled with current data being collected by WDNR (e.g., drone aerial imagery and vegetation surveys) and Great Lakes Audubon (e.g., additional bird surveys conducted in the interior of the wetland) to model different restoration scenarios to identify which activities will be most effective in enhancing the quality of the wetland for birds and taxa. On-the-ground restoration activities are not scheduled to begin until 2022-2023.

Investigating the Use of eDNA to Determine Fish Use of Otherwise Unsampleable Habitats (2019-2022): Some habitats cannot be sampled using fyke nets because of inappropriate water depth, unstable or unconsolidated bottom sediments or because that habitat is too fragile (e.g. wild rice). CoPI Valerie Brady with NRRI researcher Chan Lan Chun are investigating how well fyke net fish catches agree with fish eDNA collected from nearby benthic sediment to determine if eDNA could be used as a surrogate in situations where fish cannot be physically collected to determine habitat use.

Compiling and Assessing IBI and Environmental Stress Data to Assess Habitat Condition in the Detroit River Area of Concern (2018-2022): The Detroit River Canadian Clean-up (convened by Environment and Climate Change Canada and the Province of Ontario) is evaluating the weight of evidence for delisting several Beneficial Use Impairments in the Detroit River AOC (Degradation of Fish and Wildlife, Degradation of Benthos, and Loss of Fish and Wildlife Habitat. However, years of monitoring and assessment have failed to demonstrate clear time trends in the condition of biota (aquatic vegetation, aquatic macroinvertebrates, fishes, birds) in the Detroit River's aquatic and riparian habitats. Attempts to evaluate indices of biotic integrity (IBIs) using the Reference Condition Approach (RCA) have been limited by an inability to achieve consensus on appropriate reference conditions. CoPIs Jan Ciborowski, Greg Grabas and Doug Tozer compiled land-based stressor data at the scale of second-order watersheds for the Detroit River AOC to assess how the IBI scores for sites in the Detroit River and adjacent areas

(Lake Erie, Lake St. Clair, St. Clair River) vary as a function of environmental stress. They compiled all available biological monitoring datasets relating to aquatic vegetation, macroinvertebrates, fishes and birds within the study region and calculated composite measures of condition (IBIs) for each of the groups of biota and plotted the resulting scores against the stressor measures. They found provisional evidence of environmental stress thresholds for at least one IBI of each of the taxa investigated. Mapping the distribution of nondegraded vs. degraded watersheds for each of the biological groups will help the DRCC identify whether and where further remediation is necessary to allow delisting of the BUIs.

Minnesota Land Trust Natural Areas Project and Grassy Point Restoration (2018-2020): The Minnesota Land Trust contracted a project with the Natural Resources Research Institute in Duluth, MN to conduct bird surveys along the St. Louis River Estuary (SLRE) within nine project areas that were nominated for inclusion in the Duluth Natural Areas Program (DNAP). This program was created in 2002 to manage Duluth's environmentally significant areas to ensure the preservation of services and values such as habitat diversity and water quality. In addition to data collected for this project, CWMP coPIs Jerry Niemi and Annie Bracey also included breeding bird data collected by the CWMP at benchmark sites located within the SLRE that aligned spatially with the nine DNAP project areas. Collectively these data were used to determine if the proposed land parcels included in the nomination met the criteria of qualifying as an Important Bird Congregation Area (criteria included numeric thresholds for different guilds of species). Use of these data qualified all nine parcels as meeting the Important Bird Congregation Area criteria.

These data were then used in a spin-off project with Minnesota Land Trust, where bird communities were associated with spatially-explicit environmental and habitat variables to help guide conservation and management efforts in the SLRE. In this project we were also able to identify habitat availability at the landscape-level to identify specific features that are under-represented in the SLRE but likely important to avian species (specifically wetland-dependent species). These analyses were used to guide restoration plans at specific locations within the SLRE including Grassy Point (a wetland located in a heavily industrialized area of the SLRE). Efforts to restore this wetland site were developed by using the habitat requirements of wetland-dependent marsh bird species as a guide and restoration goal. Restoration work at Grassy Point began in 2021. NRRI CWMP teams will be involved in post-restoration monitoring of this site as well.

Deriving and Calibrating Environmental and Biological data for Lake Erie in Support of the Great Lakes Water Quality Agreement's Nearshore Framework (2016-2019): As part of the Annex 2 and Annex 7 plans of the revised GLWQA, Environment and Climate Change Canada (ECCC) and GLNPO began work to jointly develop an Integrated Nearshore Framework for the Great Lakes. The goal was to assemble scientific and technical recommendations for nearshore assessment. The assessment was expected to be used to set priorities and design an approach to identify areas of high quality for protection and areas under stress requiring restoration.

ECCC and GLNPO convened several workshops beginning in 2014. In 2016, ECCC initiated a pilot project on the Canadian side of Lake Erie to come up with a workable methodology and approach to combining assessments of different condition measures. CWM coPIs Jan Ciborowski and Greg Grabas took part in a series of workshops and contributed information collected in part from CWM wetland surveys on Lake Erie. The first overall assessment of the nearshore in Lake Erie was reported in 2018. The weight of evidence indicated that there is a strong east to west gradient in nearshore condition with the highest quality habitat and biota observed in the eastern basin, and low quality in the western basin, influenced largely by seasonal occurrences of cyanobacteria. The nearshore of the Detroit River and Lake St. Clair was classified as being of moderate quality. Insufficient data were available to assess the St. Clair River. Assessments of the condition of coastal wetland across the study area were limited by variation in the types of data collected by different programs. A future goal will be to determine how best to align data collected from other programs with information collected using the CWM protocols.

Real-Time Logging of Water Level, DO, Light, and Wind to Assess Hydrological Conditions in Great Lakes Coastal Wetlands (2019-2022): The University of Windsor is coordinating a project to test the hypothesis that the numbers and species of fishes caught in wetland fyke nets are related to temporal variation in dissolved-oxygen (DO), and that such DO variation is partly driven by seiche activity causing temporary movement of cool, well-oxygenated lakewater into and out of wetlands. This variation in DO may be especially important in the densely vegetated, shoreline-associated wetland zones (usually wet meadow but also cattail, under high-water conditions). An SOP document was developed in spring 2019 and circulated to all field crews. Each field team has been encouraged to deploy water level and DO loggers at their fyke net sites over the course of the summer. In addition to providing important basic hydrological information about the condition of coastal wetlands, the resulting Great Lakes-wide dataset will help account for variation in fish catches and ultimately improve the precision of fish IBI estimates.

Bathymetry and mapping of wetlands in Point Pelee National Park during a period of hydrologic change (2018-2020): In 2018 Point Pelee National Park (PPNP) received approval through the Parks Canada Conservation and Restoration Project to begin a 4-year marsh restoration project. The project was focused on 1) increasing open water habitat and interspersion within the marsh, and 2) reducing invasive vegetation. Members of coPI Ciborowski's CWM team were asked if they would be able to conduct a preliminary survey of PPNP wetlands to determine the bottom profile and distribution of submerged aquatic vegetation. There was a special interest in the bathymetry of Lake Pond, whose eastern shoreline had been breached by wave action from Lake Erie during the summer as a consequence of the historically high water levels. In fall 2018 and during the 2019 field season, we conducted a benchmark survey of vegetation, aquatic invertebrates and water chemistry. We also assessed water depth, macrophyte distribution and cover and sediment characteristics throughout the wetland using the remotely-operated ROVER, which was developed for shallow-water data collection in remote locations. Water level and dissolved oxygen loggers set in place in the spring provided a full-season record of the frequency of seiches and associated changes in water quality. In 2020, we attempted to sample Lake Pond in PPNP to provide Park personnel with additional pre-restoration baseline information relating to the implementation of a vegetation-removal exercise meant to reduce *Phragmites* and *Typha* encroachment and improve hydrological connectivity among several connected waterbodies.

Inventory and distribution of zooplankton in coastal wetlands (2017-2022): As part of ongoing interest in assessing the condition of CWM wetlands the CWMP Ciborowski team began assessing the community composition of zooplankton in the wetlands visited as part of the monitoring program. Pilot samples were first collected in 2017. In 2018, zooplankton samples were collected at 16 Great Lakes coastal wetlands, situated off Manitoulin Island, northern Lake Huron, the western basin of Lake Erie, the Bruce Peninsula and Georgian Bay. In each wetland, samples were collected at 3 shallow-water points along a dissolved oxygen gradient. Records of water depth, substrate characteristics and vegetation density and composition were also tabulated. The sampling methods were based on techniques proposed by Lougheed and Chow-Fraser (2002) in developing their Zooplankton Quality Index. Seven Lake Huron wetlands were sampled in 2019.

Evaluating Fish and Invertebrate Distribution in Great Lakes Coastal Wetlands - an Occupancy Modelling Approach (2018-2020): Led by University of Windsor postdoctoral fellow student Martin Jeanmougin, this project involves fish coPIs Joseph Gathman, Carl Ruetz, and Jan Ciborowski. Occupancy modelling is a statistical approach that allows one to estimate the probability that a taxon is present in an area and the probability that it can be detected by sampling. Applying this approach to the invertebrate and fish CWM data may help us identify important environmental factors influencing the likelihood that selected taxa occur in particular habitats and to more accurately estimate their distribution across the Great Lakes. Also, an analysis of the detection patterns may provide important information on potential biases in the protocols we use to sample the biota. The previous work done by K. Dykstra of Grand Valley State University (Carl Ruetz's lab) for the thesis on Yellow Perch distribution was a good starting point for this project.

Genetic Barcodes for Wetland Macroinvertebrates (2017-2021): Surveillance of aquatic macroinvertebrates in the Great Lakes is of utmost importance. However, many organisms, particularly aquatic macroinvertebrates, lack information that can assist in their identification, whether through molecular barcodes or morphological characteristics. PI Uzarski with coPI Brady used CWMP aquatic macroinvertebrate samples from throughout the Great Lakes basin to generate genetic barcodes that will assist in identification of species (MOTUs) and expand the currently available molecular genetic databases. Our work targeted specific groups to improve morphological identification to lowest taxonomic levels. These data will be used to test the usefulness of metabarcoding for Great Lakes surveillance to provide managers with valuable monitoring information.

Assessing Climate Vulnerability in Apostle Islands Coastal Wetlands (2017-2019: Funded by the National Park Service and GLRI, a team from Northland College led by coPI Cooper sampled fish, macroinvertebrates, vegetation, and hydrologic variables in lagoon wetlands throughout the Apostle Islands National Lakeshore to identify species and communities that may be particularly vulnerable to climate change. This work represents an intensification of sampling effort within a sensitive and relatively pristine area of the Great Lakes. Data from this project were analyzed in relation to CWMP data to put Apostle Islands wetlands into a broader Great Lakes context.

Functional Indicators of Coastal Wetland Condition (2016-2019): Funded by the USGS through a Cooperative Ecosystem Studies Unit (CESU), this pilot project worked to determine functional indicators of Great Lakes coastal wetland usage by Great Lakes fish species. Sampling was done during the spring and fall at about 15 US wetlands already being assessed for CWM indicators during the summer. Data collected focused on fish usage of wetlands and the forage base for those fish, evaluated using macroinvertebrate sampling and examination of fish gut contents. Special emphasis was placed on determining usage of wetlands by young or spawning fish. The resulting paper, "Functional assessment of Great Lakes coastal wetlands: insights from seasonal fish communities" details seasonal fish community variation in GL coastal wetlands across spring, summer, and fall from 2016-2018 and has been accepted for publication in 2022.

Conservation Assessment for Amphibians and Birds of the Great Lakes (2017-2020): Several members of the CWM project team have initiated an effort to examine the role that Great Lakes wetlands play in the conservation of amphibians and birds in North America. The Great Lakes have many large, intact freshwater wetlands in the interior portion of the North American continent. Their unique character, size, and plant composition supports populations of many species of amphibians and birds, many of which have been identified as endangered, threatened, or of special concern in North America. CWM PIs are using the extensive data that have been gathered by USEPA, such as the Great Lakes Environmental Indicators project and the Great Lakes Wetlands Consortium, as well as Bird Studies Canada, as critical input to this assessment.

The initial stages in the development of the conservation assessment will be to analyze habitat and landscape characteristics associated with Great Lakes coastal wetlands that are important to wetland-obligate bird species occupying these habitats. By combining breeding bird data from the sources above and incorporating landscape variables, classification trees can be developed to predict presence and relative abundance of these species across the Great Lakes Basin. These methods, outlined in Hannah Panci's thesis; 'Habitat and landscape characteristics that influence Sedge Wren (*Cisthorus platensis*) and Marsh Wren (*C. palustris*) distribution and abundance in Great Lakes Coastal Wetlands'(University of Minnesota Duluth). She compiled data for over 800 wetlands in her analysis, which will provide a basis for analyzing additional wetland-obligate species.

Influence of broadcast timing and survey duration on marsh breeding bird point count results (2015-2017): Several members of the CWMP project team, with coPI D. Tozer as lead, examined the importance of survey duration and timing of broadcast playbacks on occurrence and counts of wetland breeding birds. The results of this analysis suggest that 10-min point counts are superior to 15-min counts. This has important implications for monitoring and cost-effectiveness. These findings were published in the journal of Avian Conservation and Ecology (Tozer *et al.* 2017).

North Maumee Bay Survey of Diked Wetland vs. Un-Diked Wetland (2016-2022): Erie Marsh Preserve is being studied as a benchmark site for the CWM project. As a benchmark site, Erie Marsh Preserve serves as a comparison against randomly-selected project sites, and is being surveyed each year of the CWM program. Benchmark sampling began prior to Phase 1 of a planned restoration by The Nature Conservancy, allowing for pre- and post-restoration comparisons. In addition, biota and habitat within the diked wetlands area is being compared to conditions outside of the dike, but still within the preserve. These data are also being used for post-construction comparisons to determine what biotic and abiotic changes are occurring following restoration efforts to reconnect the diked area to the shallow waters of Lake Erie.

Cattails-to-Methane Biofuels Research (2015-2019): CWM crews collected samples of invasive plants (hybrid cattail) which were analyzed by Kettering University and their Swedish Biogas partner to determine the amount of methane that can be generated from this invasive plant. These samples were compared to their dataset of agricultural crops, sewage sludge, and livestock waste that are currently used to commercially generate methane. Results demonstrated that hybrid cattail and reed canary grass both generated adequate levels of methane for use as feedstocks for biodigestion. The results of this and other CWM data collection are summarized in a Carson *et al.* 2018 journal article. The cattails-to-methane biofuels project was also funded (separately) by GLRI.

Correlation between Wetland Macrophytes and Wetland Soil Nutrients (2013-2017): CWM vegetation crews collected wetland soil samples and provided corresponding macrophyte data to substantially increase the number of sites and samples available to the USEPA Mid-Continent Ecology Division. USEPA MED researchers studied wetland macrophyte and wetland soil nutrient correlations. The MED (now GLTED) laboratory ran the sediment nutrient analyses and shared the data with CWM PIs.

Comparative study of bulrush growth (2014-2016) between Great Lakes coastal wetlands and Pacific Northwest estuaries. This study included investigation of water level effects on bulrush growth rates in Great Lakes coastal wetlands. This effort leveraged funding from NSF for the primary project on bulrush ability to withstand wave energy.

Braddock Bay, Lake Ontario, Sedge Meadow and Barrier Beach Restoration (2013-2025): Braddock Bay is being studied as a benchmark site in conjunction with the US Army Corps of Engineers to assess the restoration of sedge meadow eroded barrier beach to reduce wetland loss. CWM crews collected pre-restoration data to help plan and implement restoration activities and are collecting post-restoration data to help plan and implement restoration activities and assess results. The results will help build a model for future sedge meadow restoration in Lake Ontario to mitigate the harmful impacts of invasive cattails and provide habitat for fish and wildlife species. Additionally, this project was expanded, in conjunction with Ducks Unlimited, to four nearby wetlands, using funding from NOAA.

Thunder Bay AOC, Lake Superior, Wetland Restoration (2013-2014): Nine wetlands around Thunder Bay were sampled for macroinvertebrates, water quality, and aquatic vegetation by CWM crews in 2013 using methods closely related to CWM methods. This provide pre-restoration baseline data for the AOC delisting process. Wetlands sampled included both wetlands in need of restoration and wetlands being used as a regional reference. All sampling was in addition to normal CWM sampling and was done with funding from Environment Canada.

Common Tern Geolocator Project (2013-2015): In early June 2013, the NRRI CWM bird team volunteered to assist the Wisconsin DNR in deploying geolocator units on Common Terns nesting on Interstate Island, Duluth, MN, the largest remaining common tern colony in the Great Lakes. In 2013, 15 birds between the ages of 4-9 yrs old were outfitted with geolocators. Body measurements and blood samples were also taken to determine the sex of each individual. In June 2014, geolocators were removed from seven birds that returned to nest on the island. Of the seven retrieved geolocators, four were from female birds and three from males. The data collected during the year was used to better understand the migratory routes of Common Terns nesting on Interstate Island. This is the first time that geolocators were placed on Common Terns nesting in the Midwest, which is important because this species is listed as threatened in Minnesota and endangered in Wisconsin. Tracking Common Terns throughout their annual cycle helps identify locations that are important during the non-breeding portion of their life cycle.

Using Monitoring Results to Improve Management of Michigan's State-Owned Costal Wetlands (2016-2017): This one-year project was awarded to Central Michigan University by the Michigan Department of Environmental Quality. It focused on the prioritization of high-quality and important state-owned coastal wetlands that have been monitored as part of the Great Lakes CWM program, and development of site-specific management plans for these wetlands which address diverse management goals and objectives with a broad focus including biodiversity, ecological services, habitat for fish and wildlife, climate change adaptation, and rare species.

Developing a Decision Support System for Prioritizing Protection and Restoration of Great Lakes Coastal Wetlands (2014-2018): While a number of large coastal wetland restoration projects have been initiated in the Great Lakes, there remains little regional or basin-scale prioritization of restoration efforts. Until recently we lacked the data necessary for making systematic prioritization decisions for wetland protection and restoration. However, now that basin-wide coastal wetland monitoring data are available, development of a robust prioritization tool is possible. Led by coPI Cooper, we developed a new Decision Support System (DSS) to prioritize protection and restoration investments. This project, funded by the Upper Midwest and Great Lakes Landscape Conservation Cooperative, the Michigan Office of the Great Lakes, and the US Army Corp. of Engineers, developed a DSS for wetlands along the US shoreline of the Great Lakes.

Quantifying Coastal Wetland – Nearshore Linkages in Lake Michigan for Sustaining Sport Fishes (2015-2018): With support from Sea Grant (Illinois-Indiana and Wisconsin programs), personnel from UND and CWM compared food webs from coastal wetlands and nearshore areas of Lake Michigan to determine the importance of coastal wetlands in sustaining the Lake Michigan food web. The project emphasis was on identifying sport fish-mediated linkages between wetland and nearshore habitats. Specifically, we (1) constructed cross-habitat food webs using stable C and N isotope mixing models, (2) estimated coastal wetland habitat use by sport fishes using otolith microchemistry, and (3) built predictive models of both linkage types that account for the major drivers of fish-mediated linkages in multiple Lake Michigan wetland types, including some wetlands sampled by the Coastal Wetland Monitoring program. Collaborators are the University of Wisconsin – Green Bay and Loyola University Chicago.

Clough Island (Duluth/Superior) Preservation and Restoration (2013-2014): The Wisconsin Department of Natural Resources requested (and funded) a special report on sites sampled using CWM protocols around Clough Island within the St. Louis River Area of Concern (AOC). Their interests were to see if CWM data indicated any differences in habitat or species composition/abundances among Clough Island and other St. Louis River sites, and also how Clough Island compared to other nearby Lake Superior coastal wetlands. The 46 page report was submitted to Cherie Hagan of the WDNR in May of 2014. Clough Island was recently acquired by the Nature Conservancy and they are using the data in the report for their development of conservation plans for the area.

Floodwood Pond and Buck Pond South, Lake Ontario, Wetland Pothole Restoration (2013-2016): Open water potholes were established in these two wetlands by The Nature Conservancy to replace openings that had filled with cattail following lake-level regulation. CWM crews collected pre- and post-restoration data as benchmark sites in both wetlands to allow TNC to assess changes.

Buck Pond West and Buttonwood Creek, Lake Ontario, Sedge Meadow Restoration (2013-2022): These two wetlands in the Rochester Embayment AOC were restored by a consortium involving Ducks Unlimited, The College at Brockport, NYS Department of Environmental Conservation, and the Town of Greece. CWM crews collected pre-restoration data as a benchmark site to help plan and implement restoration activities. Post-restoration data collection continues under CWM to help assess results and help build a model for future sedge meadow restoration in Lake Ontario to mitigate the harmful impacts of invasive cattails and provide habitat for fish and wildlife species.

Salmon/West Creek, Long Pond, and Buck Pond East, Lake Ontario, Emergent Marsh Restoration (2012-2020): These three wetlands in the Rochester Embayment AOC are being sampled as benchmark sites by CWM crews to provide the U.S. Fish and Wildlife Service with pre- and post-restoration data.

Lower Green Bay and Fox River AOC (2013-2020): Results from the Coastal Wetland Monitoring Program (CWMP) and the Great Lakes Environmental Indicators (GLEI) Project are playing a central role in a $471,000 effort to establish fish and wildlife beneficial use impairment (BUI) removal targets for the Lower Green Bay and Fox River AOC. 1) Protocols for intensive sampling of bird, anurans, and emergent wetland plants in the project area followed the exact methods used by CWMP so that results are directly comparable with sites elsewhere in the Great Lakes. 2) Data from GLEI on diatoms, plants, invertebrates, fish, birds, and anurans and from CWMP for birds and anurans were used to identify sensitive species that are known to occur in the AOC and have shown to be sensitive to environmental stressors elsewhere in the Great Lakes. These species were compiled into a database of priority conservation targets. 3) Methods of quantifying environmental condition developed and refined as part of GLEI and CWMP were being used to assess the condition of the AOC (as well as specific sites within the AOC) and to set specific targets for the removal of two important BUIs (fish and wildlife populations and fish and wildlife habitats). 4. Application of the Index of Ecological Condition method (e.g., Howe et al. 2007) for assessing the condition of wetlands using birds, anurans, and other fish and wildlife groups. Follow-up work was funded for 2018-2020 at $87,000 to continue refining field monitoring methods and metrics of 40 fish and wildlife habitats and populations.

SOGL/SOLEC Indicators (2013-2025): CWMP PIs developed a set of indicator metrics for the State of the Great Lakes/State of the Lakes Ecosystem Conference (SOLEC). These much-needed metrics filled a gap in quantifying responses of coastal wetland biotic communities to environmental stress throughout the Great Lakes. Sites for all coastal wetlands sampled by the GLEI, CWMP, and Marsh Monitoring Program efforts are scored according to several complementary indices that provide information about local and regional condition of existing wetlands.

Roxana Marsh Restoration, Lake Michigan (2015-2018): The University of Notre Dame (UND) team, led by graduate student Katherine O'Reilly and undergraduate Amelia McReynolds under the direction of project co-PI Gary Lamberti, leveraged CWMP to do an assessment of recently-restored Roxana Marsh along the south shore of Lake Michigan. Roxana Marsh is a 10-ha coastal wetland located along the Grand Calumet River in northwestern Indiana. An EPA-led cleanup of the west branch of the Grand Calumet River AOC including the marsh was completed in 2012 and involved removing approximately 235,000 cubic yards of contaminated sediment and the reestablishment of native plants. Ms. McReynolds obtained a summer 2015 fellowship from the College of Science at UND to study the biological recovery of Roxana Marsh, during which several CWMP protocols were used. This led to the discover of the invasive oriental weatherfish (*Misgurnus anguillicaudatus*) in the marsh. Oriental weatherfish are native to southeast Asia and are believed to have been introduced to the U.S. via the aquarium trade. Although there have been previous observations of *M. anguillicaudatus* in the river dating back to 2002, it was not previously recorded in Roxana Marsh, and little information is available on its biological impacts there or elsewhere. We used stable carbon and nitrogen isotopes, along with diet analysis, to determine the role of *M. anguillicaudatus* in the wetland food web and its potential for competition with native fauna for food or habitat resources. This discovery received media attention from the Illinois-Indiana Sea Grant College Program.

Chlorophyll-*a* Modeling (2015-2022): The UND team, in collaboration with Northland College, CMU, and others, is investigating the drivers that influence water column chlorophyll-*a* in coastal wetlands. Our hypothesis was that chlorophyll-*a* is related to nutrient status of wetlands and degree of development of adjoining land. Along with CWMP water data, we used GIS land use and connectivity data. Specifically, we are answering the following questions: (1) What variables best predict chlorophyll-*a* in coastal wetlands across the entire Great Lakes basin? (2) How do these variables change across each basin (i.e., Lake Michigan, Lake Erie, Lake Ontario, Lake Superior, Lake Huron)? (3) Are there differences in predictor variables across sub-basins (e.g., Lake Erie North vs. Lake Erie South)? (4) Does wetland type (lacustrine, riverine, or barrier) change chlorophyll-*a* predictors? (5) How do other potential variables, such as vegetation zone type or year, change chlorophyll-*a* predictors?

Invasion Vulnerability Index (2015-2020): The UND team, in collaboration with other CWMP teams, aims to create a usable tool that predicts which aquatic invasive species from a list of 10 Great Lakes Aquatic Nuisance Species Information System (GLANSIS) watchlist species are of highest concern for prevention and early detection. We are combining Habitat Suitability Indexes (HSIs) made using wetland site-specific physio-chemical measurements and potential pathway data (distance to potential introduction pathways and distance to known established populations). Ultimately, we will produce an interactive, exploratory tool in which a wetland can be selected and a table will appear that shows the breakdown of invasion risk by species as invasion likelihood scores. If more information is desired about how the invasion likelihood score was calculated, an attribute table will display the numerical values for each criterion in the model. One of the main concerns with invasive species is how climate change will alter habitat suitability. To accommodate this concern, we will also include versions with future climate change scenarios using published IPCC environmental conditions. This information will be packaged together in an IVI for Great Lakes wetlands usable by scientists, managers, and the general public.

Green Bay Area Wetlands (2011-2016): Data from the benchmark site Suamico River Area Wetland was requested by and shared with personnel from the Wisconsin Department of Natural Resources and The Nature Conservancy, who are involved in the restoration activities to re-connect a diked area with Green Bay. In 2011 NRRI sampled outside the diked area following CWM methods, and in 2013 we sampled within the diked area as a special request. After restoration work and the addition of “pike fingers” (shallow water areas designed to attract spawning pike), NRRI again sampled the area and showed that these “fingers” were used as habitat by spawning pike. The data were summarized for fish, invertebrates, water quality, birds, and vegetation and shared with David Halfmann (WDNR) and Nicole Van Helden (TNC).

Hybridizing fish (2013-2018): In 2013 the NRRI field crew encountered gar around the Green Bay area of Lake Michigan which exhibited mixed morphological traits of shortnose and longnose species. At that time, John Lyons at the Wisconsin Department of Natural Resources was working on a project to confirm hybrid individuals in the Fox River watershed (which drains into Green Bay, WI). Josh Dumke at NRRI contributed photos to John Lyons of gar captured in Green Bay during Coastal Wetland Monitoring fish surveys, and those contributions were acknowledged in a recently-published article: Lyons, J., and J.T. Sipiorski. 2020. Possible large-scale hybridization and introgression between Longnose Gar (*Lepisosteous osseus*) and Shortnose Gar (*Lepisosteous platostomus*) in the Fox River drainage, Wisconsin. *American Midland Naturalist*, 183:105-115). In 2014 and 2015 Coastal Wetland Monitoring fish teams collected gar fin clips across the entire Great Lakes basin for a much more comprehensive look at species distributions and hybridization.

Management alternatives for hybrid cattail (*Typha x glauca*; 2011- 2014): Differing harvest regimes for hybrid cattail were evaluated at Cheboygan, Cedarville, and Munuscong Bay in northern Michigan with USEPA GLRI funding. At all of these sites plant data were collected by CWMP teams and used as baseline data that were compared to control sites. Analyses demonstrated that during low-water conditions, native plant diversity was increased by harvest of hybrid cattail.

Impacts of hybrid cattail management on European frogbit (*Hydrocharis morsus-ranae;* 2016-2017); This study, funded by MI DNR for research by Loyola Chicago and Oregon State University, studied the response of European frogbit to cattail management using CWMP plant data collected in Munuscong Bay as baseline data. CWMP data collected from 2011 to 2015 provided documentation of the expanding range of frogbit into the western Great Lakes. The study found that open, flooded stands of hybrid cattail provided important habitat for European frogbit, but that management to remove cattail was not effective for frogbit control.

Nutrient limitation in Great Lakes coastal wetlands (2014-2017): Analyses of CWMP water quality data indicate that reactive nitrogen concentration is often much lower in wetland habitats than the adjacent Great Lake nearshore. With funding from Illinois-Indiana Sea Grant and the Wisconsin DNR, UND teams evaluated the role of nitrogen limitation on benthic algal growth in wetlands throughout Lakes Michigan, Huron, and Superior.

Support for Un-affiliated Projects

CWMP PIs and data managers provided data and support to other research projects around the Great Lakes even though CWM PIs were not collaborators on these projects.

Advanced mapping of Great Lakes coastal wetlands and invasive plants (2012-2017): Dr. Laura Bourgeau-Chavez at Michigan Tech University mapped the spatial extent of Great Lakes coastal wetlands using GIS and satellite information to help in tracking wetland gains and losses over time (Implementation of the Great Lakes Coastal Wetlands Consortium Mapping Protocol, funded by GLRI). CWMP provided her with vegetation data and sampling locations each year to assist with this effort. Dr. Bourgeau-Chavez was also given funding to assess herbicide effectiveness against *Phragmites* in Green Bay and Saginaw Bay. CWM data were used to find the best locations, provide baseline data, and provide pointers on site access (from field crew notes) in support of this project.

Reports on new locations of non-native and invasive species (2013-2025): CWMP PIs were pro-active over the years in reporting new locations of invasive vegetation and non-native fish and macroinvertebrates. To ensure that all new sightings were reported, we pull all records of non-native fish and macroinvertebrates out of the database once every year or two and send these records to the Nonindigenous Aquatic Species tracking website maintained by USGS (http://nas2.er.usgs.gov/). Wetland vegetation PIs contributed new SOLEC indicator guidelines and reports and continue to participate in the indicator review process.

Wetland Floristic Quality in the St. Louis River Estuary (2014-2018): With support from WI Sea Grant, CWMP vegetation coPI N. Danz integrated vegetation surveys from CWMP with data from 14 other recent projects in the St. Louis River Estuary. A new relational database was created to assess spatial and temporal patterns in floristic quality and to develop materials to inform and monitor wetland restorations in this AOC.

Coordination and Partnership with National Audubon (2016-2020): CWMP bird coPIs created a data sharing agreement with the National Audubon Society. CWMP provided data and guidance on appropriate use of bird data for their project “Prioritizing coastal wetlands for marsh bird conservation in the U.S. Great Lakes”. All CWMP bird and anuran co-investigators had the opportunity to contribute to the resulting manuscript (https://doi.org/10.1016/j.biocon.2020.108708) and be included as co-authors. CWMP bird PIs are currently working on another data sharing agreement with Audubon for further collaboration.

Targeting Invasive Plant Species in Wisconsin Coastal Wetlands (2018-2022): In collaboration with WI Department of Natural Resources and Lake Superior Research Institute, vegetation coPIs summarized patterns of invasive plant occurrence in Wisconsin coastal wetlands. These summaries are being used to develop a more comprehensive invasive plant monitoring strategy throughout the Wisconsin basin.

Overview of Requests for Assistance Collecting Monitoring Data

CWMP PIs provided monitoring data and interpretation of data for many wetlands where restoration activities were proposed by applicants for "Sustain Our Great Lakes" funding. This program is administered by the National Fish and Wildlife Foundation (NFWF) and includes GLRI funding. Proposal writers made data/information requests via NFWF, who communicated the requests to us. Lead PI Don Uzarski, with assistance from co-PIs, pulled relevant project data and provided interpretations of IBI scores and water quality data. This information was communicated to NFWF, who communicated with the applicants. This information sharing reflects the value of having coastal wetland monitoring data to inform restoration and protection decisions. We anticipate similar information sharing in the coming years as additional restoration and protection opportunities arise.

In addition to the NFWF program, CWM PIs received many requests to sample particular wetlands of interest to various agencies and groups. In some instances the wetlands were scheduled for restoration and it was hoped that our project could provide pre-restoration data, and perhaps also provide post-restoration data to show the beginnings of site condition improvement, depending on the timing. Such requests have come for the following AOC's: the St. Louis River (Lake Superior), Green Bay (Lake Michigan), Detroit River (Lake St. Clair), Maumee Bay (Lake Erie), and Rochester (Lake Ontario). Other groups requesting such data include the Great Lakes National Park Service and the Nature Conservancy (sites across lakes Michigan and Huron for both groups), as well as state natural resource departments. Several requests involved restorations specifically targeted to create habitat for biota that are being sampled by CWM. Examples include: a NOAA-led restoration of wetlands bordering the Little Rapids of the St. Marys River to restore critical spawning habitat for many native freshwater fishes and provide important nursery and rearing habitat in backwater areas; TNC-led restoration of pike spawning habitats on Lake Ontario and in Green Bay; a US Army Corps of Engineers project in Green Bay to create protective barrier islands, shorebird nesting habitat, and restore many acres of aquatic and wetland vegetation; a USACE project to improve wetland fish and vegetation habitat in Braddock Bay, Lake Ontario; a New York state project to increase nesting habitat for state-endangered black tern; and projects in Wisconsin to restore degraded coastal wetlands on the Lake Superior shore. Many of these restoration activities were funded through GLRI, so through collaboration we increased the efficiency and effectiveness of restoration efforts across the Great Lakes basin.

Other groups requested help sampling sites that were believed to be in very good condition (at least for their geographic location), or were among the last examples of their kind, and were on lists to be protected. These requests came from The Nature Conservancy for Green Bay sites (they developed a regional conservation strategy and are attempting to protect the best remaining sites) and the St. Louis River AOC delisting committee to provide target data for restoration work (i.e., what should a restored site "look" like). The Wisconsin DNR Natural Heritage Inventory requested assistance in looking for rare, endangered, and threatened species and habitats in all of the coastal wetlands along Wisconsin's Lake Superior coastline. Southern Lake Michigan wetlands have mostly been lost and only three remain that are truly coastal wetlands. CWM PIs are worked with Illinois agencies and conservation groups to collaboratively and thoroughly sample one of these sites, and the results will be used to help manage all 3 sites.

Other managers also requested data to help them better manage wetland areas. For example, the Michigan Clean Water Corps requested CWMP data to better understand and manage Stony Lake, Michigan. Staff of a coal-fired power plant abutting a CWMP site requested our fish data to help them better understand and manage the effects of their outfalls on the resident fish community. The Michigan Natural Features Inventory requested our data as part of a GLRI-funded invasive species mapping project. The US Fish and Wildlife Service requested all data possible from wetlands located within the Rochester, NY, Area of Concern to assess trends in the wetlands and compare data to designated delisting criteria. The NERR on Lake Erie (Old Woman Creek) requested our monitoring data to add to their own. The University of Wisconsin Green Bay used our data to monitor control of *Phragmites* in one of the wetlands they manage and are restoring. Thunder Bay National Marine Sanctuary (Lake Huron) requested our data to facilitate protection and management of coastal resources within the Sanctuary. The Wisconsin DNR requested data for the Fish Creek wetland as part of an Environmental Impact Assessment related to a proposed Confined Animal Feeding Operation upstream of the wetland.

We received a request from the USFWS for data to support development of a black tern distribution/habitat model for the Great Lakes region. The initial effort focused on lakes Huron, Erie and their connecting channels. Various FWS programs (e.g., Migratory Bird, Joint Venture, and Landscape Conservation Cooperatives) are interested in this model as an input to conservation planning for Great Lakes wetlands.

The College at Brockport notified an invasive species rapid-response team led by The Nature Conservancy after each new sighting of invasive water chestnut. Coupling the monitoring efforts of this project with a rapid-response team helped to eradicate small infestations of this new invasive before it became a more established infestation.

We also received requests to do methods comparison studies. For example, USGS and Five Fathom National Marine Park both requested data and sampling to compare with their own sampling data.

Student Research Support

Graduate Research with Leveraged Funding:

- Updating Dr. Gerald Mackie's key to Sphaeriidae (fingernail clams) of the Great lakes as informed by DNA analyses (University of Minnesota Duluth in collaboration with GLRI-funded work at Central Michigan University, the laboratory of Dr. Andrew Mahon).
- Importance of coastal wetlands to offshore fishes of the Great Lakes: Dietary support and habitat utilization (Central Michigan University; with additional funding from several small University grants and the US Fish and Wildlife Service).
- Spatial variation in macroinvertebrate communities within two emergent plant zones in Great Lakes coastal wetlands (Central Michigan University; with additional funding from CMU).
- Invertebrate co-occurrence patterns in coastal wetlands of the Great Lakes: Community assembly rules (Central Michigan University; additional funding from CMU)
- Functional indicators of Great Lakes coastal wetland health (University of Notre Dame; additional funding by Illinois-Indiana Sea Grant).
- Evaluating environmental DNA detection alongside standard fish sampling in Great Lakes coastal wetland monitoring (University of Notre Dame; additional funding by Illinois-Indiana Sea Grant).
- Nutrient-limitation in Great Lakes coastal wetlands (University of Notre Dame; additional funding by the UND College of Science).
- A summary of snapping turtle (*Chelydra serpentina*) by-catch records in Lake Ontario coastal wetlands (with additional funding by University of Toronto).
- Evaluating a zoobenthic indicator of Great Lakes wetland condition (with additional funding from University of Windsor).
- Testing and comparing the diagnostic value of three fish community indicators of Great Lakes wetland condition (with additional funding from GLRI GLIC: GLEI II and University of Windsor).
- Quantifying Aquatic Invasion Patterns Through Space and Time: A Relational Analysis of the Laurentian Great Lakes (University of Minnesota Duluth; with additional funding and data from USEPA)

- Novel Diagnostics for Biotransport of Aquatic Environmental Contaminants (University of Notre Dame, with additional funding from Advanced Diagnostics & Therapeutics program)
- Conservation of Common Terns in the Great Lakes Region (University of Minnesota; with additional funding from USFWS, MNDNR, and multiple smaller internal and external grants).
- Distribution of yellow perch in Great Lakes coastal wetlands (Grand Valley State University; with additional funding from GVSU).
- Variation in aquatic invertebrate assemblages in coastal wetland wet meadow zones of Lake Huron, of the Laurentian Great Lakes (University of Windsor; with additional funding from the University of Windsor).
- Influence of water level fluctuations and diel variation in dissolved oxygen concentrations on fish habitat use in Great Lakes coastal wetlands (University of Windsor; with additional funding from the University of Windsor).
- Bird community response to changes in wetland extent and lake level in Great Lakes coastal wetlands (University of Wisconsin-Green Bay with additional funding from Bird Studies Canada)
- Inferential measures for a quantitative ecological indicator of ecosystem health (University of Wisconsin-Green Bay)
- Per- and polyfluorinated alkyl substances (PFAS) in Great Lakes food webs and sportfish (University of Notre Dame)

Undergraduate Research with Leveraged Funding:

- Production of a short documentary film on Great Lakes coastal wetlands (University of Notre Dame; additional funding by the UND College of Arts and Letters).
- Heavy metal loads in freshwater turtle species inhabiting coastal wetlands of Lake Michigan (University of Notre Dame; additional funding by the UND College of Science, and ECI – Environmental Change Institute). Online coverage, TV and radio.
- Nitrogen-limitation in Lake Superior coastal wetlands (Northland College; additional funding from the Wisconsin DNR and Northland College).
- Patterns in chlorophyll-*a* concentrations in Great Lakes coastal wetlands (Northland College; additional funding provided by the college).
- *Phragmites australis* effects on coastal wetland nearshore fish communities of the Great Lakes basin (University of Windsor; with additional funding from GLRI GLIC: GLEI II).
- Sonar-derived estimates of macrophyte density and biomass in Great Lakes coastal wetlands (University of Windsor; with additional funding from GLRI GLIC: GLEI II presented at the International Association for Great Lakes Research annual meeting).

- Effects of disturbance frequency on the structure of coastal wetland macroinvertebrate communities (Lake Superior State University; with additional funding from LSSU's Undergraduate Research Committee; awarded Best Student Poster award at LSSU Research Symposium; presented at MI American Fisheries Society annual meeting).
- Resistance and resilience of macroinvertebrate communities in disturbed and undisturbed coastal wetlands (Lake Superior State University; with additional funding from LSSU's Undergraduate Research Committee, (presented at MI American Fisheries Society annual meeting and Midwest Fish and Wildlife Conference).
- Structure and function of restored Roxana Marsh in southern Lake Michigan (University of Notre Dame, with additional funding from the UND College of Science)
- Nutrient limitation in Great Lakes coastal wetlands (Central Michigan University, CMU Biological Station on Beaver Island)
- Effects of wetland size and adjacent land use on taxonomic richness (University of Minnesota Duluth, with additional funding from UMD's UROP program)
- Water depth optima and tolerances for St. Louis River estuary wetland plants (University of Wisconsin-Superior, with additional funding from WI Sea Grant)
- Mapping Wetland Areal Change in the St. Louis River Estuary Using GIS (University of Wisconsin-Superior, with additional funding from WI Sea Grant)
- An analysis of Microcystin concentrations in Great Lakes coastal wetlands (Central Michigan University; additional funding by CMU College of Science and Engineering).
- Bathymetry and water levels in lagoonal wetlands of the Apostle Islands National Lakeshore (Northland College; additional funding from the National Park Service). Several presentations at regional meetings and IAGLR.
- Non-native fish use of Great Lakes coastal wetlands (Northland College funding). Poster presentations by Northland College students at Wisconsin Wetland Science Meeting and IAGLR.

Graduate Research without Leveraged Funding:

- Impacts of drainage outlets on Great Lakes coastal wetlands (Central Michigan University).
- Effects of anthropogenic disturbance affecting coastal wetland vegetation (Central Michigan University).
- Great Lakes coastal wetland seed banks: what drives compositional change? (Central Michigan University).
- Spatial scale variation in patterns and mechanisms driving fish diversity in Great Lakes coastal wetlands (Central Michigan University).

- Building a model of macroinvertebrate functional feeding group community through zone succession: Does the River Continuum Concept apply to Great Lakes coastal wetlands? (Central Michigan University).
- Chemical and physical habitat variation within Great Lakes coastal wetlands; the importance of hydrology and dominant plant zonation (Central Michigan University)
- Macroinvertebrate-based Index of Biotic Integrity for Great Lakes coastal wetlands (Central Michigan University)
- Habitat conditions and invertebrate communities of Great Lakes coastal habitats dominated by Wet Meadow, and *Phragmites australis*: implications of macrophyte structure changes (Central Michigan University)
- The establishment of *Bithynia tentaculata* in coastal wetlands of the Great Lakes (Central Michigan University)
- Environmental covariates as predictors of anuran distribution in Great Lakes coastal wetlands (Central Michigan University)
- Impacts of muskrat herbivory in Great Lakes coastal wetlands (Central Michigan University).
- Mute swan interactions with native waterfowl in Great Lakes coastal wetlands (Central Michigan University).
- Effects of turbidity regimes on fish and macroinvertebrate community structure in coastal wetlands (Lake Superior State University and Oakland University).
- Scale dependence of dispersal limitation and environmental species sorting in Great Lakes wetland invertebrate meta-communities (University of Notre Dame).
- Spatial and temporal trends in invertebrate communities of Great Lakes coastal wetlands, with emphasis on Saginaw Bay of Lake Huron (University of Notre Dame).
- Model building and a comparison of the factors influencing sedge and marsh wren populations in Great Lakes coastal wetlands (University of Minnesota Duluth).
- The effect of urbanization on the stopover ecology of Neotropical migrant songbirds on the western shore of Lake Michigan (University of Minnesota Duluth).
- Assessing the role of nutrients and watershed features in cattail invasion (*Typha angustifolia* and *Typha* x *glauca*) in Lake Ontario wetlands (The College at Brockport).
- Developing captive breeding methods for bowfin (*Amia calva*) (The College at Brockport).
- Water chestnut (*Trap natans*) growth and management in Lake Ontario coastal wetlands (The College at Brockport).
- Functional diversity and temporal variation of migratory land bird assemblages in lower Green Bay (University of Wisconsin-Green Bay).

- Effects of invasive *Phragmites* on stopover habitat for migratory shorebirds in lower Green Bay, Lake Michigan (University of Wisconsin-Green Bay).
- Plant species associations and assemblages for the whole Great Lakes, developed through unconstrained ordination analyses (Oregon State University).
- Genetic barcoding to identify black and brown bullheads (Grand Valley State University).
- Coastal wetland – nearshore linkages in Lake Michigan for sustaining sport fishes (University of Notre Dame)
- Anthropogenic disturbance effects on bird and anuran communities in Lake Ontario coastal wetlands (The College at Brockport)
- A fish-based index of biotic integrity for Lake Ontario coastal wetlands (The College at Brockport)
- Modeling potential nutria habitat in Great Lakes coastal wetlands (Central Michigan University)
- Modeling of Eurasian ruffe (*Gymnocephalus cernua*) habitat preferences to predict future invasions (University of Minnesota Duluth in collaboration with USEPA MED)
- Modeling species-specific habitat associations of Great Lakes coastal wetland birds (University of Minnesota)
- The effect of urbanization on the stopover ecology of Neotropical migrant songbirds on the western shore of Lake Michigan (University of Minnesota Duluth).
- Nutrient limitation in Great Lakes coastal wetlands: gradients and their influence (Central Michigan University; with additional funding from the CMU College of Science and Engineering)
- Invasive *Phragmites australis* management (Central Michigan University; with additional funding from the CMU College of Science and Technology)
- The relationship between vegetation and ice formation in Great Lakes coastal wetlands (Central Michigan University; with additional funding from CMU College of Science and Engineering)
- PFAS accumulation by Dressenidae *spp* in Great Lakes Coastal Wetlands (Central Michigan University)
- Development of a vegetation based IBI for Great Lakes Coastal Wetlands (Central Michigan University)
- Development of a model for Great-Lakes wide invasive plant harvest for bioenergy production and nutrient recycling (Loyola Chicago and Oregon State University)

- Updating the Macroinvertebrate-based Index of Biotic Integrity for Great Lakes coastal wetlands (Central Michigan University)

Undergraduate Research without Leveraged Funding:

- Sensitivity of fish community metrics to net set locations: a comparison between Coastal Wetland Monitoring and GLEI methods (University of Minnesota Duluth).
- Larval fish usage and assemblage composition between different wetland types (Central Michigan University).
- Determining wetland health for selected Great Lakes Coastal Wetlands and incorporating management recommendations (Central Michigan University).
- Invertebrate co-occurrence trends in the wetlands of the Upper Peninsula and Western Michigan and the role of habitat disturbance levels (Central Michigan University).
- Is macroinvertebrate richness and community composition determined by habitat complexity or variation in complexity? (University of Windsor, complete; Published in *Ecosphere*).
- Modeling American coot habitat relative to faucet snail invasion potential (Central Michigan University).
- Nutrient uptake by *Phragmites australis* and native wetland plants (Central Michigan University).
- Comparison of the diagnostic accuracy two aquatic invertebrate field collection and laboratory sorting methods (University of Windsor, complete).
- Validation of a zoobenthic assemblage condition index for Great Lakes coastal wetlands (University of Windsor, complete).
- Water depth-related variation in net ecosystem production in a Great Lakes coastal wet meadow (University of Windsor, complete).
- Anuran habitat use in the Lower Green Bay and Fox River Area of Concern (University of Wisconsin-Green Bay with support from GLRI/AOC funding).
- Impacts of European frog-bit invasion on wetland macroinvertebrate communities (Lake Superior State University; presented at Midwest Fish and Wildlife Conference).

- Effects of European frog-bit on water quality and fish assemblages in St. Marys River coastal wetlands (Lake Superior State University; presented at Midwest Fish and Wildlife Conference).

- Functional diversity of macroinvertebrates in coastal wetlands along the St. Marys River (Lake Superior State University; awarded Best Student Poster award at LSSU Research Symposium; presented at Midwest Fish and Wildlife Conference).

- A comparison of macroinvertebrate assemblages in coastal wetlands exposed to varying wave disturbance (Lake Superior State University; presented at MI American Fisheries Society annual meeting).

- Coastal wetlands as nursery habitat for young-of-year fishes in the St. Marys River (Lake Superior State University; presented at MI American Fisheries Society annual meeting)

- Relationship between water level and fish assemblage structure in St. Marys River coastal wetlands (Lake Superior State University; presented at MI American Fisheries Society annual meeting)

- Dominance patterns in macroinvertebrate communities in Great Lakes coastal wetlands: does environmental stress lead to uneven community structure? Northland College.
- Understanding drivers of chlorophyll-a in Great Lakes coastal wetlands. University of Notre Dame

Jobs Created/Retained (cumulative since 2011):

- Principal Investigators (partial support): 20 (average per year)
- Post-doctoral researchers (partial support; cumulative): 7
- Total graduate students supported on project (part-time; cumulative): 113
- Unpaid undergraduate internship (summer, cumulative): 35
- Undergraduate students (paid; summer and/or part-time; cumulative): 194
- Technicians, jr. scientists (summer and/or partial support; cumulative): 135
- Volunteers (cumulative): 47

Total jobs at least partially supported: 469.
Students and post-doctoral researchers trained: 349.

At our annual meeting in February 2021, we conducted a formal discussion session on Diversity, Equity, and Inclusion (DEI). The approximately 70 meeting participants were split randomly into

10 breakout groups to discuss three questions related to best practices for enhancing DEI in the CWMP workforce. In brief, the three questions concerned 1) current practices used to enhance DEI, 2) perceived barriers to enhancing DEI, and 3) potential mechanisms for enhancing DEI in the future. After discussion, the breakout groups returned to the main meeting session for discussion of findings as reported by a group spokesperson. A useful discussion then ensued of best practices (past, current, and future) for diversifying the CWMP workforce to achieve the goal of a workforce representative of the U.S. population as a whole. A scribe for each group then submitted written points to the meeting organizers. These comments were compiled and organized, and then redistributed to all CWMP participants.

Presentations about the Coastal Wetland Monitoring Program

Albert, Dennis. 2013. Use of Great Lakes Coastal Wetland Monitoring data in restoration projects in the Great Lakes region. 5th Annual Conference on Ecosystem Restoration, Schaumburg, IL. July 30, 2013. 20 attendees, mostly managers and agency personnel.

Albert, Dennis. 2013. Data collection and use of Great Lakes Coastal Wetland Monitoring data by Great Lakes restorationists. Midwestern State Wetland Managers Meeting, Kellogg Biological Station, Gull Lake, MI, October 31, 2013. 40 attendees; Great Lakes state wetland managers.

Albert, Dennis, N. Danz, D. Wilcox, and J. Gathman. 2014. Evaluating Temporal Variability of Floristic Quality Indices in Laurentian Great Lakes Coastal Wetlands. Society of Wetland Scientists, Portland, OR. June.

Albert, Dennis, et al. 2015. Restoration of wetlands through the harvest of invasive plants, including hybrid cattail and *Phragmites australis*. Presented to Midwestern and Canadian biologists. June.

Albert, Dennis, et al. 2015. Great-Lakes wide distribution of bulrushes and invasive species. Coastal and Estuarine Research Federation Conference in Portland, Oregon. November.

Baldwin, R., B. Currell, and A. Moerke. 2014. Effects of disturbance history on resistance and resilience of coastal wetlands. Midwest Fish and Wildlife Conference, January, Kansas City, MO.

Baldwin, R., B. Currell, and A. Moerke. 2014. Effects of disturbance history on resistance and resilience of coastal wetlands. MI American Fisheries Society annual meeting, February, Holland, MI.

Bergen, E., E. Shively, M.J. Cooper. Non-native fish species richness and distributions in Great Lakes coastal wetlands. International Association for Great Lakes Research Annual Conference, June 10-14, 2019, Brockport, NY. (poster)

Bergen, E., E. Shively, M.J. Cooper. Drivers of non-native fish species richness and distribution in the Laurentian Great Lakes. February 19-21, 2019. Madison, WI. (poster)

Bozimowski, S. and D.G. Uzarski**.** 2016. The Great Lakes coastal wetland monitoring program. 2016 Wetlands Science Summit, Richfield, OH. September, Oral Presentation.

Bozimowski, A.A., B.A. Murry, and D.G. Uzarski. 2012 Invertebrate co-occurrence patterns in the wetlands of northern and eastern Lake Michigan: the interaction of the harsh-benign hypothesis and community assembly rules. 55th International Conference on Great Lakes Research, Cornwall, Ontario.

Bozimowski, A. A., B. A. Murry, P. S. Kourtev, and D. G. Uzarski. 2014. Aquatic macroinvertebrate co-occurrence patterns in the coastal wetlands of the Great Lakes: the interaction of the harsh-benign hypothesis and community assembly rules. Great Lakes Science in Action Symposium, Central Michigan University, Mt. Pleasant, MI. April.

Bozimowski, A.A., B.A. Murry, P.S. Kourtev, and D.G. Uzarski. 2015. Aquatic macroinvertebrate co-occurrence patterns in the coastal wetlands of the Great Lakes. 58th International Conference on Great Lakes Research, Burlington, VT.

Bozimowski, A.A. and D.G. Uzarski. 2017. Monitoring a changing ecosystem: Great Lakes coastal wetlands. Saginaw Bay Watershed Initiative Network's State of the Bay Conference.

Bracey, A. M., R. W. Howe, N.G. Walton, E. E. G. Giese, and G. J. Niemi. Avian responses to landscape stressors in Great Lakes coastal wetlands. 5th International Partners in Flight Conference and Conservation Workshop. Snowbird, UT, August 25-28, 2013.

Brady, V., D. Uzarski, and M. Cooper. 2013. Great Lakes Coastal Wetland Monitoring: Assessment of High-variability Ecosystems. USEPA Mid-Continent Ecology Division Seminar Series, May 2013. 50 attendees, mostly scientists (INVITED).

Brady, V., G. Host, T. Brown, L. Johnson, G. Niemi. 2013. Ecological Restoration Efforts in the St. Louis River Estuary: Application of Great Lakes Monitoring Data. 5th Annual Conference on Ecosystem Restoration, Schaumburg, IL. July 30, 2013. 20 attendees, mostly managers and agency personnel.

Brady, V. and D. Uzarski. 2013. Great Lakes Coastal Wetland Fish and Invertebrate Condition. Midwestern State Wetland Managers Meeting, Kellogg Biological Station, Gull Lake, MI, October 31, 2013. 40 attendees; Great Lakes state wetland managers.

Brady, V., D. Uzarski, T. Brown, G. Niemi, M. Cooper, R. Howe, N. Danz, D. Wilcox, D. Albert, D. Tozer, G. Grabas, C. Ruetz, L. Johnson, J. Ciborowski, J. Haynes, G. Neuderfer, T. Gehring, J. Gathman, A. Moerke, G. Lamberti, C. Normant. 2013. A Biotic Monitoring Program for Great Lakes Coastal Wetlands. Society of Wetland Scientists annual meeting, Duluth, MN, June 2013. 25 attendees, mostly scientists, some agency personnel.

Brady, V., D. Uzarski, T. Brown, G. Niemi, M. Cooper, R. Howe, N. Danz, D. Wilcox, D. Albert, D. Tozer, G. Grabas, C. Ruetz, L. Johnson, J. Ciborowski, J. Haynes, G. Neuderfer, T. Gehring, J. Gathman, A. Moerke, G. Lamberti, C. Normant. 2013. Habitat Values Provided by Great Lakes Coastal Wetlands: based on the Great Lakes Coastal Wetland Monitoring Project. Society of Wetland Scientists annual meeting, Duluth, MN, June 2013. 20 attendees, mostly scientists.

Brady, V.J., D.G. Uzarski, M.J. Cooper, D.A. Albert, N. Danz, J. Domke, T. Gehring, E. Giese, A. Grinde, R. Howe, A.H. Moerke, G. Niemi, H. Wellard-Kelly. 2018. How are Lake Superior's wetlands? Eight years, 100 wetlands sampled. State Of Lake Superior Conference. Houghton, MI. Oral Presentation.

Brady, V., G. Niemi, J. Dumke, H. Wellard Kelly, M. Cooper, N. Danz, R. Howe. 2019. The role of monitoring data in coastal wetland restoration: Case studies from Duluth and Green Bay. International Association of Great Lakes Research Annual Meeting, Brockport, NY, June 2019. Invited oral presentation.

Buckley, J.D., and J.J.H. Ciborowski. 2013. A comparison of fish indices of biological condition at Great Lakes coastal margins. 66th Canadian Conference for Freshwater Fisheries Research, Windsor, ON, January 3-5 2013. Poster Presentation.

Chorak, G.M., C.R. Ruetz III, R.A. Thum, J. Wesolek, and J. Dumke. 2015. Identification of brown and black bullheads: evaluating DNA barcoding. Poster presentation at the Annual Meeting of the Michigan Chapter of the American Fisheries Society, Bay City, Michigan. January 20-21.

Cooper, M.J. Great Lakes coastal wetland monitoring: chemical and physical parameters as co-variates and indicators of wetland health. Biennial State of the Lakes Ecosystem Conference, Erie, PA, October 26-27, 2011. Oral presentation.

Cooper, M.J. Coastal wetland monitoring: methodology and quality control. Great Lakes Coastal Wetland Monitoring Workshop, Traverse City, MI, August 30, 2011. Oral presentation.

Cooper, M.J., D.G. Uzarski, and G.L. Lamberti. GLRI: coastal wetland monitoring. Michigan Wetlands Association Annual Conference, Traverse City, MI, August 30-September 2, 2011. Oral presentation.

Cooper, M.J. Monitoring the status and trends of Great Lakes coastal wetland health: a basin-wide effort. Annual Great Lakes Conference, Institute of Water Research, Michigan State University, East Lansing, MI, March 8, 2011. Oral presentation.

Cooper, M.J., G.A. Lamberti, and D.G. Uzarski. Monitoring ecosystem health in Great Lakes coastal wetlands: a basin-wide effort at the intersection of ecology and management. Entomological Society of America, Reno, NV, November 13-16, 2011. Oral presentation

Cooper, M.J., and G.A. Lamberti. Taking the pulse of Great Lakes coastal wetlands: scientists tackle an epic monitoring challenge. Poster session at the annual meeting of the National Science Foundation Integrative Graduate Education and Research Traineeship Program, Washington, D.C., May 2012. Poster presentation.

Cooper, M.J., J.M. Kosiara, D.G. Uzarski, and G.A. Lamberti. Nitrogen and phosphorus conditions and nutrient limitation in coastal wetlands of Lakes Michigan and Huron. Annual meeting of the International Association for Great Lakes Research. Cornwall, Ontario. May 2012. Oral presentation.

Cooper, M.J., G.A. Lamberti, and D.G. Uzarski. Abiotic drivers and temporal variability of Saginaw Bay wetland invertebrate communities. International Association for Great Lakes Research, 56th annual meeting, West Lafayette, IN. June 2013. Oral presentation.

Cooper, M.J., D.G. Uzarski, J. Sherman, and D.A. Wilcox. Great Lakes coastal wetland monitoring program: support of restoration activities across the basin. National Conference on Ecosystem Restoration, Chicago, IL. July 2013. Oral presentation.

Cooper, M.J. and J. Kosiara. Great Lakes coastal wetland monitoring: Chemical and physical parameters as co-variates and indicators of wetland health. US EPA Region 5 Annual Wetlands Program Coordinating Meeting and Michigan Wetlands Association Annual Meeting. Kellogg Biological Station, Hickory Corners, MI. October 2013. Oral presentation.

Cooper, M.J. Implementing coastal wetland monitoring. Inter-agency Task Force on Data Quality for GLRI-Funded Habitat Projects. CSC Inc., Las Vegas, NV. November 2013. Web presentation, approximately 40 participants.

Cooper, M.J. Community structure and ecological significance of invertebrates in Great Lakes coastal wetlands. SUNY-Brockport, Brockport, NY. December 2013. Invited seminar.

Cooper, M.J. Great Lakes coastal wetlands: ecological monitoring and nutrient-limitation. Limno-Tech Inc., Ann Arbor, MI. December 2013. Invited seminar.

Cooper, M.J., D.G. Uzarski, and V.J. Brady. A basin-wide Great Lakes coastal wetland monitoring program: Measures of ecosystem health for conservation and management. Great Lakes Wetlands Day, Toronto, Ont. Canada, February 4, 2014. Oral presentation.

Cooper, M.J., G.A. Lamberti, and D.G. Uzarski. Supporting Great Lakes coastal wetland restoration with basin-wide monitoring. Great Lakes Science in Action Symposium. Central Michigan University. April 4, 2014.

Cooper, M.J. Expanding fish-based monitoring in Great Lakes coastal wetlands. Michigan Wetlands Association Annual Meeting. Grand Rapids, MI. August 27-29, 2014.

Cooper, M.J. Structure and function of Great Lakes coastal wetlands. Public seminar of Ph.D. dissertation research. University of Notre Dame. August 6, 2014.

Cooper, M.J., D.G. Uzarski, and T.N. Brown. Developing a decision support system for protection and restoration of Great Lakes coastal wetlands. Biodiversity without Borders Conference, NatureServe. Traverse City, MI. April 27, 2015.

Cooper, M.J. and D.G. Uzarski. Great Lakes coastal wetland monitoring for protection and restoration. Lake Superior Monitoring Symposium. Michigan Technological University. March 19, 2015.

Cooper, M.J. Where worlds collide: ecosystem structure and function at the land-water interface of the Laurentian Great Lakes. Central Michigan University Department of Biology. Public Seminar. February 5, 2015.

Cooper, M.J. Where worlds collide: ecosystem structure and function at the land-water interface of the Laurentian Great Lakes. Sigurd Olson Environmental Institute, Northland College. Public Seminar. May 4, 2015.

Cooper, M.J., and D.G. Uzarski. Great Lakes coastal wetland monitoring for protection and restoration. Lake Huron Restoration Meeting. Alpena, MI. May 14, 2015.

Cooper, M.J., D.G. Uzarski, and V.J. Brady. Developing a decision support system for restoration and protection of Great Lakes coastal wetlands. Wisconsin Wetlands Association Annual Meeting. February 24-25, 2016. Green Bay, WI.

Cooper, M.J., Stirratt, H., B. Krumwiede, and K. Kowalski. Great Lakes Resilient Lands and Waters Initiative, Deep Dive. Remote presentation to the White House Council on Environmental Quality and partner agencies, January 28, 2016.

Cooper, M., Redder, T., Brady, V. and D. Uzarski. 2016. Developing a decision support tool to guide restoration and protection of Great Lakes coastal wetlands. Annual Meeting of the Wisconsin Wetlands Association, Stevens Point, WI. February. Presentation.

Cooper, M.J.. Nutrient limitation in wetland ecosystems. Wisconsin Department of Natural Resources, February 12, 2016, Rhinelander, WI.

Cooper, M.J., D.G. Uzarski and V.J. Brady. 2016. Developing a decision support system for restoration and protection of Great Lakes coastal wetlands. Wisconsin Wetlands Association Annual Meeting, Green Bay, WI. February 24-25. Oral Presentation.

Cooper, M.J.. Monitoring biotic and abiotic conditions in Great Lakes coastal wetlands. Wisconsin DNR Annual Surface Water Quality Conference. May 2016, Tomahawk, WI.

Cooper, M.J. The Depth of Wisconsin's Water Resources. Panel Discussion, Wisconsin History Tour, Northern Great Lakes Visitors Center, June 15, 2016, Ashland, WI.

Cooper, M.J.. Great Lakes Coastal Wetlands. The White House Resilient Lands and Waters Initiative Roundtable. Washington, DC, November 17, 2016.

Cooper, M.J. Translating Science Into Action in the Great Lakes. Marvin Pertzik Lecture Series. Northland College, May 2016.

Cooper, M.C., C. Hippensteel, D.G. Uzarski, and T.M. Redder. Developing a decision support tool for Great Lakes coastal wetlands. LCC Coastal Conservation Working Group Annual Meeting, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, Oct. 6, 2016.

Cooper, M.J., T.M. Redder, C. Hippensteel, V.J. Brady, D.G. Uzarski. Developing a decision support tool to guide restoration and protection of Great Lakes coastal wetlands. Midwest Fish and Wildlife Conference, Feb. 5-8, 2017, Lincoln, NE.

Cooper, M.J., T.M. Redder, V.J. Brady, D.G. Uzarski. Developing a decision support tool to guide restoration and protection of Great Lakes coastal wetlands. Wisconsin Wetlands Association Annual Conference, February 28-March 2, 2017, Steven's Point, WI.

Cooper, M.J. Coastal Wetlands as Metabolic Gates, Sediment Filters, Swiss Army Knife Habitats, and Biogeochemical Hotspots. Science on Tap, Ashland, WI, March 21, 2017.

Cooper, M.J., Brady, V.J., Uzarski, D.G., Lamberti, G.A., Moerke, A.H., Ruetz, C.R., Wilcox, D.A., Ciborowski, J.J.H., Gathman, J.P., Grabas, G.P., and Johnson, L.B. An Expanded Fish-Based Index of Biotic Integrity for Great Lakes Coastal Wetlands. International Association for Great Lakes Research 60th Annual Meeting, Detroit, MI, May 15-19, 2017.

Cooper, M.J., D.G. Uzarski, and A. Gar
wood. Great Lakes Coastal Wetland Monitoring." Webinar hosted by Michigan Department of Environmental Quality, April 14, 2017. 78 attendees.

Cooper, M.J., A. Hefko, M. Wheeler. Nitrogen limitation of Lake Superior coastal wetlands. Society for Freshwater Science Annual Conference, May 20-24, 2018, Detroit, MI.

Cooper, M.J. The Role of Wetlands in Maintaining Water Quality. Briefing to the International Joint Commission, Ashland, WI, September 26, 2019.

Cooper, M.J., V.J. Brady, and D.G. Uzarski. Great Lakes Coastal Wetland Monitoring. Plenary Presentation, Great Lakes Coastal Wetland Symposium, Oregon, OH, September 19, 2019.

Cooper, M.J. and S. Johnson. Life on the Soggy Edges. Madeline Island Wilderness Preserve Lecture Series, Madeline Island Museum, La Pointe, WI, June 19, 2019.

Cooper, M.J., T.M. Redder, V.J. Brady, D.G. Uzarski. A data visualization tool to support protection and restoration of Great Lakes coastal wetlands. International Association for Great Lakes Research Annual Conference, June 10-14, 2019, Brockport, NY

Curell, Brian. 2014. Effects of disturbance frequency on macroinvertebrate communities in coastal wetlands. MI American Fisheries Society annual meeting, February, Holland, MI.

Dahlberg, N., N.P. Danz, and S. Schooler. 2015. Integrating prior vegetation surveys from the St. Louis River estuary. Poster presentation at the 2015 Annual St. Louis River Summit, Superior, WI.

Dahlberg, N., N.P. Danz, and S. Schooler. 2017. 2012 Flood Impacts on St. Louis River Plant Communities. Poster presentation at St. Louis River Summit, Superior, WI.

Danz, N.P. 2014. Floristic quality of Wisconsin coastal wetlands. Oral presentation at the Wisconsin Wetlands Association 19th Annual Wetlands Conference, LaCrosse, WI. Audience mostly scientists.

Danz, N.P. Floristic Quality of Coastal and Inland Wetlands of the Great Lakes Region. Invited presentation at the University of Minnesota Duluth, Duluth, MN.

Danz, N.P., S. Schooler, and N. Dahlberg. 2015. Floristic quality of St. Louis River estuary wetlands. Oral presentation at the 2015 Annual St. Louis River Summit, Superior, WI.

Danz, N.P. 2016. Floristic quality of St. Louis River estuary wetlands. Invited presentation at the Center for Water and the Environment, Natural Resources Research Institute, Duluth, MN.

Danz, N.P. 2017. Connections Between Human Stress, Wetland Setting, and Vegetation in the St. Louis River Estuary. Oral presentation at the Wetland Science Conference, Stevens Point, WI.

Danz, N.P. 2017. 10 Things We Learned from Your Vegetation Data. Oral presentation at the St. Louis River Summit, Superior, WI.

Daly, D., T. Dunn, and A. Moerke. 2016. Effects of European frog-bit on water quality and fish assemblages in St. Marys River wetlands. Midwest Fish and Wildlife Conference, Grand Rapids, MI. January 24-27.

Des Jardin, K. and D.A. Wilcox. 2014. Water chestnut: germination, competition, seed viability, and competition in Lake Ontario. New York State Wetlands Forum, Rochester, NY.

Dumke, J.D., V.J. Brady, J. Ciborowski, J. Gathman, J. Buckley, D. Uzarski, A. Moerke, C. Ruetz III. 2013. Fish communities of the upper Great Lakes: Lake Huron's Georgian Bay is an outlier. Society for Wetland Scientists, Duluth, Minnesota. 30 attendees, scientists and managers.

Dumke, J.D., V.J. Brady, R. Hell, A. Moerke, C. Ruetz III, D. Uzarski, J. Gathman, J. Ciborowski. 2013. A comparison of St. Louis River estuary and the upper Great Lakes fish communities (poster). Minnesota American Fisheries Society, St. Cloud, Minnesota. Attendees scientists, managers, and agency personnel.

Dumke, J.D., V.J. Brady, R. Hell, A. Moerke, C. Ruetz III, D. Uzarski, J. Gathman, J. Ciborowski. 2013. A comparison of wetland fish communities in the St. Louis River estuary and the upper Great Lakes. St. Louis River Estuary Summit, Superior, Wisconsin. 150 attendees, including scientists, managers, agency personnel, and others.

Dumke, J.D., V.J. Brady, J. Erickson, A. Bracey, N. Danz. 2014. Using non-degraded areas in the St. Louis River estuary to set biotic delisting/restoration targets. St. Louis River Estuary

Summit, Superior, Wisconsin. 150 attendees, including scientists, managers, agency personnel, and others.

Dumke, J., C.R. Ruetz III, G.M. Chorak, R.A. Thum, and J. Wesolek. 2015. New information regarding identification of young brown and black bullheads. Oral presentation at the Annual Meeting of the Wisconsin Chapter of the American Fisheries Society, Eau Claire, Wisconsin. February 24-26. 150 attendees, including scientists, managers, agency personnel, and others.

Dunn, T., D. Daly, and A. Moerke. 2016. Impacts of European frog-bit invasion on Great Lakes wetlands macroinvertebrate communities. Midwest Fish and Wildlife Conference, Grand Rapids, MI. January 24-27.

Dykstra, K.M., C.R. Ruetz III, M.J. Cooper, and D.G. Uzarski. 2018. Occupancy and detection of yellow perch in Great Lakes coastal wetlands. Poster presentation at the Annual Meeting of the Society for Freshwater Science, Detroit, Michigan. May 20-24.

Dykstra (Emelander), K.M., C.R. Ruetz III, M.J. Cooper, and D.G. Uzarski. 2018. Occupancy and detection of yellow perch in Great Lakes coastal wetlands: preliminary results. Poster presentation at the annual meeting of the Michigan Chapter of the American Fisheries Society, Port Huron, Michigan. February 13-14.

Elliot, L.H., A.M. Bracey, G.J. Niemi, D.H. Johnson, T.M. Gehring, E.E. Gnass Giese, G.P. Grabas, R.W. Howe, C.J. Norment, and D.C. Tozer. Habitat Associations of Coastal Wetland Birds in the Great Lakes Basin. American Ornithological Society Meeting, East Lansing, Michigan. Poster Presentation. 31 July-5 August 2017.

Elliott, L.H., A. Bracey, G. Niemi, D.H. Johnson, T. Gehring, E. Giese, G. Grabas, R. Howe, C. Norment, and D.C. Tozer. 2018. Hierarchical modeling to identify habitat associations of secretive marsh birds in the Great Lakes. IAGLR Conference, Toronto, Canada. Oral Presentation. 18-22 June 2018.

Fraley, E.F. and D.G. Uzarski 2017. The relationship between vegetation and ice formation in Great Lakes coastal wetlands. 60th Annual Meeting of the International Association of Great Lakes Research. Detroit, MI. Poster.

Fraley, E.F. and D.G. Uzarski. 2016. The Impacts of Ice on Plant Communities in Great Lakes Coastal Wetlands. 7th Annual Meeting of the Michigan Consortium of Botanists, Grand Rapids, MI. October. Poster.

Gathman, J.P. 2013. How healthy are Great Lakes wetlands? Using plant and animal indicators of ecological condition across the Great Lakes basin. Presentation to Minnesota Native Plant Society. November 7, 2013.

Gathman, J.P., J.J.J. Ciborowski, G. Grabas, V. Brady, and K.E. Kovalenko. 2013. Great Lakes Coastal Wetland Monitoring project: progress report for Canada. 66th Canadian Conference for Freshwater Fisheries Research, Windsor, ON, January 3-5, 2013. Poster Presentation.

Gilbert, J.M., N. Vidler, P. Cloud Sr., D. Jacobs, E. Slavik, F. Letourneau, K. Alexander. 2014. *Phragmites australis* at the crossroads: Why we cannot afford to ignore this invasion. Great Lakes Wetlands Day Conference, Toronto, ON, February 4, 2014.

Gilbert, J.M. 2013. Phragmites Management in Ontario. Can we manage without herbicide? Webinar, Great Lakes *Phragmites* Collaborative, April 5, 2013.

Gilbert, J.M. 2012. *Phragmites australis*: a significant threat to Laurentian Great Lakes Wetlands, Oral Presentation, International Association of Great Lakes Wetlands, Cornwall, ON, May 2012

Gilbert, J.M. 2012. *Phragmites australis:* a significant threat to Laurentian Great Lakes Wetlands, Oral Presentation to Waterfowl and Wetlands Research, Management and Conservation in the Lower Great Lakes. Partners' Forum, St. Williams, ON, May 2012.

Gil de LaMadrid, D., and N.P. Danz. 2015. Water depth optima and tolerances for St. Louis River estuary wetland plants. Poster presentation at the 2015 Annual St. Louis River Summit, Superior, WI.

Gnass Giese, E.E. 2015. Great Lakes Wetland Frog Monitoring. Annual Lower Fox River Watershed Monitoring Program Symposium at the University of Wisconsin-Green Bay, Green Bay, Wisconsin. April 14, 2015. Oral Presentation.

Gnass Giese, E.E. 2015. Wetland Birds and Amphibians: Great Lakes Monitoring. Northeastern Wisconsin Audubon Society meeting at the Bay Beach Wildlife Sanctuary, Green Bay, Wisconsin. February 19, 2015. Oral Presentation.

Gnass Giese, E.E., R.W. Howe, N.G. Walton, G.J. Niemi, D.C. Tozer, W.B. Gaul, A. Bracey, J. Shrovnal, C.J. Norment, and T.M. Gehring. 2016. Assessing wetland health using breeding birds as indicators. Wisconsin Wetlands Association Conference, Radisson Hotel & Convention Center, Green Bay, Wisconsin. February 24, 2016. Poster Presentation.

Gnass Giese, E., R. Howe, A. Wolf, and G. Niemi. 2017. Breeding Birds and Anurans of Dynamic Green Bay Coastal Wetlands. State of Lake Michigan Conference, Green Bay, Wisconsin.

Oral Presentation. 8 November 2017.Gnass Giese, E.E., R.W. Howe, A.T. Wolf, N.A. Miller, and N.G. Walton. An ecological index of forest health based on breeding birds. 2013. Webpage: http://www.uwgb.edu/biodiversity/forest-index/

Gnass Giese, E.E., R.W. Howe, A.T. Wolf, N.A. Miller, and N.G. Walton. 2014. Using Bird Data to Assess Condition of Western Great Lakes Forests. Midwest Bird Conservation and Monitoring Workshop, Port Washington, Wisconsin. Poster Presentation. 4-8 August 2014.Gnass Giese, E.E. 2013. Monitoring forest condition using breeding birds in the western Great Lakes region, USA. Editors: N. Miller, R. Howe, C. Hall, and D. Ewert. Internal Report. Madison, WI and Lansing, MI: The Nature Conservancy. 44 pp.

Gunsch, D., J.P. Gathman, and J.J.H. Ciborowski . 2018. Variation in dissolved-oxygen profiles along a depth gradient in Lake Huron coastal wet meadows relative to vegetation density and agricultural stress over 24 hours. IAGLR Conference, Toronto, Canada. Poster Presentation. 18-22 June 2018.

Gurholt, C.G. and D.G. Uzarski. 2013. Into the future: Great Lakes coastal wetland seed banks. IGLR Graduate Symposium, Central Michigan University, Mt. Pleasant, MI. March.

Gurholt, C.G. and D.G. Uzarski. 2013. Seed Bank Purgatory: What Drives Compositional Change of Great Lakes Coastal Wetlands. 56th International Association for Great Lakes Research Conference, Purdue University, West Lafayette, IN. June.

Harrison, A.M., M.J. Cooper, and D.G. Uzarski. 2019. Spatial and temporal (2011-2018) variation of water quality in Great Lakes coastal wetlands. International Association for Great Lakes Research. Brockport, NY. Presentation.

Hefko, A.G., M. Wheeler, M.J. Cooper. Nitrogen limitation of algal biofilms in Lake Superior coastal wetlands. International Association for Great Lakes Research Annual Conference, June 10-14, 2019, Brockport, NY. (poster)

Hein, M.C. and Cooper, M.J. Untangling drivers of chlorophyll a in Great Lakes coastal wetlands. International Association for Great Lakes Research 60th Annual Meeting, Detroit, MI, May 15-19, 2017.

Hohman, T., B. Howe, E. Giese, A. Wolf, and D. Tozer. 2019. Bird Community Response to Changes in Wetland Extent and Interspersion in Great Lakes Coastal Wetlands. Heckrodt Birding Club Meeting, Menasha, Wisconsin. Oral Presentation. 6 August 2019.

Hohman, T.R., R.W. Howe, A.T. Wolf, E.E.Gnass Giese, D.C. Tozer, T.M. Gehring, G.P. Grabas, G.J. Niemi, and C.J. Norment. 2019. Bird Community Response to Changes in Wetland Extent and Interspersion in Great Lakes Coastal Wetlands. Presented at the 62nd Annual

Meeting of the International Association of Great Lakes Research (IAGLR), 12 June 2019, Brockport, NY.

Houghton, C.J., C.C. Moratz, P.S. Forsythe, G.A. Lamberti, D.G. Uzarski, and M.B. Berg. 2016. Relative use of wetland and nearshore habitats by sportfishes of Green Bay. 59th International Conference on Great Lakes Research, Guelph, Ontario Canada. May. Oral Presentation.

Howe, R.W., R.P. Axler, V.J. Brady, T.N. Brown, J.J.H. Ciborowski, N.P. Danz, J.P. Gathman, G.E. Host, L.B. Johnson, K.E. Kovalenko, G.J. Niemi, and E.D. Reavie. 2012. Multi-species indicators of ecological condition in the coastal zone of the Laurentian Great Lakes. 97th Annual Meeting of the Ecological Society of America. Portland, OR.

Howe, B., E. Giese, A. Wolf, and B. Kupsky. 2019. Restoration Targets for Great Lakes Coastal Wetlands in the Lower Green Bay & Fox River AOC. International Association for Great Lakes Research, Brockport, New York. Oral Presentation. 12 June 2019.

Howe, R.W., G.J. Niemi, N.G. Walton, E.E.G. Giese, A.M. Bracey, V.J. Brady, T.N. Brown, J.J.H. Ciborowski, N.P. Danz, J.P. Gathman, G.E. Host, L.B. Johnson, K.E. Kovalenko, and E.D. Reavie. 2014. Measurable Responses of Great Lakes Coastal Wetland Biota to Environmental Stressors. International Association for Great Lakes Research Annual Conference, Hamilton, Ontario (Canada). May 26-30, 2014. Oral Presentation.

Howe, B., A. Wolf, E. Giese, V. Pappas, B. Kupsky, M. Grimm, and N. Van Helden. 2018. Lower Green Bay & Fox River Area of Concern Wildlife and Habitat Assessment Tools. AOC RAP Meeting, Green Bay, Wisconsin. Oral Presentation. 25 April 2018.

Howe, B., A. Wolf, E. Giese, V. Pappas, B. Kupsky, M. Grimm, and N. Van Helden. 2018. Assessing the Fish and Wildlife Habitat BUI for the Lower Green Bay and Fox River Area of Concern. Annual Great Lakes Areas of Concern Conference, Sheboygan, Wisconsin. Oral Presentation. 16 May 2018.

Howe, R.W., A.T. Wolf, and E.E. Gnass Giese. 2016. What's so special about Green Bay wetlands? Wisconsin Wetlands Association Conference, Radisson Hotel & Convention Center, Green Bay, Wisconsin. February 23-25, 2016. Oral Presentation.

Howe, R.W., N.G. Walton, E.G. Giese, G.J. Niemi, and A.M. Bracey. 2013. Avian responses to landscape stressors in Great Lakes coastal wetlands. Society of Wetland Scientists, Duluth, Minnesota. June 2-6, 2013. Poster Presentation.

Howe, R.W., N.G. Walton, E.E.G. Giese, G.J. Niemi, N.P. Danz, V.J. Brady, T.N. Brown, J.J.H. Ciborowski, J.P. Gathman, G.E. Host, L.B. Johnson, E.D. Reavie. 2013. How do different taxa respond to landscape stressors in Great Lakes coastal wetlands? Ecological Society of America, Minneapolis, Minnesota. August 4-9, 2013. Poster Presentation.

Howe, R.W., A.T. Wolf, J. Noordyk, and J. Stoll. 2017. Benefits and outcomes of Green Bay restoration: ecosystem and economic perspectives. Presented at the Summit on the Ecological and Socio-Economic Tradeoffs of Restoration in the Green Bay, Lake Michigan, Ecosystem (July 18-20, 2017).

Howe, R.W., A.T. Wolf, and E.E. Giese. 2016. Proposed AOC de-listing process. Presentation to Lower Green Bay and Fox River AOC stakeholders. 16 December 2016.

Howe, R.W., A.T. Wolf, and E.E. Giese. 2017. Lower Green Bay & Fox River Area of Concern: A Plan for Delisting Fish and Wildlife Habitat & Populations Beneficial Use Impairments. A paper presented to AOC Technical Advisory Group. 3 August 2017.

Johnson, L., M. Cai, D. Allan, N. Danz, D. Uzarski. 2015. Use and interpretation of human disturbance gradients for condition assessment in Great Lakes coastal ecosystems. International Association for Great Lakes Research Conference, Burlington, VT.

Johnson, Z., M. Markel, and A. Moerke. 2019. Functional diversity of macroinvertebrates in coastal wetlands along the St. Marys River. Midwest Fish and Wildlife Conference, Cleveland, OH.

Kneisel, A.N., M.J. Cooper, and D.G. Uzarski. 2016. The impact of Phragmites australis invasion on macroinvertebrate communities in the coastal wetlands of Thunder Bay, MI. Institute for Great Lakes Research, 4th Annual Student Research Symposium, Central Michigan University, Mt. Pleasant, MI. February. Oral Presentation.

Kneisel, A.N., M.J. Cooper, and D.G. Uzarski. 2016. Impact of *Phragmites* invasion on macroinvertebrate communities in wetlands of Thunder Bay, MI. 59th International Conference on Great Lakes Research, Guelph, Ontario Canada. May. Oral Presentation.

Kosiara, J.M., M.J. Cooper, D.G. Uzarski, and G.A. Lamberti. 2013. Relationships between community metabolism and fish production in Great Lakes coastal wetlands. International Association for Great Lakes Research, 56th annual meeting. June 2-6, 2013. West Lafayette, IN. Poster presentation.

Kneisel, A.N., M.J. Cooper, and D.G. Uzarski. 2017. The impact of Phragmites australis invasion on Great Lakes coastal wetlands. 60th International Conference on Great Lakes Research, Detroit, MI. May. Presentation.

Kneisel, A.K., M.J. Cooper, D.G. Uzarski. 2018. Coastal wetland monitoring data as a resource for invasive species management. ELLS-IAGLR Big Lakes Small World Conference. Évian, France. September. Poster.Kosiara, J.K., J.J. Student, and D.G. Uzarski. 2017. Exploring coastal habitat-use patterns of Great Lakes yellow perch with otolith microchemistry. 60th International Conference on Great Lakes Research, Detroit, MI. May. Presentation.

Kosiara, J.M., J. Student and D.G. Uzarski. 2016. Assessment of yellow perch movement between coastal wetland and nearshore waters of the Great Lakes. 59th International Conference on Great Lakes Research, Guelph, Ontario Canada. May. Oral Presentation.

Kowalke, C.J. and D.G. Uzarski. 2019. Assessing the competitive impacts of invasive round goby on lake whitefish in northern Lake Michigan. International Association for Great Lakes Research. Brockport, NY. Poster.

Lamberti, G.A., D.G. Uzarski, V.J. Brady, M.J. Cooper, T.N. Brown, L.B. Johnson, J.J. Ciborowski, G.P. Grabas, D.A. Wilcox, R.W. Howe, and D. C. Tozer. An integrated monitoring program for Great Lakes coastal wetlands. Society for Freshwater Science Annual Meeting. Jacksonville, FL. May 2013. Poster presentation.

Lamberti, G.A. Pacific Salmon in Natal Alaska and Introduced Great Lakes Ecosystems: The Good, the Bad, and the Ugly. Department of Biology, Brigham Young University. Dec 5, 2013. Invited seminar.

Lamberti, G. A. The Global Freshwater Crisis. The Richard Stockton College of New Jersey and South Jersey Notre Dame Club. November 18, 2014.

Lamberti, G. A. The Global Freshwater Crisis. Smithsonian Journey Group and several University Alumni Groups. March 1, 2015.

Lamberti, G.A. The Global Freshwater Crisis. Newman University and Notre Dame Alumni Club of Wichita. September 28, 2016.

Lamberti, G.A. The Global Freshwater Crisis. Air and Wastewater Management Association and Notre Dame Alumni Club of Northeastern New York. December 2, 2016.

Lamberti, G.A. The Global Freshwater Crisis: Lessons for the Amazon. Association of University Alumni Clubs. Iquitos, Peru. September 9, 2019.

Lamberti, G. A. Pacific Salmon in Natal Alaska and Introduced Great Lakes Ecosystems: The Good, the Bad, and the Ugly. Annis Water Resources Institute, Grand Valley State University. December 12, 2014.

Lamberti, G.A., M.A. Brueseke, W.M. Conard, K.E. O'Reilly, D.G. Uzarski, V.J. Brady, M.J. Cooper, T.M. Redder, L.B. Johnson, J.H. Ciborowski, G.P. Grabas, D.A. Wilcox, R.W. Howe, D.C. Tozer, and T.K. O'Donnell. Great Lakes Coastal Wetland Monitoring Program: Vital resources for scientists, agencies and the public. Society for Freshwater Science Annual Metting. Raleigh, NC. June4-9, 2017. Poster.

Langer, T.A., K. Pangle, B.A. Murray, and D.G. Uzarski. 2014. Beta Diversity of Great Lakes Coastal Wetland Communities: Spatiotemporal Structuring of Fish and Macroinvertebrate Assemblages. American Fisheries Society, Holland, MI. February.

Langer, T., K. Pangle, B. Murray, D. Uzarski. 2013. Spatiotemporal influences, diversity patterns and mechanisms structuring Great Lakes coastal wetland fish assemblages. Poster. Institute for Great Lakes Research 1st Symposium, MI. March.

Lemein, T.J., D.A. Albert, D.A. Wilcox, B.M. Mudrzynski, J. Gathman, N.P. Danz, D. Rokitnicki-Wojcik, and G.P. Grabas. 2014. Correlation of physical factors to coastal wetland vegetation community distribution in the Laurentian Great Lakes. Society of Wetland Scientists/Joint Aquatic Sciences Meeting, Portland, OR.

MacDonald, J.L., L.S. Schoen, J.J. Student, and D.G. Uzarski. 2016. Variation in yellow perch (*Perca flavescens*) growth rate in the Great Lakes. 59th International Conference on Great Lakes Research, Guelph, Ontario Canada. May. Oral Presentation.

Makish, C.S., K.E. Kovalenko, J.P. Gathman, and J.J.H. Ciborowski. 2013. invasive phragmites effects on coastal wetland fish communities of the Great Lakes basin. 66th Canadian Conference for Freshwater Fisheries Research, Windsor, ON, January 3-5, 2013. Poster Presentation.

Markel, M., Z. Johnson, and A. Moerke. 2019. A comparison of macroinvertebrate assemblages in coastal wetlands exposed to varying wave disturbance. March 13-15, Gaylord, MI.

McReynolds, A.T., K.E. O'Reilly, and G.A. Lamberti. 2016. Food web structure of a recently restored Indiana wetland. University of Notre Dame College of Science Joint Annual Meeting, Notre Dame, IN.

Moerke, A. 2015. Coastal wetland monitoring in the Great Lakes. Sault Naturalist meeting, Sault Sainte Marie, MI; approximately 40 community members present.

Monks, A., S. Lishawa, D. Albert, B. Mudrzynski, D.A. Wilcox, and K. Wellons. 2019. Innovative management of European frogbit and invasive cattail. International Association for Great Lakes Research. Brockport, NY

Moore, L.M., M.J. Cooper, and D.G. Uzarski. 2017. Nutrient limitation in Great Lakes coastal wetlands: gradients and their influence. 60th International Conference on Great Lakes Research, Detroit, MI. May 17. Presentation.

Mudrzynski, B.M., N.P. Danz, D.A. Wilcox, D.A. Albert, D. Rokitnicki-Wojcik, and J. Gathman. 2016. Great Lakes wetland plant Index of Biotic Integrity (IBI) development: balancing broad applicability and accuracy. Society of Wetland Scientists, Corpus Christi, TX.

Mudrzynski, B.M., D.A. Wilcox, and A. Heminway. 2012. Habitats invaded by European frogbit (Hydrocharis morsus-ranae) in Lake Ontario coastal wetlands. INTECOL/Society of Wetland Scientists, Orlando, FL.

Mudrzynski, B.M., D.A. Wilcox, and A.W. Heminway. 2013. European frogbit (Hydrocharis morsus-ranae): current distribution and predicted expansion in the Great Lakes using niche-modeling. Society of Wetland Scientists, Duluth, MN.

Mudrzynski, B.M. and D.A. Wilcox. 2014. Effect of coefficient of conservatism list choice and hydrogeographic type on floristic quality assessment of Lake Ontario wetlands. Society of Wetland Scientists/Joint Aquatic Sciences Meeting, Portland, OR.

Mudrzynski, B.M., K. Des Jardin, and D.A. Wilcox. 2015. Predicting seed bank emergence within flooded zones of Lake Ontario wetlands under novel hydrologic conditions. Society of Wetlands Scientists. Providence, RI.

Newman, W.L., L.P. Moore, M.J. Cooper, D.G. Uzarski, and S.N. Francoeur. 2019. Nitrogen-Fixing Diatoms as Indicators of Historical Nitrogen Limitation in Laurentian Great Lakes Coastal Wetlands. Society for Freshwater Science. Salt Lake City, UT. Presentation.

O'Donnell, T.K., Winter, C., Uzarski, D.G., Brady, V.J., and Cooper, M.J. 2017. Great Lakes coastal wetland monitoring: moving from assessment to action. Ecological Society of America Annual Conference. Portland, OR. August 6-11. Presentation.

O'Donnell, T.K., D.G. Uzarski, V.J. Brady, and M.J. Cooper. 2016. Great Lakes Coastal Wetland Monitoring: Moving from Assessment to Action. 10th National Monitoring Conference; Working Together for Clean Water, Tampa, Florida. May. Oral Presentation.

O'Reilly, K.E., A. McReynolds, and G.A. Lamberti. Quantifying Lake Michigan coastal wetland-nearshore linkages for sustaining sport fishes using stable isotope mixing models. Annual Meeting of the Ecological Society of America. Baltimore, MD. August 9-14, 2015.

O'Reilly, K.E., A. McReynolds, C. Stricker, and G.A. Lamberti. Quantifying Lake Michigan coastal wetland-nearshore linkages for sustaining sport fishes. State of Lake Michigan Conference. Traverse City, MI. October 28-30, 2015.

O'Reilly, K.E., A. McReynolds, C. Stricker, and G.A. Lamberti. 2016. Quantifying Lake Michigan coastal wetland-nearshore linkages for sustaining sport fishes. Society for Freshwater Science, Sacramento, CA.

O'Reilly, K.E., A. McReynolds, C. Stricker, and G.A. Lamberti. 2016. Quantifying Lake Michigan coastal wetland-nearshore linkages for sustaining sport fishes. International Association for Great Lakes Research, Guelph, ON.

O'Reilly, K.E., J.J. Student, B.S. Gerig, and G.A. Lamberti. 2019. Metalheads: What can sport fish otoliths reveal about heavy metal exposure over time? Annual Meeting of the Society for Freshwater Science, Salt Lake City, UT.

Otto, M., J. Marty, E.G. Gnass Giese, R. Howe, and A. Wolf. Anuran habitat use in the Lower Green Bay and Fox River Area of Concern (Wisconsin). University of Wisconsin-Green Bay Academic Excellence Symposium, Green Bay, Wisconsin. April 6, 2017. Poster Presentation.

Otto, M., J. Marty, E.G. Gnass Giese, R. Howe, and A. Wolf. Anuran habitat use in the Lower Green Bay and Fox River Area of Concern (Wisconsin). Green Bay Conservation Partners Spring Roundtable Meeting, Green Bay, Wisconsin. April 25, 2017. Poster Presentation.

Redder, T.M., D.G. Uzarski, V.J. Brady, M.J. Cooper, and T.K. O'Donnell. 2018. Application of data management and decision support tools to support coastal wetland management in the Laurentian Great Lakes. National Conference on Ecosystem Restoration. New Orleans, LA. August 26-30, 2018. Oral Presentation.

Reisinger, L. S., Pangle, K. L., Cooper, M. J., Learman, D. R., Uzarski, D. G., Woolnough, D. A., Bugaj, M. R., Burck, E. K., Dollard, R. E., Goetz, A., Goss, M., Gu, S., Karl, K., Rose, V. A., Scheunemann, A. E., Webster, R., Weldon, C. R., and J., Yan. 2017. The influence of water currents on community and ecosystem dynamics in coastal Lake Michigan. 60th International Conference on Great Lakes Research, Detroit, MI. May. Presentation.

Reisinger, A. J., and D. G., Uzarski. 2017. Natural and anthropogenic disturbances affect water quality of Great Lakes coastal wetlands. 60th International Conference on Great Lakes Research, Detroit, MI. May. Presentation.

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Uzarski, D.G. 2018. Monitoring multiple biological attributes in Great Lakes coastal wetlands: database access for invasive species management. Association of State Wetlands Managers. Webinar Presentation.

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