Journal of Great Lakes Research 46 (2020) 910–919

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/ijglr

Ecological data as a resource for invasive species management in U.S. Great Lakes coastal wetlands

Allison N. Kneisel [a,*], Matthew J. Cooper [b], Anna K. Monfils [c], Salma Haidar [d], Donald G. Uzarski [a]

[a] Institute for Great Lakes Research and Biology Department, Central Michigan University, Mount Pleasant, MI 48859, USA
[b] Burke Center for Freshwater Innovation, Northland College, Ashland, WI 54806, USA
[c] Institute for Great Lakes Research, Biology Department, and Central Michigan University Herbarium, Central Michigan University, Mount Pleasant, MI 48859, USA
[d] School of Health Sciences, Central Michigan University, Mount Pleasant, MI 48859, USA

ARTICLE INFO

Article history:
Received 29 June 2019
Accepted 5 January 2020
Available online 29 January 2020
Communicated by Orlane Anneville

Keywords:
Invasive species
Management
Coastal wetlands
Laurentian Great Lakes
Database

ABSTRACT

The coordinated use of ecological data is critical to the proper management of invasive species in the coastal wetlands of the Laurentian Great Lakes. Researchers and government programs have been increasingly calling for the use of data in management activities to increase the likelihood of success and add transparency in decision making. Web-enabled databases have the potential to provide managers working in Great Lakes coastal wetlands with relevant data to support management decisions. To assess the potential value of these databases to managers in Laurentian Great Lakes states, we surveyed wetland managers to determine their current data usage as well as their future data interests and catalogued the online databases currently available. Surveys were disseminated via email to managers in 56 different organizations overseeing invasive species management efforts in Great Lakes coastal wetlands; 46 responses were included in this analysis. Of the survey respondents, all reported using raw biotic data for decision making, (i.e. presence of target species) but many indicated that they would prefer to incorporate a greater variety of data, as well as more complex information. Our survey found that managers used web-enabled databases, but most databases that we catalogued only provided presence data for wetland biota. We concluded that databases can provide the types of data sought by invasive species managers but have unmet potential to be integrated into responsive management processes.

Introduction

The Laurentian Great Lakes are an ecologically and anthropologically complex ecosystem that requires coordinated and evidence-based invasive species management, particularly in coastal regions. Regional experts have ranked invasive species and invasive species-related issues as three of the top five most important stressors for the Laurentian Great Lakes and their associated wetlands (Smith et al., 2015). Invasive species in these Great Lakes have been shown to outcompete or crowd out native species (Janssen and Jude, 2001; Tulbure et al., 2007), create lower habitat quality (Lawrence et al., 2016), and act as a nuisance to area businesses and residents (Pejchar and Mooney, 2009). The management of invasive species in Great Lakes wetlands is complicated by the systems acting as a sink for materials originating from the surrounding landscape (Zedler and Kercher, 2004) and their patchwork of ownership, making them difficult to manage in isolation. To overcome these challenges, the principal document governing the management of the Laurentian Great Lakes, the Great Lakes Water Quality Agreement (GLWQA), outlines the importance of accountability and using science-based management, both generally and when specifically addressing invasive species (GLWQA, 2012). In response, the use of ecological data and information has been recommended in recent management strategies including the Great Lakes Nearshore Framework (Lakewide Management Annex Nearshore Framework Task Team, 2016) and the Great Lakes Restoration Initiative (Great Lakes Interagency Task Force, 2010). These and other efforts seek to improve project outcomes and facilitate collaboration through the use of ecological data by wetland managers.

The Coastal Wetland Monitoring Program (CWMP) is one project aimed at providing ecological data for management activities in the Laurentian Great Lakes. Funded by the US EPA, the CWMP completed its first 5-year field sampling cycle in 2015 (Uzarski

* Corresponding author at: 1455 Calumet Court, Bioscience Building, Central Michigan University, Mount Pleasant, MI 48859, USA.
E-mail address: kneis1an@cmich.edu (A.N. Kneisel).

https://doi.org/10.1016/j.jglr.2020.01.006
0380-1330/

et al., 2017), with a second sampling cycle spanning the years 2016–2020. This monitoring has generated data on water quality and the fish, macroinvertebrate, bird, anuran, and vegetation communities in wetlands across the Laurentian Great Lakes basin. In addition to raw data collection, this project also provides metrics of ecosystem condition, which are available on the program's online mapping tool (greatlakeswetlands.org/map). In a related project, a decision support tool has been developed that uses the wetland monitoring data from the CWMP to inform management recommendations (greatlakeswetlands.org/dst). The tool integrates monitoring data including environmental condition metrics, percent coverage of *Phragmites australis*, catch per unit effort for game fish, and water chemistry, along with other physical and geographic data with a goal of facilitating data-driven decisions on restoration and protection investments.

The benefits of incorporating ecological data into management practices are well documented in the literature on restoration and conservation methods (Cook et al., 2016). Adaptive management, which combines experimental design and management efforts, requires baseline data to create models as well as monitoring data to quantify outcomes (Walters and Holling, 1990). When choosing among several potential sites for restoration, prioritization requires ecological data to compare sites in a standardized manner and select those that have the highest likelihood of achieving the desired outcomes (Cipollini et al., 2005). Other approaches to evidence-based management, decision triggers for example, can make management more accountable to stakeholders using data-based standards and can prompt discussion on the suitability of management activities (Nie and Schultz, 2012). For the management of invasive species, data on the surrounding landscape and physical site characteristics can be equally as important as the control method in predicting management outcomes (Rohal et al., 2019).

Despite the acknowledged value of ecological data in restoration literature and considerable Great Lakes investment in monitoring efforts, there has been little research into the use of data by natural resource managers or the current availability of data to managers. Data sharing requirements by research funders and journals have increased the amount of publicly available data for systematic reviews (Pullin and Salafsky, 2010; Vetter et al., 2016) and management activities (Hampton et al., 2013), but the usability of these datasets to managers is relatively unknown. For protected area managers in Australia, research, population monitoring data, and condition assessments were highly valued in the management decision process, but these data were not always available or accessible (Cook et al., 2012). Online access to information sources could lower barriers to relevant data. In an international survey of invasive species managers, researchers and policymakers, free and online access were both important factors in whether or not scientific research was used when making management decisions (Bayliss et al., 2012). Online databases (henceforth, databases) may facilitate data distribution, but it is necessary to know what data are most helpful to managers and where there are unmet needs.

The purpose of this study was to assess the value that databases, such as the ones provided by the CWMP, provide to invasive species managers working in the U.S. Laurentian Great Lakes coastal wetlands. Specifically, we surveyed managers to learn what ecological data are currently being used and if there are data for which managers would like improved access. Additionally, we cataloged the data that are currently available through databases for coastal wetlands in the U.S. Great Lakes states. Our goals were to identify gaps in data availability, discover data that may be underutilized, and better understand how managers incorporate online tools into their management activities.

Table 1
The information collected from each online database that met the eligibility criteria.

Information Recorded	Example
The search parameters that located the database	Google Search: "Wetland" AND "Invertebrate" AND "Database"
The organization that manages the website where database is housed	Michigan State University, NOAA, etc.
If an account is required to access any or all data	Yes, No, Partial
If payment is required to access any or all data	Yes, No, Partial
The type of groups that collected the data	Professional, Volunteer, etc.
The categories of raw biotic data available on the database	Presence, abundance, diversity, etc.
The taxonomic groups represented by the raw data	Fish, birds, invertebrates, etc.
The synthesized information available on the database	Index of biotic integrity, floristic quality index
The taxonomic group represented by synthesized information	Fish, birds, invertebrates, etc.
The abiotic data or information available on the database	Water quality, sediment characteristics, etc.

Table 2
The types of organizations represented by survey respondents. The "other" responses included regional government, cooperative weed management area, and regional planning organization.

Organization	Respondents (%)
Local Government	20
State Government	7
Federal or Tribal Government	15
Neighborhood or Community Association	2
Large Non-profit	13
Small Non-profit	37
Other	7

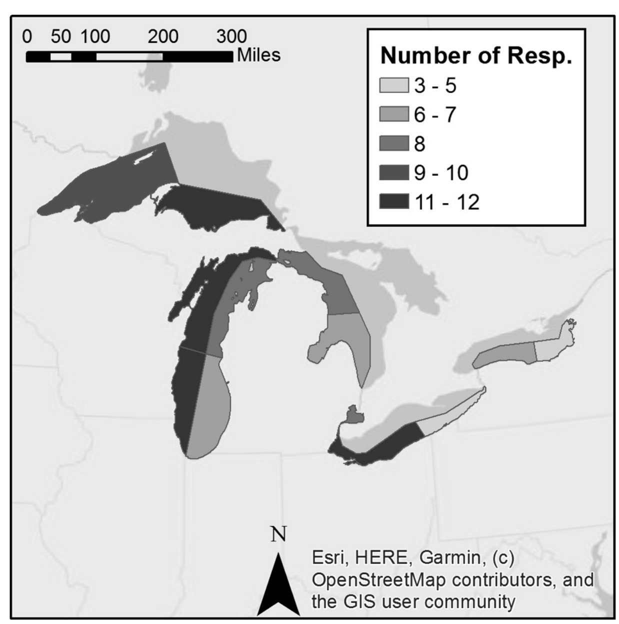

Fig. 1. The number of respondents that had conducted invasive species management work in wetlands by region of the Great Lakes. n = 46.

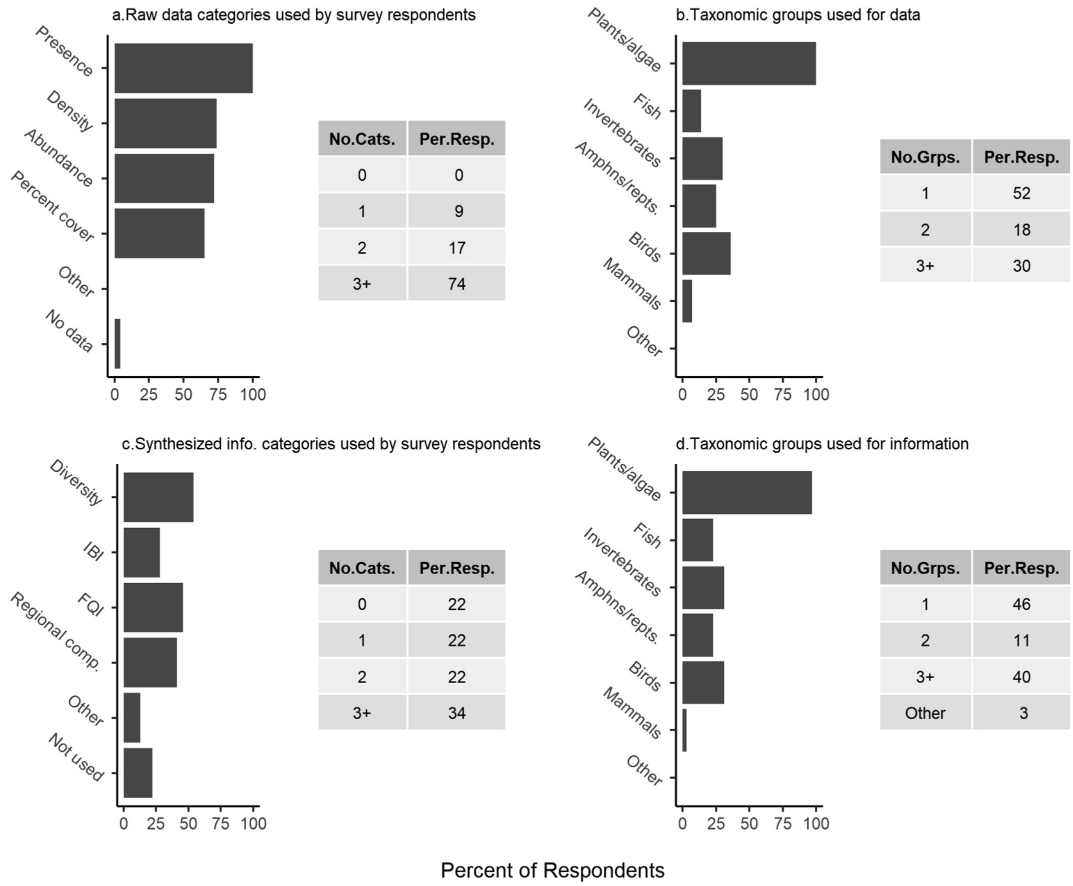

Fig. 2. The data and information that had been used by survey respondents, a. The percentage of survey respondents (Per.Resp.) that selected each data category and the number of categories (No.Cats.) selected when asked what kinds of raw data they had used (n = 46). b. The taxonomic groups on which the data used by respondents were based. (n = 44) c. The percentage of survey respondents that selected each information category and the number of categories selected when asked what kinds of information they had used (n = 46). (IBI = Index of biotic integrity, FQI = Floristic quality index, Regional comp. = Regional comparison tool) d. The taxonomic groups on which the information used by respondents was based (n = 35).

Methods

Survey design

To understand what types of data are being used in the management of invasive species, we created a survey consisting of 29 questions, which covered respondent demographics, current use of data, interest in additional data, and factors that affect the use of data (Table S1). The survey was created to be administered via email, using the online service SurveyMonkey (SurveyMonkey Inc, San Mateo, California, USA, www.surveymonkey.com). To better parse the data and evidence used in the management process, we distinguished between raw data and synthesized information. In the survey, raw data referred to any measurement directly collected from a wetland while synthesized information referred to any scores, rankings or categories derived from data that provide additional insight into the ecosystem's condition relative to other systems. In the questions about current and desired data use, respondents were asked to select from a list of raw data categories (Presence, Abundance, Density, Percent Cover) or to provide additional categories. Questions about the use of synthesized information were similarly formatted, allowing respondents to select from a list of synthesized information categories (Diversity, Index of Biotic Integrity, Floristic Quality Index, Regional Comparison). After each question about categories of biotic data or information, respondents were questioned about the taxonomic groups on which the data were based. Managers were also asked specifically about their use of water quality data and information. We did not differentiate between collection methodologies (automated vs human collected, volunteer vs professional, etc.) when asking managers about their data use. However, in the final section of the survey, we asked managers what metadata they would like to access with the ecological data.

The survey was submitted to Central Michigan University's Institutional Review Board (IRB, Project #1050888) as required when using human research subjects, but the survey met the criteria for exemption from continued IRB review.

Population surveyed

Organizations to survey were identified from multiple sources, including lists of projects funded by the US EPA or other conservation organizations, partner lists from the websites of Great Lakes states' Department of Natural Resources (or equivalent), and through larger invasive species networks such as the Great Lakes Phragmites Collaborative. From each organization, one to four individuals were invited to participate based on the availability of contact information and the size of the organization. Using this approach, 72 representatives of 56 organizations were contacted.

Response and analysis

In November of 2017, each potential respondent was contacted via email to explain the purpose of the survey several days prior to receiving an email with the survey link. One month after initially receiving the survey, a reminder was sent to all individuals and

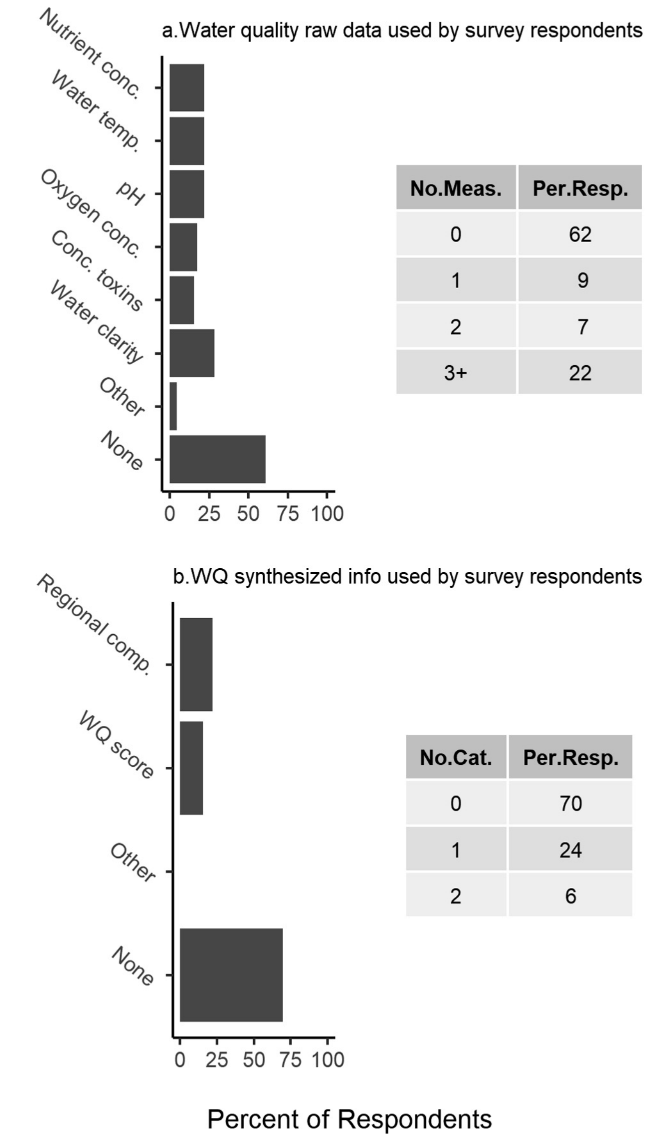

Fig. 3. The water quality data and information that had been used by survey respondents, a. The percentage of survey respondents (Per.Resp.) that selected each water quality measure and the number of measures (No.Meas.) selected when asked what kinds of water quality data they had used (n = 45). b. The percentage of survey respondents that selected each water quality information category and the number of categories selected when asked what kinds of information they had used (n = 46).

the survey remained open for another two weeks. For managers to be eligible, they had to confirm that they were involved in the decision-making process concerning invasive species management in Laurentian Great Lakes coastal wetlands. Any responses in which less than 75% of required questions were answered, not including the demographic and eligibility questions, were excluded from the analysis. As some organizations had separate projects or offices that could differ in focus when managing invasive species, we decided to analyze data at the individual level in order to capture variation within organizations.

We assumed that our list of potential respondents represented the majority of the groups managing U.S. Great Lakes coastal wetlands, and therefore we used Fisher's exact tests to determine if the proportions of respondents for each organization type and region differed from the original list. To explore any patterns in the distribution of respondents, a Kendall's tau test was used to look for a relationship between the number of respondents from a region and the area of wetland coverage in that region. Wetland area coverage was calculated using the Great Lakes Coastal Wetland Inventory polygons developed by the Great Lakes Coastal Wetland Consortium (Databasin.org, accessed January 14th, 2019) in ArcMap 10.4.1 (Esri, 2016). Fisher's exact tests were also used to look for differences between the data used by groups working across a smaller geographic scale (local government, small non-profits) compared to groups working across a larger geographic scale (large non-profits, state governments, and federal governments). Analysis of data was performed in RStudio version 1.1.463 (RStudio Team, 2016).

Database review

A systematic review of databases was used to determine available data resources utilizing search methods adapted from Smart and Burling (2001). First, we compiled a list of institutions that could collect data on Great Lakes coastal wetlands. We chose to focus on research universities and governmental agencies (Federal, State, and Tribal) in the Great Lakes states as we felt that these organizations were most likely to have publicly available data on a scale large enough to be relevant and to be hosted on a website that was continually managed. The websites of each of these organization types were systematically searched for databases using predetermined phrases (Tables S2 and S3). We chose search phrases to reflect the categories of data and information that were asked about in the survey as well as descriptors that would relate to databases specific to the area of interest (Great Lakes coastal wetlands) and those that could contain relevant data among more broad topics (freshwater or wetlands) more generally. For the second approach, we used similar search phrases to search Google.com. After briefly reviewing the first thirty websites from the Google.com search, all sites that appeared to relate to ecological data were checked for a database. With either method, PDF results and other non-webpage results were not included, as we wanted to focus on databases that were accessible directly through a search or via a link from a webpage because managers are unlikely to have time to read through documents to find a reference to a database and then locate it independently.

When a database was located using either approach, it was compared to the following eligibility criteria before it was reviewed for data, information, and metadata: 1) must be associated with an academic, governmental, non-profit organization, or private company; 2) must have the possibility of including data linked to a Great Lakes coastal wetland (i.e. was focused on a geographic area that included the Laurentian Great Lakes); 3) data must have a geographic reference to an area smaller than a county; and 4) data must be presented in a form that allows individuals to search for or extract a subset of data. The association with an academic, governmental, non-profit organization, or private company was required in an attempt to limit the results to databases that had traceable origins (although this was not always the case) and databases that were maintained over multiple years. The county-level threshold was selected in order to only include databases that provide data at a level that can be linked to a specific coastal wetland or adjacent coastal area. When reviewing databases that met the eligibility criteria, the information listed in Table 1 was recorded into a database in Microsoft Access (version 1808).

Results

Survey participants

We received 46 complete survey responses, representing a 64% response rate. Respondents represented a variety of organization

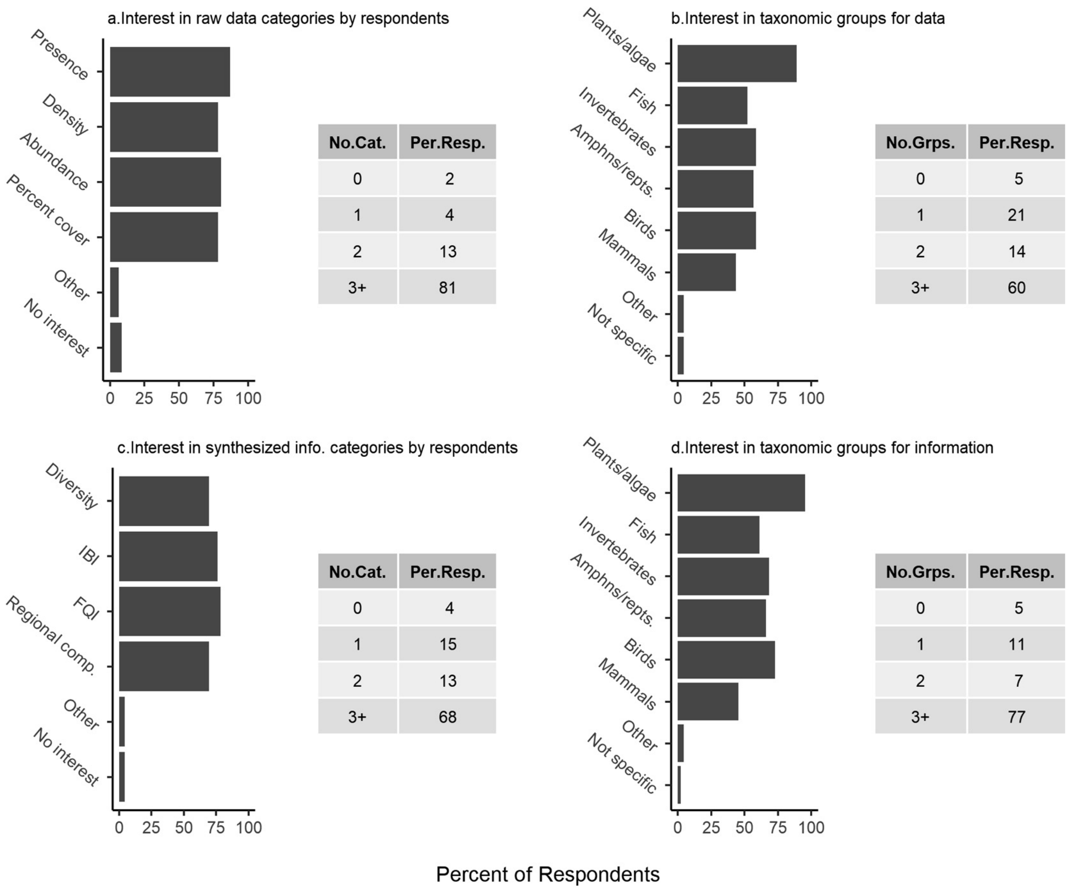

Fig. 4. The data and information that survey respondents indicated they would like to use or use more, a. The percentage of survey respondents (Per.Resp.) that selected each raw data category and the number of categories (No.Cats.) selected when asked what kinds of raw data they would like to use (n = 45). b. The taxonomic groups for which respondents are interested in having more data (n = 43). c. The percentage of survey respondents that selected each information category and the number of categories when asked what kinds of information they would like to use (n = 46). (IBI = Index of biotic integrity, FQI = Floristic quality index, Regional comp. = Regional comparison tool) d. The taxonomic groups for which respondents are interested in having more information (n = 44).

types that work across the Great Lakes Basin, but organizations working at a smaller geographic scale (i.e. groups that work in a single state, including small non-profits) were more common (Table 2). To better understand the management experience of the respondents, each lake (with the exception of Lake St. Clair) had its coastline divided into quarters, so that respondents could select in which of the US regions they have worked (Fig. 1). The proportions of respondents that represented each organization type and the proportions that work in each region did not significantly differ from the proportions seen in the list of managers who were initially contacted, as determined by Fisher's exact tests. A Kendall's tau test determined that there was no relationship between the number of respondents from a region and the area of wetland coverage in that region. All respondents indicated that they had experience managing invasive plant species, 20% of respondents indicated having experience working with invasive invertebrates, less than 10% indicated that they had worked with invasive fish or birds, and no respondents had worked with invasive mammals.

Respondent data usage

In response to questions about raw data usage, all respondents indicated that they had used presence data and 74% had used three or more of the raw data categories listed (Fig. 2a). When asked which taxonomic groups constituted the raw data that they had used, all managers that responded to the question selected plants/algae. Each of the other taxonomic groups were selected by less than 40% of respondents and 18% of respondents had used raw data based on three or more taxonomic groups (Fig. 2b). The use rates were lower for synthesized information, with 22% of respondents having never used any synthesized information, and only 34% of respondents having had used three or more categories of synthesized information. Diversity was the most used category of information at 54%, with all other categories used by less than half of the respondents (Fig. 2c). Similar to the pattern seen with raw data, plants/algae were the taxonomic group most often used to generate information. Forty-six percent of respondents that had used synthesized information only used information based on plants/algae (Fig. 2d). One manager indicated that the information that they used was not based on a specific taxonomic group.

When questioned specifically about water quality data, 62% of respondents had never used any water quality data and 70% had not used synthesized information. All the measures of raw water quality data (Fig. 3a) and information (Fig. 3b) that we included in the survey had been used by less than a third of respondents.

Respondent data interests

All data and information categories received a high level of interest from respondents who indicated they would like to have access (or improved access) to a variety of data types. Ninety-eight percent of respondents selected at least one category of raw data that they would use more and 81% of respondents

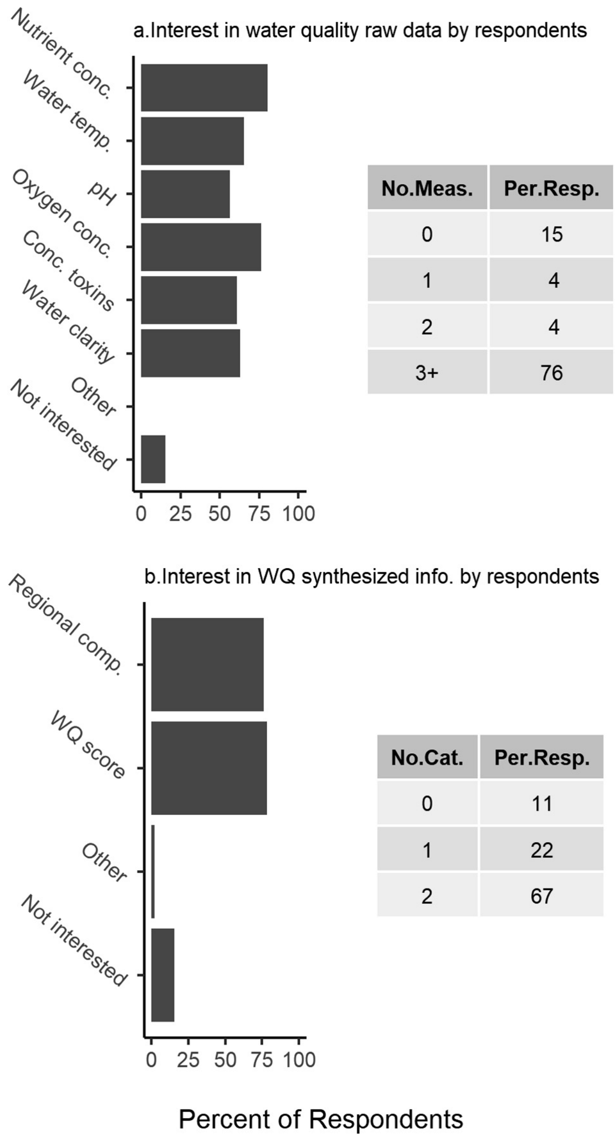

Fig. 5. The water quality data and information that survey respondents (Per.Resp.) indicated they would like to use or use more, a. The percentage of survey respondents that selected each water quality measure and the number of measures (No.Meas.) selected when asked what kinds of water quality data they would like to use (n = 46). b. The percentage of survey respondents that selected each water quality information category and the number of categories selected when asked what kinds of information they would like to use (n = 46).

selected three or more of the data categories listed (Fig. 4a). Respondents also suggested genetic data, geospatial data, historical data, climate data, Lake Michigan currents, and sedimentation rates in the ''other'' category. When asked for which taxonomic groups managers would like more raw data, plants/algae were most selected, but five categories were selected by more than 50% of managers (Fig. 4b). Over 50% of respondents were interested in having better access to each category of synthesized information and 68% of respondents wanted access to three or more of the categories (Fig. 4c). The interest in information based on specific taxonomic groups mimicked that of raw data, with most categories being selected by at least 50% of respondents and plants/algae being selected the most. Seventy-seven percent of respondents had an interest in having improved access to information based on three or more different taxonomic groups (Fig. 4d).

Table 3
The percentage of respondents that indicated using data at each step of the management process.

Management step when ecological data are used	Respondents (%)
Measuring the success of management activities	78
Applying for grants or other funding	74
Selecting a location for management	67
Setting management goals	65
Determining the best management technique	32
Other	7

Table 4
The percentage of respondents that indicated they would like to access each type of metadata when accessing ecological data and information.

Metadata	Respondents (%)
Date the data were collected	84
GPS location of samples	84
Sampling design	69
Analysis used to generate information	69
Sampling equipment used	53
Who collected the data	53
Method of organism identification	42
If biotic samples were DNA barcoded (genetically identified)	33
If vouchers were collected	29
I am not interested in collection methods	4
Other (please specify)	0

Eighty-nine percent of participants selected that they were interested in water quality data and information. Of those, over half were interested in all water quality measures listed (Fig. 5a) and more than 67% of respondents expressed interest in using both categories of water quality-based synthesized information (Fig. 5b).

The final questions of the survey helped to illustrate when data were being used and the origin of those data. Table 3 presents the step in the management process when managers indicated that they used data or information and Table 4 shows which types of metadata were most relevant to managers. When asked where they currently obtain data or information, self-collected or partner-collected data was the most common answer at 84%, but 39% of respondents selected two or more sources (Fig. 6). The average number of databases known to a respondent was four, while the average number of databases used was two (Table 5).

Databases reviewed

Of the 234 potential databases located, 78 met our criteria and were cataloged. Thirty-three of the databases were only found searching the websites of government and academic institutions, 10 were found only through the Google.com searches, and 35 were found using both methods. The majority (60%) of databases were found in the results of five unique searches or less, although one database (Water Quality Portal) was found in the results of 43 different search phrases either on Google or agency websites. Databases hosted by a government agency constituted 40% of the databases, 45% were hosted by academic institutions, 14% were non-profit hosted, and 1% were hosted by private companies. Of all the databases, 38% were created through a partnership of organizations. To access these data, 90% of the databases did not require any kind of account, while the remaining 10% required an account to access some or all of the available data. No databases required payment for access; however, several organizations offered services that would provide natural community data for project sites for a fee. As they were not available in the form of an online database, these were excluded. The data in 72% of the databases was exclusively collected by professionals, 14% of the

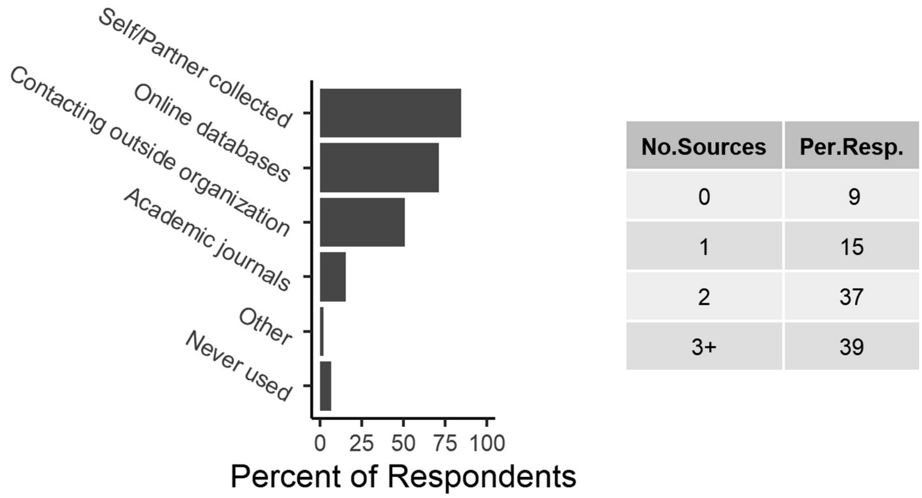

Fig. 6. The percentage of survey respondents (Per.Resp.) that selected each source and the number of sources selected when asked "Where do you currently get raw data or information for the management of invasive species in Great Lakes coastal wetlands? (Select all that apply)" n = 45.

Table 5
Percentage of managers that were familiar with an online database and the percentage that had used each database.

Databases	Familiar (%)	Used (%)
Great Lakes Coastal Wetland Monitoring Program Mapping Tool	61	20
Midwest Invasive Species Information Network (MISIN)	59	39
NatureServe	52	24
iNaturalist	41	13
Great Lakes Environmental Database (GLENDA)	39	9
USGS Nonindigenous Aquatic Species Database	39	15
Great Lakes Coastal Wetland Decision Support Tool (CWDST)	37	9
Great Lakes Observing System (GLOS)	33	9
Biodiversity Information Serving Our Nation (BISON)	22	9
Water Quality Portal (WQP)	11	4
SEINet Portal Network	9	4
Global Biodiversity Information Facility (GBIF)	7	2
Data Basin	4	2
Integrated Digitized Biocollections (iDigBio)	4	4
VertNet	4	4
Dryad Digital Repository	2	2

databases used a mix of professionals and volunteers, 11% used volunteers with a data quality check system or training, and 3% of the databases were not clear about what group specifically collected the data.

Available data

Raw data were available on the majority of the databases (81%), while only 15% of the databases contained synthesized information. Presence data were the most common category of raw data found on databases and raw biotic data were available for all taxonomic groups (Fig. 7a and b). IBIs were the most common category of information but were still only present on 6% of the databases (Fig. 7c). Of the 15% of databases that contained synthesized information, plants/algae, fish, and invertebrates were the most common taxonomic groups featured (Fig. 7d). For abiotic data, 15% of databases had raw water quality data, 5% had raw sediment data, and one database had raw data on gas exchange within wetland areas. Only 5% of databases had any kind of score or categorization based on water quality, 3% had a restoration potential score or ranking, and less than 1% had an ecosystem impairment list or regional ranking system. Eight of the databases contained only data on invasive species, and one contained only data on threatened or endangered species. Data or information were available for all of the predetermined regions of the Great Lakes (Fig. 8), and the number of databases that contained data for each region was not related to the area coverage of wetlands in that region, as determined by Kendall's tau test.

Discussion

Data used in management

Our results suggested that the majority of managers have used raw biotic data when making management decisions and that more than half have used multiple categories of raw biotic data or synthesized information. The use of raw biotic data is not surprising, as invasive species management requires determining the location and extent of invasions prior to almost any management approach (Hulme, 2006). A survey by Cook et al. (2012) found that occurrence data for species and ecosystem types were ranked the highest priority for protected area managers in Australia. Presence data were also found more often via our search of databases than other categories of raw data or synthesized information. Although plants were the most used taxonomic group by survey respondents, vegetation data were not found more often on the reviewed databases than other taxa. The high rate of use of vegetative data relative to other taxonomic groups could be the result of all respondents having experience managing invasive plants, the popularity of plants as indicator species (Siddig et al., 2016), the high number of invasive plants in the Great Lakes region (Mills et al., 1993), or the continuing increase of invasive plant coverage in Great Lakes coastal wetlands (Lemein et al., 2017).

The steps of the management process in which ecological data and information were most used included the planning and post-management stages to measure success. Data use at these steps has been shown to be important in evaluating positive ecological outcomes (Alexander and Allan, 2007) and should continue to be supported.

Gaps in current data use

While respondents indicated using data in the management process, the survey also highlighted the need to improve data

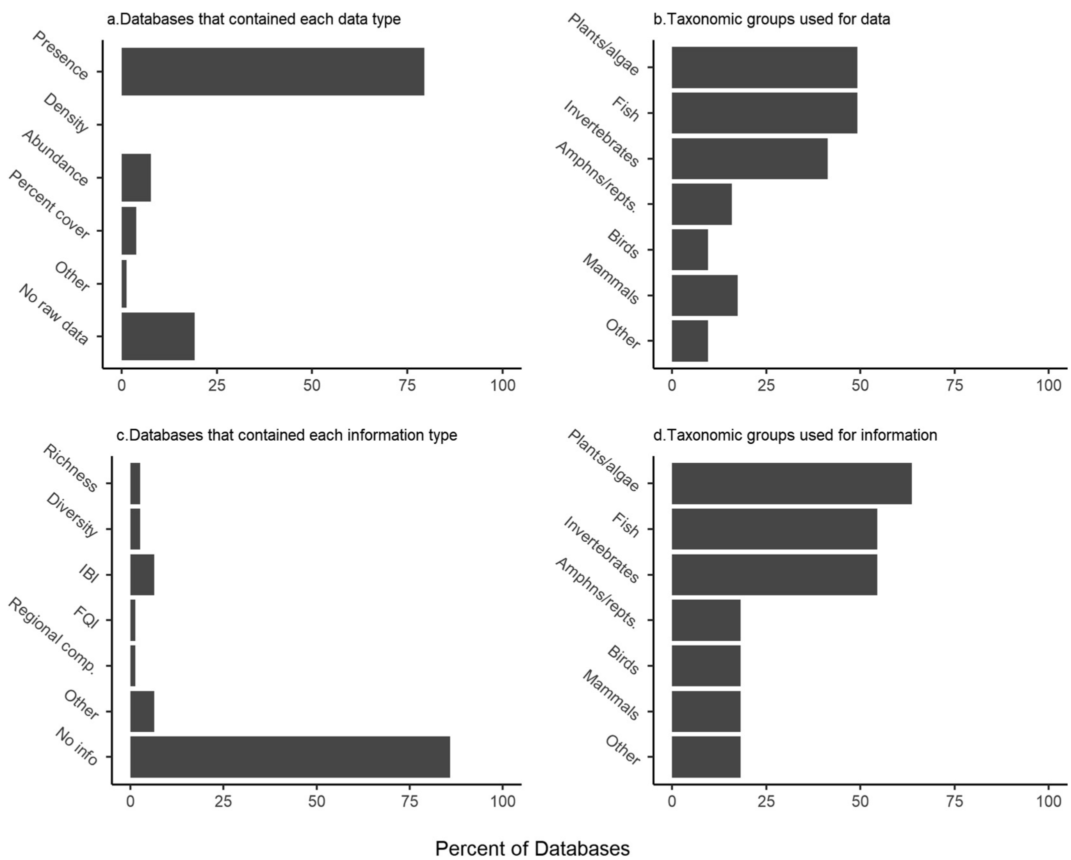

Fig. 7. The data and information available through online databases, a. The percentage of databases containing each raw data category (n = 78). b. The percentage of databases that contained raw data relating to each taxonomic group (n = 63). c. The percentage of databases that contain each synthesized information category (n = 78). c. The percentage of databases that contained information relating to each taxonomic group (n = 11).

sources, as signified by more than 90% of respondents wanting access (or better access) to at least one type of data or information. With more than 65% of respondents showing interest in multiple data and information categories, and more than 60% of respondents showing interest in data and information based on multiple taxonomic groups (Fig. 4), it appears that managers are interested in using a variety of data types in their decision making. Australian protected area managers, surveyed by Cook et al. (2012), also valued having access to as much information as possible, scoring all "components of management decisions" as important. One of the larger discrepancies between respondents' interests (Fig. 5) and current use (Fig. 3) was water quality related data and information. Enabling the use of water quality data would help managers achieve whole-system management that is promoted by Hulme (2006) and address the interactions between invasive species and water quality (Smith et al., 2019; Zedler and Kercher, 2004). An "ecosystem approach" that incorporates the relationship between the water and the biota is also one of the guiding principles of the GLWQA (GLWQA, 2012).

Role of databases

Databases appear to inform management decisions, as 70% of managers surveyed used databases as a data source (Fig. 6), and on average a respondent had used two of the databases listed in Table 5. This counters Seavy and Howell (2010) who found that online information sources were generally not considered important or accessible to California land managers. Additionally, data collection within the organization (or partner organizations) was the most common data source, but our survey did not determine whether these data were stored or shared in any way.

While our respondents used databases, there is still potential for these databases to better meet manager needs, particularly as seen in the low availability of synthesized information. Synthesized information, which we found on only 15% of the databases (Fig. 7), may rarely be available due to the large datasets and complex analyses needed to create and test synthesized metrics (Borja and Dauer, 2008) or identify reference areas (Soranno et al., 2011). Databases that do provide synthesized information, like the two CWMP websites, may need to increase their visibility in online searches (Bayliss et al., 2012) or work with managers when they use these tools to provide context and guidance (Seavy and Howell, 2010) in order to maximize the value they provide. Best practices for curators of databases, and data collectors providing the data to these aggregators, would be to provide the metadata (data associated with the data collection methods, scope, and scale), as it was valued by the managers surveyed (Table 4). This is consistent with the recent recommendations of Guralnick et al. (2018).

Limitations and future research

It is important to note that these conclusions are limited by the scope of both managers and databases that were considered in this study and that any extrapolation of these results to other regions should be done with caution. As we are evaluating data use in the context of the CWMP tools, we chose to look at a very specific population: managers who have done invasive species work in U.S. Great Lakes coastal wetlands. Because of the specificity of this

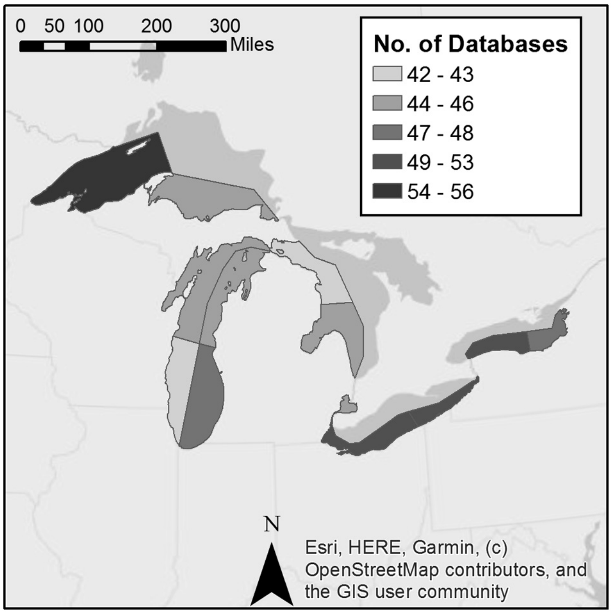

Fig. 8. The number of databases that provide data or information on wetlands located in each region of the Great Lakes.

population, the overall number of individual responses is limited, however, the response rate was high, as was the potential number of organizations included. We are unsure what factors influenced the number of respondents representing each region, as it did not appear to be related to wetland area. It is possible that our initial list of organizations to survey was biased or that the distribution of invasive species, human populations, and financial resources played a role. This approach also excluded Canadian managers working on invasive species in Great Lakes coastal wetlands, who are also working under the same strategy outlined in the Great Lakes Water Quality Agreement but may differ in data needs from their U.S. counterparts. Future research that provides more information on the organizations that manage coastal wetlands and their goals is warranted to support the use of data in management activities.

Conclusions

In our survey, coastal wetland managers in the Laurentian Great Lakes indicated that they are using web-accessible datasets to make decisions throughout the invasive species management process, and they are interested in diversifying the types of data and information that they use. The interest from managers in using synthesized information and water quality data, as well as their high use rate of online resources suggests that databases, like those created by the CWMP, can provide valuable information to wetland managers. It is also apparent that these types of data resources may currently be underutilized, and the curators of databases should continue to engage managers, data scientists, and ecologists to increase data access and usability.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A portion of this research was funded by the Landscape Conservation Cooperative Network (Project #F14AP00412) via the US Fish and Wildlife Service and through Central Michigan University scholarships. Authors Allison Kneisel, Donald Uzarski, and Matthew Cooper are involved in the USEPA Great Lakes Coastal Wetland Monitoring Program referenced in this study.

Acknowledgements

A portion of this research was funded by the Landscape Conservation Cooperative Network (Project #F14AP00412) via the US Fish and Wildlife Service. Funding for the CWMP program has been provided by the USEPA Great Lakes National Program Office through the Great Lakes Restoration Initiative (grant #'s GL-00E00612-0 and GL-00E01567). We would like to thank the managers who took the time to complete the survey and Marion Whitney and Daniel E. and Mildred G. Wujek for providing support for this work through Central Michigan University Biology Department scholarships. We also thank the editors and two reviewers for their helpful comments. Additionally, the authors would like to thank Bridget Wheelock for manuscript edits. This is contribution #139 of the Central Michigan University Institute for Great Lakes Research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2020.01.006.

References

Alexander, G.G., Allan, J.D., 2007. Ecological success in stream restoration: Case studies from the midwestern United States. Environ. Manage. 40, 245–255.
Bayliss, H.R., Wilcox, A., Stewart, G.B., Randall, N.P., 2012. Does research information meet the needs of stakeholders? Exploring evidence selection in the global management of invasive species. Evid. Policy 8, 37–56.
Borja, A., Dauer, D.M., 2008. Assessing the environmental quality status in estuarine and coastal systems: Comparing methodologies and indices. Ecol. Ind. 8, 331–337.
Cipollini, K.A., Maruyama, A.L., Zimmerman, C.L., 2005. Planning for restoration: A decision analysis approach to prioritization. Restor. Ecol. 13, 460–470.
Cook, C.N., Carter (Bill), R.W., Fuller, R.A., Hockings, M., 2012. Managers consider multiple lines of evidence important for biodiversity management decisions. J. Environ. Manage. 113, 341–346.
Cook, C.N., de Bie, K., Keith, D.A., Addison, P.F.E., 2016. Decision triggers are a critical part of evidence-based conservation. Biol. Conserv. 195, 46–51.
Esri, 2016. ArcGIS Desktop (Version 10.4.1) [Computer Software] Redlands, CA.
Great Lakes Interagency Task Force, 2010. Great Lakes Restoration Initiative Action Plan. http://greatlakesrestoration.us/pdfs/glri_actionplan.pdf.
Great Lakes Water Quality Agreement (GLWQA), 2012. https://binational.net/2012/09/05/2012-glwqa-aqegl/.
Guralnick, R., Walls, R., Jetz, W., 2018. Humboldt Core – toward a standardized capture of biological inventories for biodiversity monitoring, modeling and assessment. Ecography (Cop.) 40, 713–725. https://doi.org/10.1111/ecog.02942.
Hampton, S.E., Strasser, C.A., Tewksbury, J.J., Gram, W.K., Budden, A.E., Batcheller, A. L., Duke, C.S., Porter, J.H., 2013. Big data and the future of ecology. Front. Ecol. Environ. 11, 156–162.
Hulme, P.E., 2006. Beyond control: Wider implications for the management of biological invasions. J. Appl. Ecol. 43, 835–847.
Janssen, J., Jude, D.J., 2001. Recruitment failure of mottled sculpin *Cottus bairdi* in Calumet Harbor, southern Lake Michigan, induced by the newly introduced round goby *Neogobius melanostomus*. J. Great Lakes Res. 27, 319–328.
Lakewide Management Annex Nearshore Framework Task Team, 2016. The Great Lakes Nearshore Framework. https://binational.net/wp-content/uploads/2016/09/Nearshore-Framework-EN.pdf.
Lawrence, B.A., Bourke, K., Lishawa, S.C., Tuchman, N.C., 2016. *Typha* invasion associated with reduced aquatic macroinvertebrate abundance in northern Lake Huron coastal wetlands. J. Great Lakes Res. 42, 1412–1419.
Lemein, T., Albert, D.A., Del Giudice Tuttle, E., 2017. Coastal wetland vegetation community classification and distribution across environmental gradients throughout the Laurentian Great Lakes. J. Great Lakes Res. 43, 658–669.
Mills, E.L., Leach, J.H., Carlton, J.T., Secor, C.L., 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19, 1–54.
Nie, M.A., Schultz, C.A., 2012. Decision-making triggers in adaptive management. Conserv. Biol. 26, 1137–1144.
Pejchar, L., Mooney, H.A., 2009. Invasive species, ecosystem services and human well-being. Trends Ecol. Evol. 24, 497–504.
Pullin, A.S., Salafsky, N., 2010. Save the whales? Save the rainforest? Save the data!. Conserv. Biol. 24, 915–917.
Rohal, C.B., Cranney, C., Kettenring, K.M., 2019. Abiotic and landscape factors constrain restoration outcomes across spatial scales of a widespread invasive plant. Front. Plant Sci. 10.

RStudio Team, 2016. RStudio: Integrated Development Environment for R (Version 1.1.463) [Computer Software] Boston, MA. http://www.rstudio.com/.

Seavy, N.E., Howell, C.A., 2010. How can we improve information delivery to support conservation and restoration decisions?. Biodivers. Conserv. 19, 1261–1267.

Siddig, A.A.H., Ellison, A.M., Ochs, A., Villar-Leeman, C., Lau, M.K., 2016. How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in Ecological Indicators. Ecol. Ind. 60, 223–230.

Smart, J.M., Burling, D., 2001. Radiology and the internet: A systematic review of patient information resources. Clin. Radiol. 56, 867–870.

Smith, S.D.P., Bunnell, D.B., Burton, G.A., Ciborowski, J.J.H., Davidson, A.D., Dickinson, C.E., Eaton, L.A., Esselman, P.C., Evans, M.A., Kashian, D.R., Manning, N.F., McIntyre, P.B., Nalepa, T.F., Pérez-Fuentetaja, A., Steinman, A.D., Uzarski, D.G., Allan, J.D., 2019. Evidence for interactions among environmental stressors in the Laurentian Great Lakes. Ecol. Ind. 101, 203–211.

Smith, S.D.P., Mcintyre, P.B., Halpern, B.S., Cooke, R.M., Marino, A.L., Boyer, G.L., Buchsbaum, A., Burton, G.A., Campbell, L.M., Ciborowski, J.J.H., Doran, P.J., Infante, D.M., Johnson, L.B., Read, J.G., Rose, J.B., Rutherford, E.S., Steinman, A.D., Allan, D.J., 2015. Rating impacts in a multi-stressor world: a quantitative assessment of 50 stressors affecting the Great Lakes. Ecol. Appl. 25, 717–728.

Soranno, P.A., Wagner, T., Martin, S.L., McLean, C., Novitski, L.N., Provence, C.D., Rober, A.R., 2011. Quantifying regional reference conditions for freshwater ecosystem management: A comparison of approaches and future research needs. Lake Reserv. Manage. 27, 138–148.

SurveyMonkey Inc., San Mateo, CA. www.surveymonkey.com.

Tulbure, M.G., Johnston, C.A., Auger, D.L., 2007. Rapid invasion of a Great Lakes coastal wetland by non-native *Phragmites australis* and *Typha*. J. Great Lakes Res. 33, 269–279.

Uzarski, D.G., Brady, V.J., Cooper, M.J., Wilcox, D.A., Albert, D.A., Axler, R.P., Bostwick, P., Brown, T.N., Ciborowski, J.J.H., Danz, N.P., Gathman, J.P., Gehring, T.M., Grabas, G.P., Garwood, A., Howe, R.W., Johnson, L.B., Lamberti, G.A., Moerke, A.H., Murry, B.A., Niemi, G.J., Norment, C.J., Ruetz, C.R., Steinman, A.D., Tozer, D.C., Wheeler, R., O'Donnell, T.K., Schneider, J.P., 2017. Standardized measures of coastal wetland condition: Implementation at a Laurentian Great Lakes basin-wide scale. Wetlands 37, 15–32.

Vetter, D., Storch, I., Bissonette, J.A., 2016. Advancing landscape ecology as a science: the need for consistent reporting guidelines. Landsc. Ecol. 31, 469–479.

Walters, C.J., Holling, C.S., 1990. Large-scale management experiments and learning by doing. Ecology 71, 2060–2068.

Zedler, J.B., Kercher, S., 2004. Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes. Crit. Rev. Plant Sci. 23, 431–452.