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Development and implementation of an adaptive management approach for monitoring non-indigenous fishes in lower Green Bay, Lake Michigan

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ABSTRACT

The Laurentian Great Lakes have had numerous introductions of non-indigenous fishes. Some of these species became invasive, resulting in negative economic and ecological impacts. Given the vulnerability of the Great Lakes to future introductions, monitoring for non-indigenous fishes is necessary to protect the Great Lakes ecosystem. This manuscript describes the adaptive development (2013–2017) and results of an early detection and monitoring (EDM) program for non-indigenous fishes in lower Green Bay and the Fox River, a high-risk location for species introductions in Lake Michigan and a potential vector between the Great Lakes and inland ecosystems. The adaptive management approach to EDM has been a continuous cycle of refining sampling gears and methods to improve monitoring each successive year and determining a new method to assess survey performance (determining the contemporary fish community). To date, no non-indigenous fishes previously unknown to the Great Lakes have been detected. Survey performance (i.e., ability to capture species in the fish communty) of this EDM program has increased since its inception in 2013, and a target of 90% survey performance was achieved or nearly met in 2014–2017. Gears and methods will continue to be adaptively refined; however, the current sampling regime and survey performance should provide effective early detection of new non-indigenous fishes, allowing managers to respond early in the introduction phase, when management actions may be more effective.

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Introduction

The introduction of aquatic non-indigenous species is occurring in both marine and freshwater systems across the globe (Mills et al., 1993; Hewitt et al., 2004; Molnar et al., 2008). Greater than 180 aquatic non-indigenous species have been introduced to the Laurentian Great Lakes (hereafter Great Lakes) through several vectors, and it is estimated that a new introduction (or the subsequent detection) has occurred, on average, every 28 weeks since the opening of the St. Lawrence Seaway in 1959 (Ricciardi, 2006). Some aquatic non-indigenous species have become invasive and altered the trophic dynamics of Lake Michigan, such as: zebra *Dreissena polymorpha* and quagga mussels *D. bugensis*, round goby *Neogobius melanostomus*, alewife *Alosa pseudoharengus*, and sea lamprey *Petromyzon marinus* (Madenjian et al., 2002; Madenjian et al., 2015). Given the negative impact of current invasive species and high likelihood of new introductions (especially silver *Hypophthalmicthys molitrix* and bighead carp *H. nobilis*) and their potential negative impacts, Great Lakes researchers and managers have increasingly supported more intensive, coordinated monitoring efforts for non-indigenous species in the Great Lakes (Vander Zanden et al., 2010).

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Early detection monitoring programs for non-indigenous fishes (NIF) either target specific high-risk NIF or conduct broad-spectrum monitoring (focus on detecting any NIF), with a common goal of detecting NIF early in their introduction phase (when they are present in low abundance) to facilitate eradication and control measures (Ricciardi and MacIsaac, 2000; Trebitz et al., 2017). Regardless of the approach used, many aspects need to be considered when designing a scientific survey, such as: safety, available resources, level of effort, sampling gear, assessment methods, etc., but the design is ultimately driven by the study objectives (Hansen et al., 2007). For example, fisheries dependent surveys are species-specific and size-selective – typically requiring only a single sampling gear (Rotherham et al., 2007). In contrast, fisheries independent surveys are not species- or size-selective (i.e., assess fish community) and require a multi-gear sampling approach where gears and methods are modified experimentally to reduce selectivity (Rotherham et al., 2007). The sampling design of early detection and monitoring (EDM) programs for NIF has added challenges compared to traditional fisheries surveys but broadly follows one of these strategies depending on the monitoring approach (i.e., target species or broad-spectrum) used.

Many studies have sought to improve the effectiveness of EDM for NIF in the Great Lakes. Kolar and Lodge (2001) developed quantitative approaches to species-risk assessments to determine species most likely to cause damage if introduced into the Great Lakes. Mills et al. (1993)

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and Ricciardi (2006) determined the most likely pathways and vectors of species introductions into the Great Lakes. The U.S. Environmental Protection Agency (2008) later combined these ideas to show how monitoring could be focused at the most vulnerable Great Lakes ports based on known introduction vectors and the highest-risk species based on habitat suitability. A randomization analysis by Trebitz et al. (2009) in the St. Louis River/Duluth-Superior Harbor, Lake Superior optimized species detection rates and sampling efficiency by exploiting patchiness in fish distributions – allocating the most sampling effort towards those habitats or gear types that yielded the most total, invasive, or unique taxa and then some effort towards all distinct habitats. Also in the Duluth-Superior Harbor, Lake Superior, Hoffman et al. (2011) determined that targeted sampling of high species richness sites and sites with rare species yielded higher species richness, detected non-native species with a significantly higher probability, and also that substantial sampling effort (could exceed 100 units) is needed to detect 95% or more of the species present. Hoffman et al. (2016) outlined an annual evaluation cycle of "implement – evaluate – refine" to be used when adaptively developing EDM programs and also optimized gear-based sampling effort allocation in three Lake Superior ports that reduced the sampling effort required for effective monitoring and increased sampling efficiency.

These first steps towards EDM for NIF in the Great Lakes were instrumental to the development and refinement of future EDM programs. Through risk and vector assessments, an annual adaptive evaluation cycle, and study design considerations, these studies to improved EDM programs by determining: high-risk species, likely vectors of introduction, high-risk sampling locations, appropriate gears, gear allocations, and assessment methods for determining survey performance. The U.S. Fish and Wildlife Service (USFWS) adopted the work of the U.S. EPA (2008 [sources of Great Lakes invasions]), Trebitz et al. (2009), and Hoffman et al. (2011) in their strategic framework (USFWS, 2014) of goals and objectives to guide the development of EDM monitoring programs in the Great Lakes. An improved sampling design for EDM monitoring by Hoffman et al. (2016) was also taken into consideration by the USFWS; however, the authors noted that the use of an annual adaptive evaluation cycle in other Great Lakes ports would likely yield different strategies to optimize EDM programs than what they found in the Duluth-Superior Harbor.

In Lake Michigan, there are several locations that were found to be hotspots for introductions of NIF based on a risk analysis (Hayer et al., 2017 [completed in 2013]). Lower Green Bay and the Fox River, Wisconsin is the largest and also one of the highest risk locations for introductions of NIF in Lake Michigan. The process of implementing an EDM program for NIF in lower Green Bay began in 2013, and the adaptive framework followed the guidelines in the USFWS strategic framework. Here we describe the process of adapting an EDM program for NIF to lower Green Bay and the Fox River (hereafter referred to as lower Green Bay) and provide a summary of 2013–2017 monitoring results. Our study objectives were to: 1) develop an adaptive EDM program to effectively sample the fish community and detect new NIF in lower Green Bay, 2) describe the contemporary fish community of lower Green Bay, and 3) assess the survey performance (i.e., effectiveness) of our EDM program through quantitative and qualitative evaluation techniques.

Methods

Study area

Lower Green Bay is among the largest freshwater estuaries in the world. The Fox River, which drains nearly 17,000 km^2 of primarily agricultural and industrial land, enters Lake Michigan at the city of Green Bay, WI, the principal city of a large metropolitan area bordering Lake Michigan with ~300,000 people (Fig. 1). Due to inputs from the Fox River and the shallow bathymetry (<5 m) of lower Green Bay, it is the most productive (eutrophic-hypereutrophic) region of Lake Michigan. The coastline is composed predominantly of residential properties, coastal wetlands, barrier islands, and industrial development. Lower Green Bay and the Fox River below De Pere dam (hereafter referred to as lower Green Bay) have been listed as a Great Lakes area of concern since 1980 due to pollution from past industrial use. The port of Green Bay remains active, receiving both commercial and recreational boat traffic; and lower Green Bay is one of the highest risk locations for new introductions of NIF into Lake Michigan (Hayer et al., 2017). The sampling boundary of our EDM program extends from the Fox River downstream of De Pere dam and approximately 12 km out into lower Green Bay (Fig. 1; total sampling area = 81.2 km^2).

Adaptive management strategy

Our approach to the development of an EDM program for NIF followed an adaptive management framework (Fig. 2). Under the direction of the USFWS strategic framework (2014), our implementation plan included a risk assessment for the introduction of NIF that identified lower Green Bay as one of the highest-risk sites in Lake Michigan (Hayer et al., 2017). To most effectively and adaptively monitor for NIF, a multi-gear, broad spectrum species monitoring approach was used to sample the fish community of lower Green Bay and detect any NIF present (Trebitz et al., 2017). A list of fish species at high-risk of being introduced to the Great Lakes was compiled from peer-reviewed literature and was updated as new information became available. Recently, we adopted the watch list of NIF of concern created by Alsip et al. (2017) that included 28 NIF likely to survive and have negative ecological impacts if introduced into the Great Lakes. Taxonomic information was compiled for watch list species, and all staff members have participated (since 2016) in an identification workshop for NIF at the University of Michigan Museum of Zoology, where the identifying characteristics of 24 of 28 watch list species (museum specimens) were visualized and photographed.

The adaptive cycle consisted of evaluating different sampling gears, gear configurations, sampling methods, and amassing catch-based spatial information to refine future sampling efforts. In this way, we sought to rapidly improve monitoring in lower Green Bay to achieve a ≥90% survey performance (i.e., ability to detect 90% of the fish community), indicating a high potential to detect novel NIF present in low abundance and/or with limited distributions (i.e., rare). Following annual monitoring, survey performance was evaluated using species accumulation curves (SAC), the known, contemporary fish community of lower Green Bay, and the capture of rare species to determine whether adaptive sampling adjustments increased the effectiveness of our EDM program. For example, if observed species richness was $N = 30$ in a given year and $N = 60$ species comprised the known, contemporary fish community (or asymptotic species richness from SAC) then survey performance would be $(30/60) \times 100$ or 50%. To allow this comparison, we needed to define what units of sampling effort (i.e., catch data) comprised "annual" monitoring. Hence, catch data from all sampling gears used in 2013–2015 are included because these early years were solely experimental. Since 2016, only catch data from modified AFS (American Fisheries Society) gill nets, nighttime boat electrofishing, and AFS standard fyke nets were considered annual monitoring. Thus, any new gear, gear variation, or deployment method used for the first time to try and improve monitoring was considered experimental until it was determined whether it should be incorporated into annual monitoring efforts based on results of field experiments. A general overview of the adaptive process since 2013 with respect to monitoring, experimentation, and adopting and refining sampling gears and methods in lower Green Bay is provided in the following section.

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