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Approaches To Improving Detection Of Invasive Fish Species In Western Lake Erie Through Analysis Of Monitoring Efficiencies And Metrics Of Community Distribution

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APPROACHES TO IMPROVING DETECTION OF INVASIVE FISH SPECIES IN WESTERN LAKE ERIE THROUGH ANALYSIS OF MONITORING EFFICIENCIES AND METRICS OF COMMUNITY DISTRIBUTION

by

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THESIS

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DEDICATION

To those that have kept me sane, and supported me throughout this process.

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: IMPROVING THE DETECTION OF RARE AND INVASIVE FISH SPECIES THROUGH AN EVALUATION OF MONITORING EFFICIENCY IN WESTERN LAKE ERIE

Introduction

The introduction and invasion of non-native species into new ecosystems is of great concern to resource managers and the public. Native communities have evolved symbiotically, and rely on other member species to perform functions specially tailored to their ecological niche, such as nutrient cycling via biological, chemical, and physical processes (Simon and Townsend 2003). The synergism of native species in a community are carefully regulated and maintained through the constant interactions across all trophic levels within their ecosystem. Even small imbalances to an ecosystem caused by invasive species can be of significant magnitude, reach, or duration (Cardinale et al. 2006). Populations within the community may change in abundance and spatial distribution, and these complex community dynamics may change through both direct and indirect alterations to trophic level interactions (Simon and Townsend 2003).

Aquatic systems may be particularly vulnerable to the impacts of invasive species because perturbations can result in a cascading effect among the trophic levels much stronger than experienced in terrestrial systems (Shurin et al. 2002). Aquatic systems impacted by invasive species experience losses in biodiversity (Butchart et al. 2010). Additionally, losses in commercial fish, and impacts to industry and utilities may occur (MacIsaac 1996). These impacts can lead to changes in entire ecosystems and their connected economies

Management efforts for non-natives rely upon effective monitoring and appropriate responses by local agencies. The likelihood of success of managing non-native species is higher if they are detected early and at low abundances (Courchamp et al. 2003). The early detection of invasive species is therefore critical to future containment and eradication efforts. Once a population has reached self-sustained reproductive capacity in an ecosystem, it's logistically and economically difficult to target or remove that species without somehow influencing or affecting other species coexisting in that ecosystem (Myers et al. 2000). Most current programs focus on management strategies to mitigate impact and slow the spread of these invaders. For example, Anderson (2005) reported the successful remediation and management of *Caulerpa taxifolia*, an invasive marine alga that appeared to be detected early after an initial introduction and where containment and eradication treatments began just 17 days after initial discovery in the coastal waters of California in 2000. In contrast, after the same species was detected in the Mediterranean Sea in 1984, no action was taken for 5 years, during which time it had colonized more than 100 km^2 of benthic habitat (Hulme 2006). Invasive species are great concern to the ecosystems of the Great Lakes, and monitoring strategies that focus on early detection with optimized assessment strategies are crucial to managing the spread of these species.

Monitoring programs should be cost effective and efficient, as most conservation and management groups have limited funds and personnel. Increasing efficiency translates to a more thorough and complete understanding of when a new species has arrived and in what quantities. The rapid response to invasive species, ideally before they influence native populations, is the most practical and effective management plan currently available (Courchamp et al. 2003). In a study examining the incidence of native and non-native fish species in Duluth harbor, Trebitz et al. (2009) developed a framework for improved monitoring techniques by utilizing multiple complementary sampling gear types and targeting multiple habitat types to optimize their early detection of invasive species.

The Great Lakes are an important resource for the states adjacent to the region. Used as a source for recreation, sports fishing, commercial food stocks, and fresh water, the lakes are an economic staple for those close enough to exploit them. Lake Erie is a hub for international shipping and commerce, and at the southwestern end of Lake Erie Toledo Harbor is a major port in the Great Lakes for trans-Atlantic shipping and the last stop for saltwater vessels prior to entering the upper Great Lakes. The Great Lakes region sees over 1800 saltwater ships annually entering the freshwater basin originating from over 250 separate ports around the world (Keller et al. 2011). Therefore this high traffic area lends itself readily to nonnative species introduction through accidental transport in ballast water discharge, animal trafficking, recreational fishing, and migration up the St. Lawrence River from the Atlantic Ocean (Mandrak and Cudmore 2010). Monitoring high traffic, high risk sites for non-native species introduction should be a top priority for sustaining lake productivity. This means effective monitoring and prevention in Lake Erie could be a key site for protecting the health and stability of the Great Lake ecosystems for future economic and recreational use.

The Ohio Department of Natural Resources (ODNR) annually monitors between 31-40 trawl sites and between 7-19 gillnet sites multiple times each sampling season in the US waters of western Lake Erie. Using both trawl and gillnet collection techniques provide a broad spectrum sampling of the current spatial distribution and abundance of extant fish species in the local area. These ODNR monitoring efforts are primarily focused on assessing key economic species, including walleye and yellow perch which require quantitative surveys in order to maintain stable communities and their associated habitats in the face of large scale anthropogenic stressors (Ohio Department of Wildlife 2012). Nevertheless, since these fish surveys may also detect rare and non-native species, an interesting question is whether they may also provide early detection warnings of new introductions.

The primary objective of this study was to evaluate the efficiency of current monitoring and collection strategies for the detection of rare and invasive species over multiple years of sampling. The compositional analysis of fish populations in the western basin of Lake Erie was documented to determine species rarity and the fluctuations of incidence concerning known non-native invaders over long time scales to provide information on sample targeting and community composition. Patterns of invasive species success and correlated community responses were analyzed to determine possible causal relationships, as well as potential future trends in the community. Finally, computer modeling was utilized to determine optimized strategies to reduce man hours and overhead of sampling while maintaining benchmark sampling efficiencies.

Methods

Study Site

This study focused on District 1 of Lake Erie as designated by the ODNR (Figure 1), which is located at the western end of the lake and contains the port of Toledo. This part of Lake Erie is much shallower than the central basin or the eastern shores, and is a suitable habitat for many potential invaders. The port of Toledo is the second largest port in the Great Lakes, after Duluth-Superior harbor, in the number and volume of ballast water discharges in the Great Lakes (EPA 2008) and has been cited by the Environmental Protection Agency (EPA) as the “port of greatest concern” for receiving sufficient propagules and providing the most suitable habitat (EPA 2008).

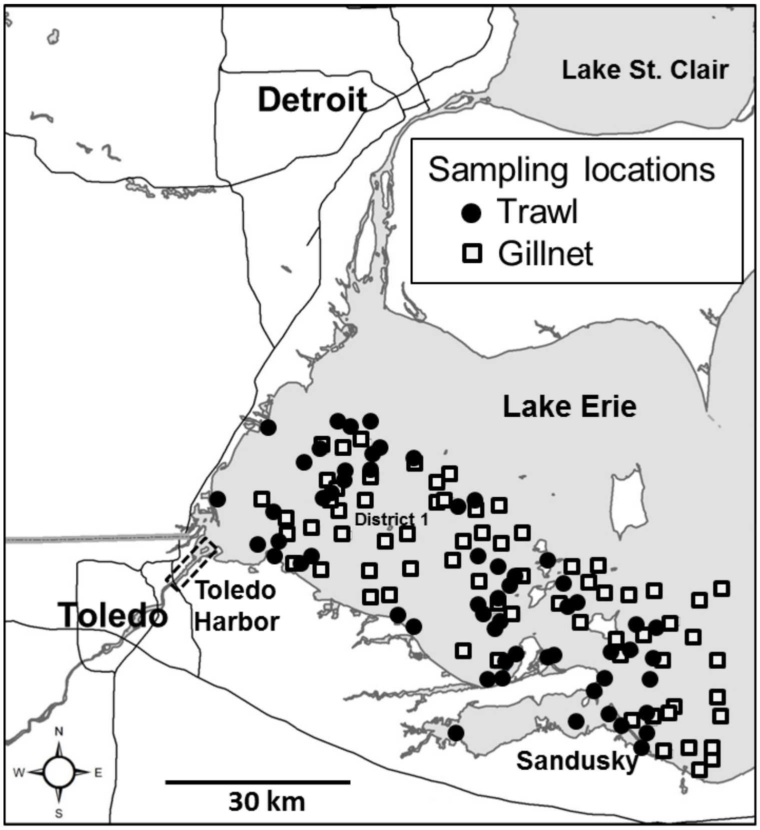

Figure 1: Trawl and gillnet sampling locations in District One of the Ohio Department of Natural Resources fish monitoring program.

Data set

This study analyzed historical fish collection data obtained from the Ohio Department of Natural Resources (ODNR) spanning the last 21 years (1990-2010). Fish were sampled using trawl and gillnet methods along the coast of Ohio including the Toledo harbor area. The majority of sample sites were visited multiple times annually, with specific grid locations being added and removed between each season for fish tracking optimization. Trawl samples were collected between May and August, while gillnets were deployed between September and November each year (Ohio Department of Wildlife 2012). Trawl collections employed flat-bottomed semi-ballooned otter trawls with 13 mm bar mesh at four depth strata (Ohio Department of Wildlife 2012). Gillnet collections utilized 51-127 mm mesh kegged gillnets and both 32-76 mm mesh and 76-127 mm mesh bottom gillnets (Ohio Department of Wildlife 2012).

Maximizing species richness

Species richness (number of species present) for the western basin was calculated by determining all unique species collected for each sampling strategy every year, as well as a composite analysis which combined all collection types and determined total species richness annually. Mean species richness for each collection type, as well as combined collection types were determined by averaging the species richness totals over all years. Statistical analysis was performed to validate differences among collection strategies via one-way ANOVA single factor analysis. If ANOVA indicated significant main effects ($p < 0.05$), a least significant difference (LSD) test with a Bonferroni correction was used to test for differences among treatments.

Gear type efficiency

To determine the efficiency of collections (i.e., how completely all species in the ecosystem have been sampled) the actual number of species collected was compared to the total number of species predicted by Chao biodiversity estimation methods (Chao et al. 2009). The efficiency is the ratio of the number of species collected in a year to the estimated total number of species for the year, expressed as a percentage.

Efficiency values were calculated for each gear type separately and all types combined for each year. Additionally, mean efficiency values over the entire 21-year collection period were calculated. Annual asymptotic accumulation estimates for ODNR data sets met recommended sizes to reduce bias from under-sampling while utilizing chao2 incidence estimations for acquired fish species (Lopez et al. 2012). The Chao biodiversity calculation can also estimate the amount of effort (samples taken) needed to achieve various target levels of efficiency, and was used for this study to determine estimated numbers of samples needed to meet benchmark collection percentages of 90%, 95%, and 99.9% efficiency.

Variations in sampling ratios

Computer simulations of various sample sizes of both gill net and trawl samples were conducted to determine how sampling efficiency might be affected by different ratios and intensity of sampling effort by the two gear types. A Monte Carlo analysis was run using R version 3.0.1 (R Development Core Team 2010) by repeatedly (each permutation was run 100 times and averaged) choosing randomly from among actual sampling data up to a given sampling intensity (number of samples) for each gear type. The species richness counts for different simulated numbers of samples were evaluated for increasingly larger numbers of samples of each gear type. Next, the program simulated different ratios of sampling effort by the two gear types within a total fixed total amount of sampling effort (e.g., total number of samples = 200; ratios of gill net to trawling effort equal to 1:9, 2:8, 3:7, etc. within the total 200 samples), and the efficiency of sampling of the combined sampling efforts was determined for each ratio. For each iteration, samples were randomly drawn from the actual data sets with no replacements, and the analysis was done for each year of the 21 years of data. These replacements were generated up to the maximum number of gillnet samples (since there were fewer of these, in some years higher ratios of gill net to trawl samples could not be tested) taken for each year.

Species incidence and changes over time

The gear-specific average incidence of each fish species in western Lake Erie during the entire 21-year sampling period was calculated by averaging the incidence obtained for each species from each year for each gear type. Additionally, a combined average incidence was calculated for both gear types combined. Incidence rates were categorized into three ranges, similar to those used for incidence analysis by Trebitz et al (2010): Common, Rare-20, and Rare-5. Rare-20 and Rare-5 represent species that were present in only 20% or 5% of the samples, respectively.

To determine which species are currently major threats as well as those that have the potential to be major threats in the future, the non-native species were identified in all samples, and their incidence category (Common, Rare-20, or Rare-5) were determined. Lastly, changes in incidence were tracked for all fish species in each of the 21 years of data to find species experiencing notable changes in overall incidence (native and invasive) and to examine potential impacts of changes in non-native species in relation to native species over time.

Results

Maximizing species richness

Annual fish surveys conducted by the ODNR produced repeated yearly samples from which to analyze long term efficiency. Annual analysis of species richness (Figure 2A) shows that while yearly individual totals of species richness by gear type varies, trawl collections captured more taxa each year compared to gillnet survey methods, and the number of taxa collected by both gears combined yielded more species than either gear alone (Figure 2B, p<0.001). Trawl nets and gillnets produced average species richness totals of 28 and 15 species, respectively, while the total number detected in a year for trawl and gill net combined averaged 31 species. These relationships were consistent despite fluctuations in sample sizes (sampling trips) from as low as 80 in 2001 to 224 in 1995 (Figure 3), except for 1991 and 1999 when relatively low numbers

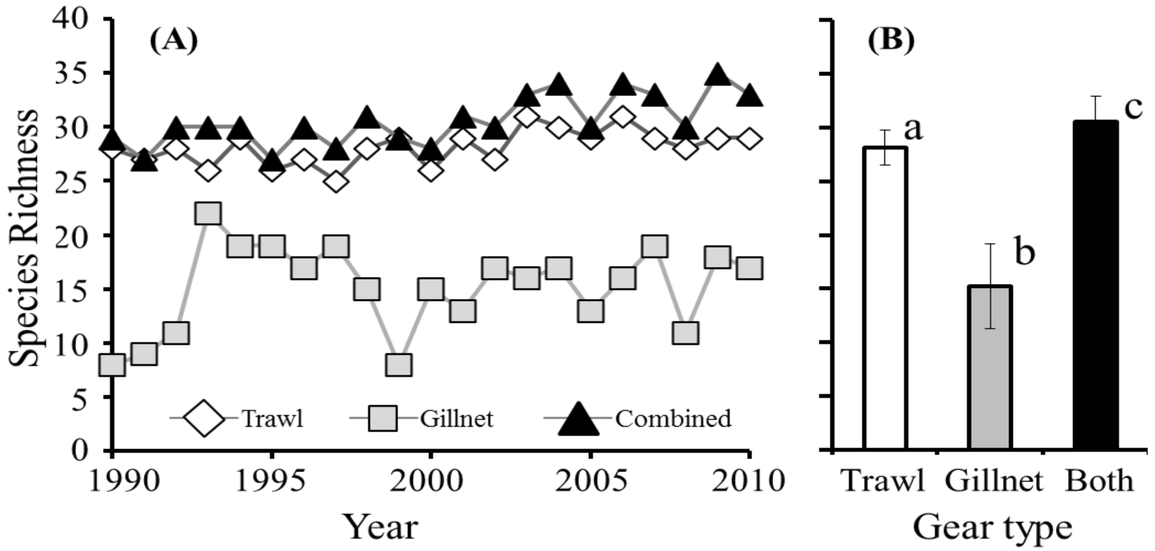

Figure 2: Species richness of fish caught by trawl, gillnet and combined capture methods by the Ohio Department of Natural Resources in District One: (A) for each year, 1990 - 2010 and (B) values given as means ± 1 / SD of species richness between 1990 and 2010. Bars with the with different letters are significantly different (p<.0.05) as determined ANOVA with additional paired two-tailed t-tests between each collection strategy.

of gillnet samples (9 and 10, respectively) failed to increase the total number of species captured in those years.

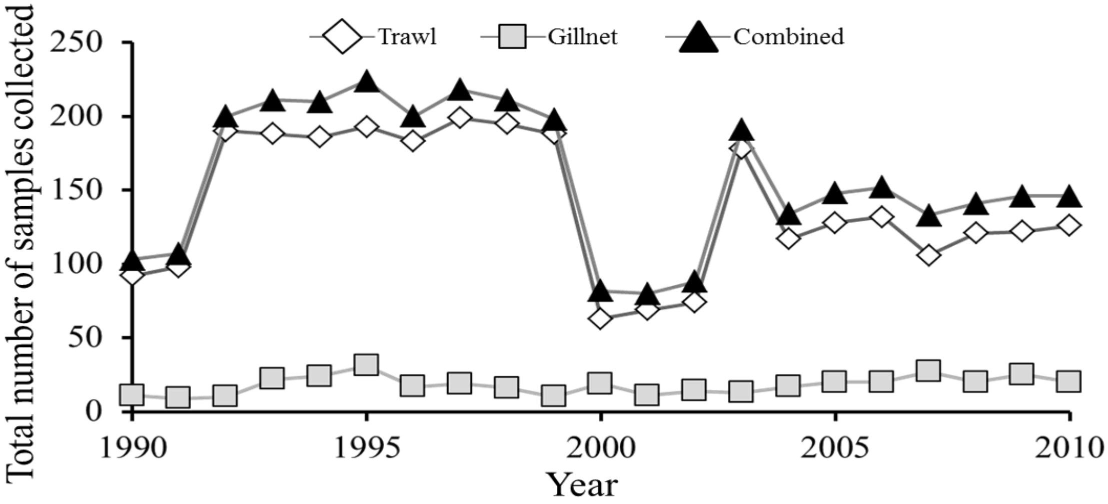

Figure 3: Total number of fish surveys done by trawl, gillnet or combined methods by the Ohio Department of Natural Resources per year between 1990 and 2010 in District One.

Gear type efficiency

Sampling efficiency for both gear types showed large variations from year to year (Figure 4A). Despite a lower annual average species richness (Figure 2B), there was no significant difference (p=.84) between the average sampling efficiency (Figure 4B) of collection by gill nets (81%) compared to efficiency of sampling by trawling (80.4%). Collection efficiency of both sampling methods combined produced an average of 78.5%, which was not significantly different from gillnets (p=.57) nor trawl netting (p=.54) alone. However, the total estimated species richness with the combined analysis (i.e., the richness multiplied by 1/efficiency) is notably larger than would have been predicted utilizing a single gear type. For comparison, the number of species predicted by gill net collections was only 18; richness predicted by trawling alone was

33; and richness predicted when using both gears (i.e., combined data sets) was 39.

While efficiency estimates hovered around 80% for each gear type with a total of around 150 samples collected annually, further calculations predicted the number of additional samples needed to achieve 90%, 95%, and 99.9% of the estimated number of species (Figure 5). For example, to increase the efficiency of trawl net fish surveys from 80.4% to 90% would require an additional 227 samples to be collected. Similarly, the additional samples needed to achieve 95% and 99.9% efficiency are 294 and 977, respectively. Comparably large increases in the numbers of collections were also required to achieve >90% efficiencies for the gill net and both gear types combined.

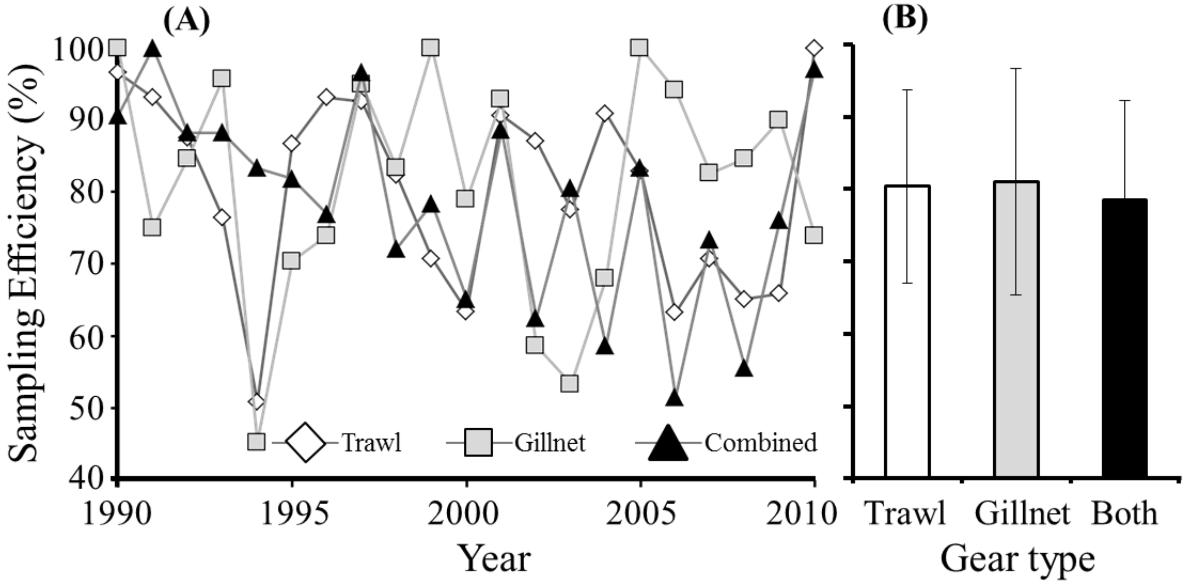

Figure 4: Sampling efficiencies of trawl, gillnet, and total combined sampling strategies by the Ohio Department of Natural Resources in District One. Efficiencies were derived based on comparison of actual ODNR collections and calculated (Chao) biodiversity, annually. (A) For each year, 1990-2010 and (B) values given as means ± 1 / SD of sampling efficiency between 1990 and 2010.

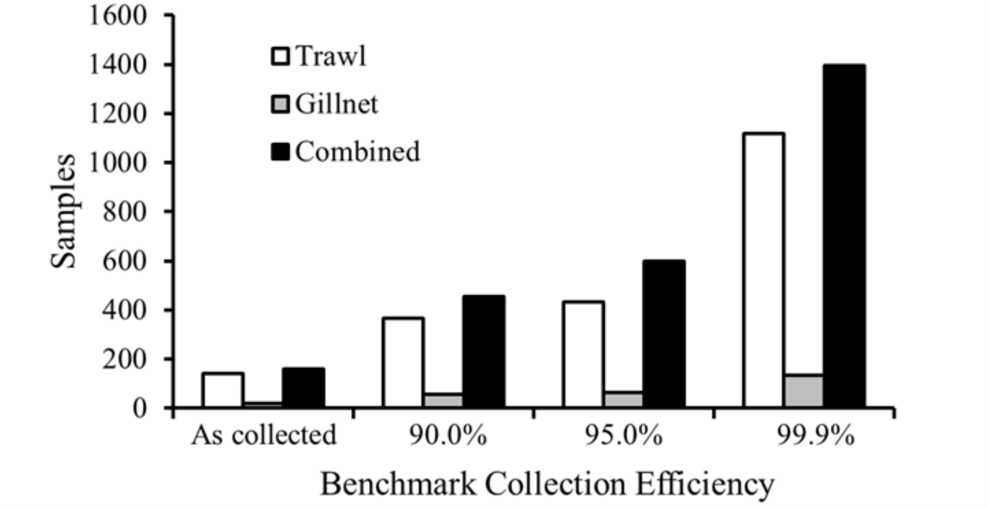

Figure 5: Calculated sampling effort (# additional samples needed) to reach benchmark collection efficiencies based on estimated rarity of trawl, gillnet, and combined capture methods by the Ohio Department of Natural Resources in District One. Actual collection percentage present for comparison (y-axis represents samples taken, not additional samples).

Variations in sampling ratios

As is usually the case when collecting from a diverse population, the number of different species observed increased with the number of samples collected but the rate of increase of species decreased as sample number increased (Figure 6). However, when a fixed effort (i.e., constant number of total samples) is spread between two different gear types, simulations of collecting results based on random selections of actual samples show increases

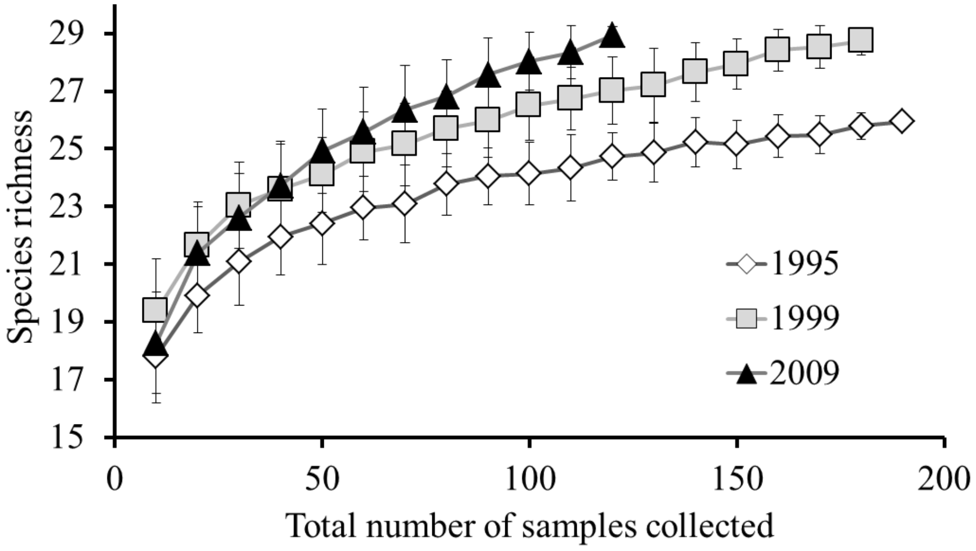

Figure 6: Computer randomization sampling analysis of the Ohio Department of Natural Resources collection data of District One using trawl net sampling and incremental sampling sizes. Sampling years from 1990-2010 were compiled to determine trends in sampling effort. Typical years with large sample sizes are presented.

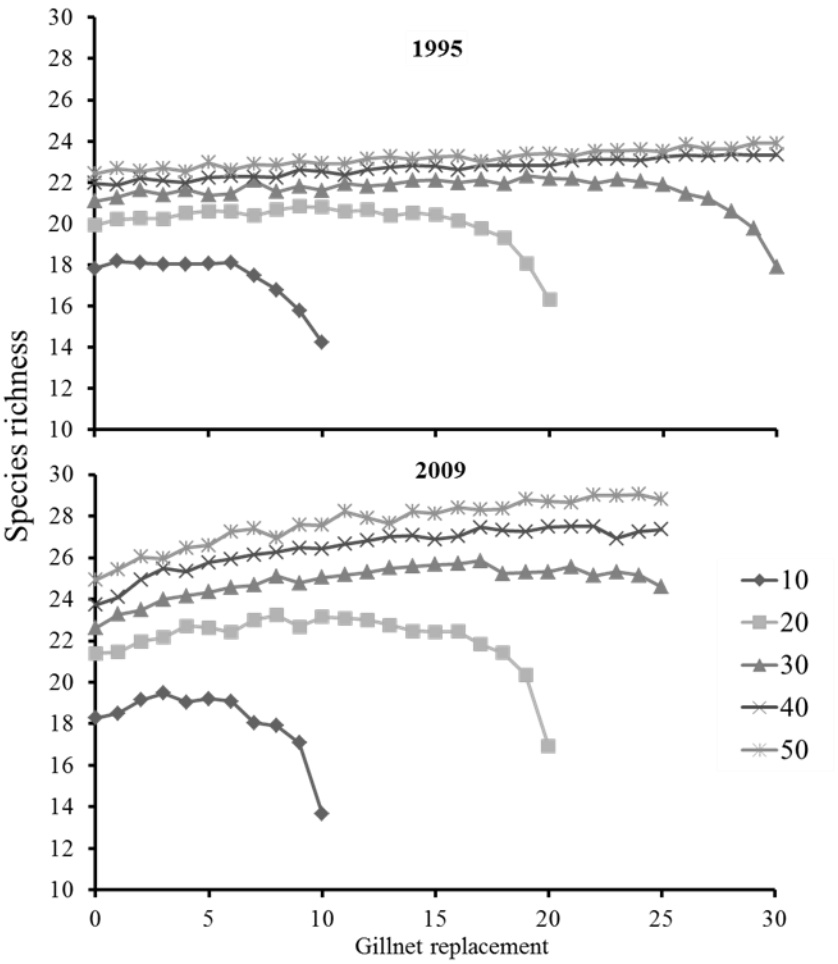

Figure 7: Computer randomization sampling analysis of the Ohio Department of Natural Resources collection data of District One using trawl net sampling for various total sampling sizes, and replacing a fixed number of samples with a second gear type (gillnet) to determine methods of maximizing species richness while utilizing finite sampling effort. The two years that are shown are representative of 21 years of data that were analyzed. The legend represents total sample sizes in each yearly analysis.

in species richness as substitutions increase away from only utilizing one gear type with no change in sample size (Figure 7). Variations in effectiveness and substitution ratio were dependent on total sample sizes. Typical years with large sets of both trawl and gillnet data show obvious trends in species richness at different ratios of both gear types. Gillnet replacement appears to reach its greatest effectiveness at approximately 75-80% of total sample size. Averaging all different sample sets (10 series) from across all years, showed an average increase of 1.2 ± 2.0 new species were collected after replacing a total of 10 trawl samples with gillnet samples. Although not statistically significant, these results show a trend towards improved species counts. In years where gillnet sample sizes were sufficiently large

(>10 samples), species richness continued to increase, albeit at a diminishing rate, as more gillnet samples were substituted for trawl samples, until a maximum point was reached. For example, as the results in Figure 7 show for sample sizes >40 in 1995 illustrate, the species incidence increased by a full species over trawl alone when gillnet substituted for 30 trawl samples.

Species incidence and changes over time

Although no single year yielded more than 35 species, over the 21 years of fish surveys in western Lake Erie and Toledo Harbor, 64 different fish species were collected. While 34 of these species were caught by both trawl and gillnet methods, 25 species were uniquely collected by trawl and 5 species were uniquely collected in gillnets (Figure 8). These 64 species encompassed 10 non-native species. Three non-native species were acquired only in trawl samples (stickleback, tubenose goby, and orange spotted sunfish), and one species (chinook salmon) was collected exclusively in gillnets. The fish taxa that were exclusively collected by only one gear type were categorized as Rare-5 species, and so were extremely uncommon. Trawl sampling uniquely collected three species categorized as

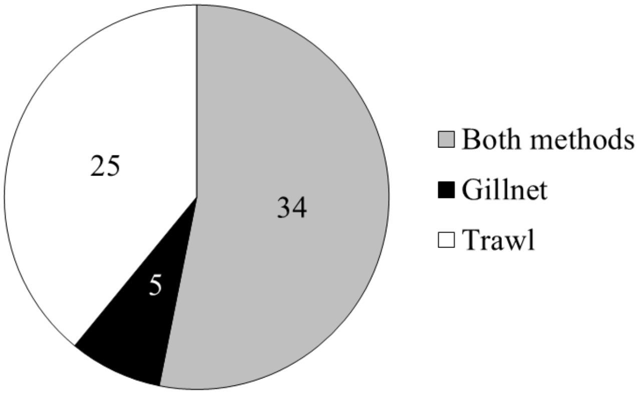

Figure 8: Species incidence analysis of trawl, gillnet, and combined collections by the Ohio Department of Natural resources in District One showing species caught by each method. While about half of the species were caught by both gear types, a larger number of species were uniquely caught only by trawl than by gillnet.

Common (mimic shiner, emerald shiner, and troutperch), and one Rare-20 (log perch) species. Species incidence records showed that 14 of the 64 species collected were Common (occurred in more than 20% of samples), including three non-native species, the rainbow smelt, round goby, and white perch. Seven species, including two non-natives, were Rare-20 (between 5-20% of total sample incidence). The alewife was Common until declining around 2003 (Figure 9), to become categorized at present as a Rare-20 species. Rare-5 species comprised 43 (67%) of the 64 species, indicating that a majority of fish species in Lake Erie were not common. However, in any particular year, the distribution of Common, Rare-20, and Rare-5 species averaged 44%, 20%, and 36% of observed species, respectively.

Among the non-native species that first appeared in western Lake Erie during the

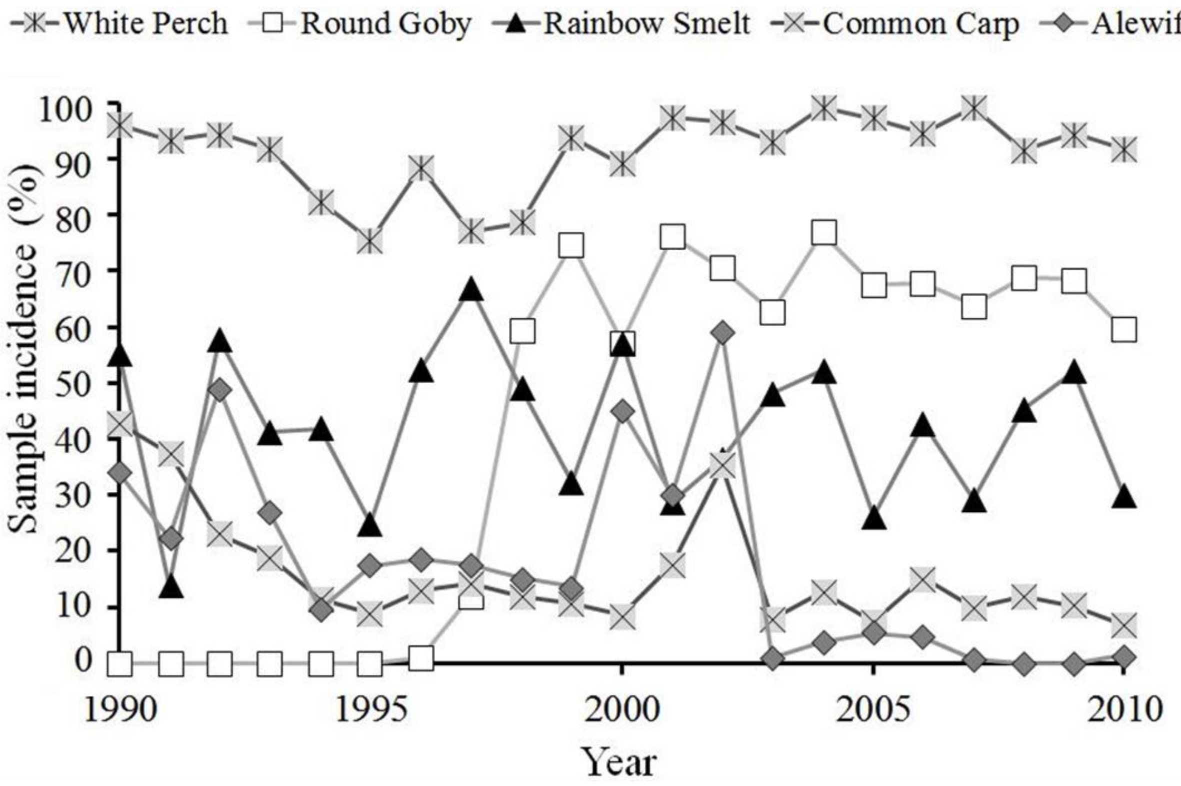

Figure 9: Species incidence of the top 5 (out of 10 known, 5 of which are below 5% incidence) non-native species in western Lake Erie, listed by year sampled by the Ohio Department of Natural Resources in District One

study period, the round goby was first detected in the Toledo Harbor area and increased from 1% of total samples in 1996 to 59% by 1998. At the same time that gobies were increasing, changes in other species occurred. Among non-native species, the alewife and common carp decreased in incidence over the same time period. Among native species, the mimic shiner, an Ohio species that had become quite rare, began to appear in samples in the year 2000 (Figure 10), and has appeared in 30% to 40% of samples since that date. At the same time, spot tail shiner and silver chub have decreased. Five non-native species in the Rare-5 group did not achieve much population growth in the area during the study period.

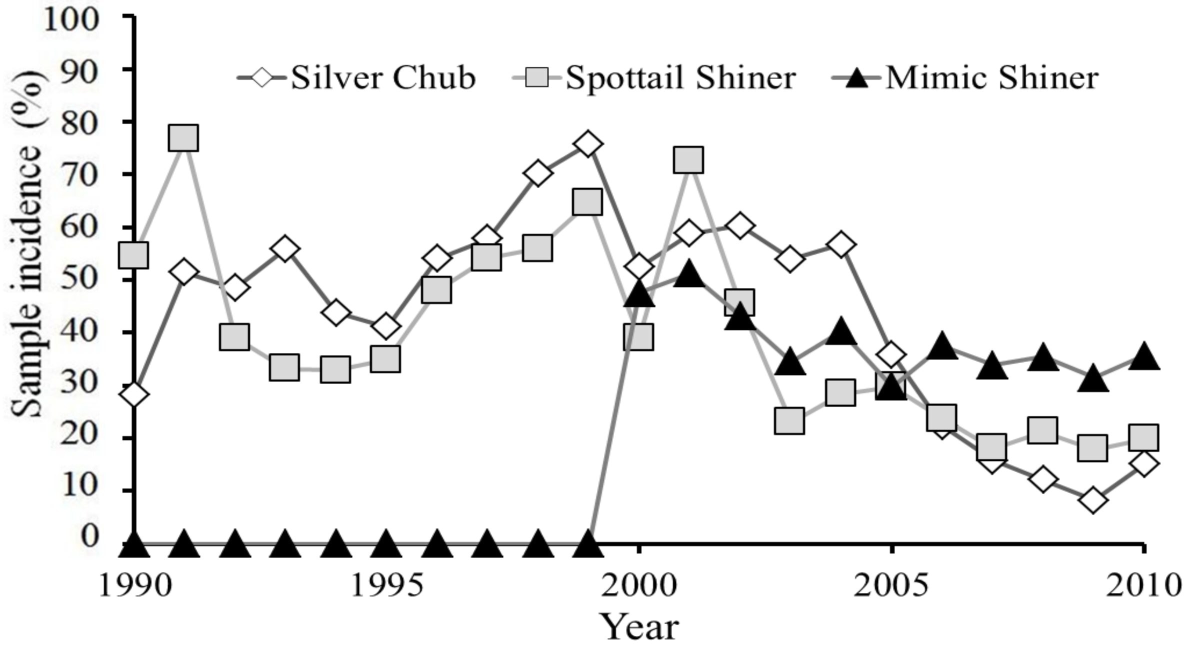

Figure 10: Species incidence of 3 native Lake Erie fish species. Graphed by consecutive years of sampling by the Ohio Department of Natural Resources in District One.

Discussion

Intensive annual fish surveys are one method by which new non-native fish might be detected in locations at high risk for invasions. Since state departments of natural resources already do fish surveys for other purposes, this paper investigated whether the survey conducted by the Ohio Department of Natural Resources is likely to be intensive enough to function as an invasive species "early detection" strategy. Over a time span of 21 years, annual fish surveys by gill net and trawling in the western district of Lake Erie in Ohio detected about 30 species of fish each year and more than 60 species over the entire time span. Differences in what species were caught each year could be due to inadequate sampling (i.e., in a particular year, more species were present but weren't caught that year), or to changes in what fish were present in the environment, e.g., new non-native fish. The time span covered a period during which several new non-native fish invasions occurred in the Great Lakes, including round gobies. Questions that arise from this study include: Should we consider the initial small number of gobies detected in 1996 to be an example of "early detection"? Is the survey strategy used by ODNR sufficiently intense that new introductions are likely to be caught early in an invasion (and what do we mean by "early"?)? Do the data and analysis here indicate ways in which the annual surveys by ODNR could be improved to better facilitate early detection? What is the relationship, if any among several species whose proportion in the population underwent drastic increases or declines?

The observation of round gobies in the survey data in 1996 occurred relatively late in the invasion of this species. Round gobies were first found in the Great Lakes region in 1990 in the St. Clair River (Jude et al. 1992). Round gobies reportedly appeared in Lake Erie as early as 1993 (Steinhart et al. 2004), and were reported in the proceedings of a 1993 conference (Jude et al. 1995)). Therefore, the sighting of round gobies in the annual fish surveys in 1996, three years after the initial sightings, represents a relatively late date, clearly not a case of “early detection.” Part of the explanation for the relatively late sightings by ODNR could be that the initial sightings were at locations (e.g., Michigan) not sampled by ODNR. Finally, once gobies began appearing in ODNR surveys, their numbers increased within two years to be present in the majority of trawl samples, which indicates that the trawl surveys were efficient at monitoring gobies once they had appeared in the Toledo Harbor area (this study).

To assure that sampling is likely to be an early detector of species, the EPA proposed that surveys should strive for “oversampling” of the target sites. In its call for Great Lakes Restoration Initiative proposals on “early detection” in 2010, EPA proposed that “A provisional definition of “oversampling” is a level of sampling that captures and identifies roughly ~90% or more of all taxa present in the chosen biological component of the system sampled.” (Quoted from the U.S. EPA Great Lakes Restoration Initiative 2010 Request for Applications, p. I-17). The annual fish surveys by ODNR therefore miss this mark by a considerable amount; since the 30 or so average number of species found in a given year is estimated to be only about 80% of the species present (see Figure 4). We estimated that, with current methods, it would take more than a doubling of the present effort (Figure 5) to sample >90% of species present in a given year. This result is comparable to the sampling intensity in a previous study of Duluth Harbor, in which fish surveys achieved an estimated sampling efficiency of 74% for trawl sampling but higher efficiencies for electrofishing (87%) and fyke nets (87%), two methods not used in the present study (Trebitz et al. 2009).

Since current survey methods are achieving considerably less than the target of 90% of species in a given area, it is worth considering what would be the most cost-efficient method for achieving that goal. The current study and previous ones in Duluth Harbor (Trebitz et al. 2009), indicate that more species are collected by using a combination of collecting gear and a mix of sampled habitats. In addition, this study showed that certain sampling gear collected only specific subsets of the actual species composition of Lake Erie. This could be attributed to many factors, including the diversity of habitats, the geographic distribution of these habitats, and the size, behavior, or physical properties of each fish species inhabiting Lake Erie. In the present study, the beneficial effect of sampling with two gear types, gillnets and trawl, was investigated. In the observed data, the addition of gillnets enabled on average the detection of three more species each year than with trawl alone (Figure 2B). These results verified that reliance on any one collection technique would likely miss collecting specific species when sampling complex heterogeneous lake habitats (Hulme 2006, Trebitz et al. 2009, Mandrak and Cudmore 2010). In this study, simulation analysis based on changing the ratios of trawl samples to gillnet samples determined that the addition of even a small proportion of trawl samples to gill net samples increased the richness of the resultant catch greatly. Potentially, another way of detecting more of the undetected species may be to add yet another gear type and/or sampled habitat to the fish survey collection strategy. Additional sampling at shallower depths (e.g., with fyke nets) and using electrofishing may be the easiest way to increase the number of species observed. For a cost-effective approach, this could possibly be accomplished by substituting these additional gear types for some of the trawl samples taken each year.

In addition to the above considerations relating to early detection of non-native species, these data indicate that some significant changes in species composition have taken place over the 21-year study period. Most community changes were declines of specific species in current populations. Among those affected were both native and non-native species. Invasive alewife and common carp (Figure 9) both declined, along with native silver chub and spot tail shiner in the region (Figure 10). This could be due to the growth of the round goby as a benthic competitor over the same period. Besides the round goby's prolific success since introduction, this study documents the reestablishment of native mimic shiners from near obscurity, which could be tied to restoration efforts of vital coastal wetland habitats. However the only clear trend is a reduction in incidence rates of many species which may ultimately result in a loss of biodiversity.

To respond to the impacts of increased globalization and the threat of non-native species introduction, current monitoring programs should be improved to detect rare low incidence fish populations and potential early stage invaders. Augmentations to current collecting strategies are expected have long term benefits through increased completeness of sampling. Effort should be expanded with new sampling regimes that cover new habitats, as well as behavioral and physiological differences of fish. Trebitz et al. (2009) shows a need to provide at least one sampling strategy for each unique habitat identified in a lake to take into account variation in community structure at these locations. The present study indicates that expending additional effort with current sampling methods may be only marginally beneficial in detecting additional species; though changing the ratio of gear types within current sampling schemes may be cost effective. We speculate that addition or substitution of other methods and gear types for a portion of the current collecting techniques may be a more cost-effective and complete sampling of species for the purposes of early detection of new introductions of non-native species. A varied and comprehensive approach to sampling is most likely to detect low incidence and new species in the environment.

CHAPTER 2: INVASION OF FISH COMMUNITIES IN WESTERN LAKE ERIE: NEAR AND OFF SHORE DYNAMICS, NON-NATIVE DISTRIBUTION, AND DETERMINING AREAS OF CONCERN

Introduction

Improvements to understanding fish population dynamics including dispersal can provide valuable information which can be used to enhance the efficiency of monitoring programs to better detect and predict the movement of invasive species. Variations in fish species density corresponding to differences in lake conditions reflect the non-uniform distribution of fish populations across the Lake Erie basin.Native fish communities have coevolved niches so that member populations have segregated to fill the wide variation in environmental conditions, and available food sources (Hutchinson 1957). The introduction of non-indigenous organisms has upset long established food webs in the Great Lakes, and has had far reaching spatial and temporal impacts on lake productivity and function (Mandrak and Cudmore 2010). Fundamentally, invasive species entrenchment and reproductive success are contingent on finding suitable resources (e.g. food sources and habitat) in which to survive and procreate. Invasive species are now in a constant standoff with local natural resource management offices for control of new territory. While current local monitoring strategies in the Lake Erie region focus on maintaining important fish stocks and assessing yearly catch limits (Ohio Department of Wildlife 2012), modifications to these procedural guidelines could have important implications for earlier detection of low incidence species (primarily new invasives) and lowering costs (economic and environmental consequences) associated with their disruptive influence.

The North American Great Lakes are complex heterogeneous systems with spatial variation in fish community function and organization. This spatial variation in native lake communities stems from fluctuations in the abiotic and bioticvariables that comprise the local ecosystem. Communities are in part controlled by variation in abiotic factors, such as the chemical composition and physical properties of their local environment (Whittaker 1956), which lead to preferential areas for feeding, and reproduction. Likewise, biotic control models suggest that horizontal competition between competitors for resources (Connell 1983, Schoener 1983) and predator-prey interactions(Reinertsen et al. 1986) are the primary factors structuring communities in terms of species incidence and their relative abundance. Consumer abundance in an ecosystem has been shown to be of primary concern for regulating a community as fluctuation in these populations can disturb non-adjacent lower trophic levels through systemic cascades of prey species abundance (Carpenter and Kitchell 1988). Although both models of variation influence native and invasive species distribution, they are not mutually exclusive.

Local factors known and attributed to current changes in fish community composition (native and invasive) in the Great Lakes are diverse and affect community organization and trophic structure through multiple vectors. Main factors that result in changes in species composition or community structure include the cultural eutrophication of the Great Lakes, fisheries harvesting, global warming, environmental contaminants, and invasive species (Madenjian et al. 2002, Bronte et al. 2003, Dobiesz et al. 2005). The increasing numbers of invasive species in the Great Lakes (Ricciardi and Atkinson 2004) and pressures from fish harvesting (Koonce et al. 1999), are of increasing concern and expense to local management offices and governments (Colautti et al. 2006). Some alterations, such as reducing phosphorus loads and the associated improvements in water quality (Mills et al. 2003) and recent reductions in contaminant loadings (DeVault et al. 1996), have had positive impacts on Great Lake native fish community's health and distribution. For example, the alewife (*Alosa pseudoharengus*) which is an invasive planktivore, has exhibited large shifts in population sizes due to its sensitivity to unusually cold conditions during spring. This annual variation in alewife populations results in a corresponding surge or reduction in many invertebrate and fish populations (Rand et al. 1995, Rand and Stewart 1998) through direct and indirect effects of resource consumption (Carpenter and Kitchell 1988). In light of these influences to the native communities, management goals need to focus on preventative measures to prevent such cascading influences. Invasive species in Lake Erie colonize a wide variety of environmental niches and can't be easily targeted specifically or effectively for control after insinuating themselves into the local food webs.

The Great Lakes consist of multiple ecosystems, some of which are more conducive to supporting the resource and habitat needs of invading species than others. Identifying areas of greatest concern for community instability and invasion by non-native species allows prioritization of management strategies to minimize potential impacts and control future outbreaks faster. This could potentially provide the entire Great Lakes ecosystem with a much improved outlook concerning future introductions. Non-native introductions occur through a variety of means, but the most notable method, which accounts for 65% of the 185 documented species introduced to Great

Lakes is through shipping and ballast water (EPA 2008). Those figures provide clear indication concerning the importance of monitoring ports as a primary vector of invasive introduction and spread. While Duluth Harbor in Minnesota and the western end of Lake Superior receive more shipping traffic and ballast water than any other port, accounting for slightly more than 70% of the ballast water exchange from 1981 to 2000, they have been the primary vector for seven recognized invasions since 1959 (Holeck et al. 2004). On the other hand, Western Lake Erie (which includes the port of Toledo), and the Detroit River have seen the largest number of establishing invaders (10 species) since 1959, while Toledo port accounts for less than 20% of ballast exchange during the same time period (Holeck et al. 2004). Other sites of concern, the waters connecting eastern Lake Erie and Ontario documented the arrival of four recognized invasions, and The St. Mary's River (connecting Lake Superior and Huron) was the primary introductory point for two non-native species (Holeck et al. 2004). These hot spots, which account for less than 6% of the Great Lakes water surface account for 54% of all invasions since 1959 (Grigorovich et al. 2003). Genetic Algorithms for Rule-Set Production (GARP) species distribution modeling, which is considered a good indicator of habitat suitability for species distribution (EPA 2008), was used to assess risk in the Great Lakes by the Environmental Protection Agency (EPA) for invasive species survival. Results from the GARP model indicated that of 14 non-native species either introduced or considered a high risk of introduction to the Great Lakes, that Lake Erie and Lake Ontario provided the most hospitable conditions and hadthe highest likelihood of invasion success (EPA 2008). Historically Toledo harbor and the western Lake Erie corridor have been at great risk for invasion, and should be the first line of defense against future threats to the Great Lakes as a whole.

To ensure the health of the Great Lakes, particularly in areas of high risk such as the port of Toledo, the specific habitats where invasive species are most likely to establish needs to be determined, and adjust sampling targets appropriately for earliest response time. Firstly, an expanded analysis of gear type effectiveness and efficiency in the western Lake Erie basin spanning all areas of fish habitat over a single sampling season was conducted to ensure coverage and account for all extant fish species. Second, differences in fish species comprising various communities were analyzed between nearshore and offshore habitats to assess variation and possible redistribution of sampling effort allocation. Lastly, using species incidence data and chao biodiversity calculations for sites across the western Lake Erie basin, areas of specific sampling interest (i.e. high biodiversity) and sites of risk were determined to improve targeting under existing sampling strategies. Together, improvements to current state agency monitoring programs can help reduce response time to invasive species and improve understanding of native community dynamics to reduce costs and improve environmental health.

Methods

Study site

The port of Toledo, its harbor and waters extending though the western basin of Lake Erie were chosen as the primary focus of this spatial study (Figure 1). The EPA designated it as the port of greatest concern for receiving sufficient propagules and providing the most suitable habitat for invasive species (EPA 2008). The shallower topography of this area compared to other parts of the Great Lakes is ideal for increased productivity. Comparisons between the Great Lakes and Ponto-Caspian region which is a significant source of nonindigenous species show that temperature, chlorophyll a concentrations, diffuse light attenuation, and normalized water-leaving radiance (indicator of productivity) (EPA 2008). These similarities provide essential habitat for nonindigenous species to lay the groundwork for invader establishment and large scale invasion of an extremely important lake system.

Data sets

The distribution of invasive fish species in Lake Erie, and calculations for determining sites of sampling interest were conducted by an analysis of historical fish collection data obtained from the Ohio Department of Natural Resources (ODNR) spanning the last 21 years (1990-2010). The ODNR sampled every summer during this period, continuously between the months of May and November. Fish were sampled using active trawl and passive gillnet gear types in the United States territorial waters off the coast of Ohio including the Toledo harbor area. Trawl collections employed flat-bottomed semi-ballooned otter trawls with 13 mm bar mesh at four depth strata (Ohio Department of Wildlife 2012). Gillnet collections utilized 51-127 mm mesh kegged gillnets and both 32-76 mm mesh and 76-127 mm mesh bottom gillnets (Ohio Department of Wildlife 2012).

Comparisons between near and offshore sampling strategies and resulting community differences were conducted specifically using data obtained over the 2011 sampling season. Offshore gillnet and trawl surveys were obtained from the ODNR, while The University of Toledo provided nearshore shallow water electrofishing surveys to depths of approximately 10 feet, which stretched along the southern coastline of the shallower western basin of Lake Erie.

Gear type efficiency and species targeting

All gear types (trawling, gillnets, and electrofishing) used for sampling were evaluated for their individual collection efficiencies and which fish species each targeted. To determine the efficiency of collections (i.e., how completely all species in the ecosystem have been sampled) the actual number of species collected by each sampling method was compared to the projected number of species predicted by Chao biodiversity estimation methods for each sampling method (Chao et al. 2009). The efficiency was then expressed as the ratio of the number of species collected in a year to the estimated total number of species for the year. Asymptotic accumulation estimates for 2011 ODNR and University of Toledo data sets met EPA recommended sizes to reduce bias from under sampling while utilizing chao2 incidence estimations for acquired fish species (Lopez et al. 2012). For each gear type individual species incidence was cataloged and compared to determine both species richness obtained by sampling strategy as well as differences in species targeting.

Nearshore vs. offshore fish community structure

Differences in species incidence for nearshore and offshore fish communities were evaluated to determine variation in spatial distribution of fish species and habitat preferences to improve sampling coverage by monitoring agencies. Utilizing 2011 catch data from both the ODNR and University of Toledo differences in species richness, species rarity, and invasive species distribution were cataloged. Species richness was obtained by counting all species collected offshore and nearshore separately. Species rarity rates for both habitat divisions of western Lake Erie were categorized into three ranges; Common, Rare-20, and Rare-5, similar to those used for incidence analysis in Duluth harbor for early detection of invasive species (Trebitz et al. 2009). Rare-20 and Rare-5 represent species that were present in only 20% or 5% of the samples, respectively. To determine which species are currently major threats as well as those that have the potential to be major threats in the future, the non-native species were identified in all samples, and their incidence category (Common, Rare-20, or Rare-5) were determined.

Determining areas of concern

Efforts to determine areas of concern for increased focus of future sampling trips were conducted by analyzing all grid locations in western Lake Erie sampled by ODNR monitoring agencies across a 21-year period (1990-2010). Utilizing Chao biodiversity estimation statistics, each grid location was analyzed and given a value (q_0) coinciding with the percent likelihood of the next sample taken at that location producing a previously unsampled fish species. These values that were generated through Chao analysis take into account sample totals, and total species richness collected. Then comparing those totals to unique incidence species (species that appeared only once), and duplicate incidence species (species that appears exactly twice) the specific likelihood of a new species being sampled is generated. Using these q0 sampling point values and species richness values, along with mapping software (ArcGIS 10.1e with Spatial Analyst extension) (ESRI (Environmental Systems Resource Institute) 2009), heat maps were generated by using tensioned interpolation methods to show variations in the statistical likelihood of new species sampling and detection across the western

Lake Erie basin. To ensure better map resolution sites with less than 20 samples taken were later excluded to ensure variation do to undersampling were minimized as recommended by the EPA (Quoted from the U.S. EPA Great Lakes Restoration Initiative 2010 Request for Applications, p. I-17). Additionally, non-native species incidence was tracked and plotted at each ODNR grid location to determine their spatial distribution across the western basin of Lake Erie. This monitoring helps determine important locations for continued monitoring, and likely areas of further encroachment by various invasive species.

Results

Gear type efficiency and species targeting

Data collected from the 2011 ODNR and University of Toledo sampling season shows large temporal and spatial differences in coverage (i.e. frequency of use and placement of collection) between the various gear types (trawling, gillnets, and electrofishing) that were utilized. In the western end of Lake Erie and Toledo harbor samples were collected from 33 trawl sites, 17 gillnet sites, and 25 electrofishing locations. Records showed that species richness counts were highest with nearshore electrofishing methods (40), while offshore trawl and gillnet strategies sampled 27 and 14 species respectively over the same sampling season. Chao biodiversity analysis showed that the sampling efficiency of gillnets was also low at 50%, while both trawling (96.4%) and electrofishing (90.9%) sampling efficiency achieved recommended benchmark levels set forth by the EPA. Combined, all gear types accounted for the collection of 43 distinct species, of which seven were known invasive species (common carp, goldfish, ghost shiner, orange spotted sunfish, rainbow smelt, round goby, and white perch); no new invasive species were identified from this data set. The large incidence of species captured by nearshore electrofishing resulted in significant overlap in species collections compared with other methods. Trawl collections accounted for three species (including invasive rainbow smelt) not found in electroshock sampling. Meanwhile, gillnet collections did not yield any unique species compared to that of the other gear types for the 2011 season. Additionally analyzing the predictive ability of Chao analysis on local species incidence showed that although both trawl and gillnet sampling achieved different species richness counts during their sampling periods, Chao biodiversity estimation predicted approximately 28 species present for both in their offshore sampling ranges.

Nearshore vs. offshore fish community structure

Comparison between fish species sampled in nearshore littoral regions and offshore pelagic and profundal zones showed remarkable variation in their community assemblages. The Chao biodiversity analysis of the collection data showed that both areas were sampled at or near the EPA recommended oversampling benchmark of 90% species incidence coverage, nearshore was 90.9% and offshore coverage totaled 87.9%. In the Toledo harbor and western Lake Erie basin, an additional 11 species were sampled in nearshore (40 in total) regions as opposed to offshore (29 total). Combining all gear type collections 43 fish species were cataloged, of which 11 were unique to littoral habitat (including invasive orange spotted sunfish, and ghost shiner), and 3 unique to deeper water (including invasive rainbow smelt). While many common native species (yellow perch, channel catfish, freshwater drum, emerald and spot tail shiners, and gizzard shad) maintain similar distribution thresholds throughout the extent

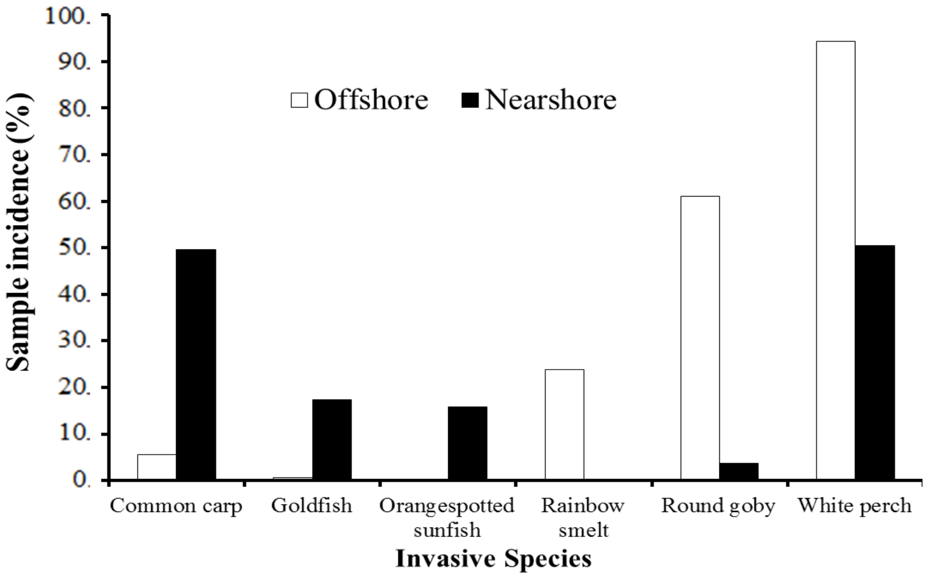

Figure 11: Invasive species incidence rates in different lake zones of western Lake Erie during the 2011 sampling season.

of the western basin, many others experience less success outside specific habitat types. Both lake zones supported invasive species, although total incidence metrics indicate that invasive species (like many native species) preferentially occupy different habitats (Figure 11), including rainbow smelt and orange spotted sunfish which have been exclusively found in from offshore and nearshore habitats respectively. Invasive white perch has spread across multiple habitats, although appears more widely distributed in offshore waters. Also, common carp and goldfish were far more prevalent in nearshore waters, where in investigations by ODNR their incidence rates are notably rarer. Additionally, examining incidence rates of fish species (within their respective communities) show that there is a noticeable shift in ratios from Rare-5 to

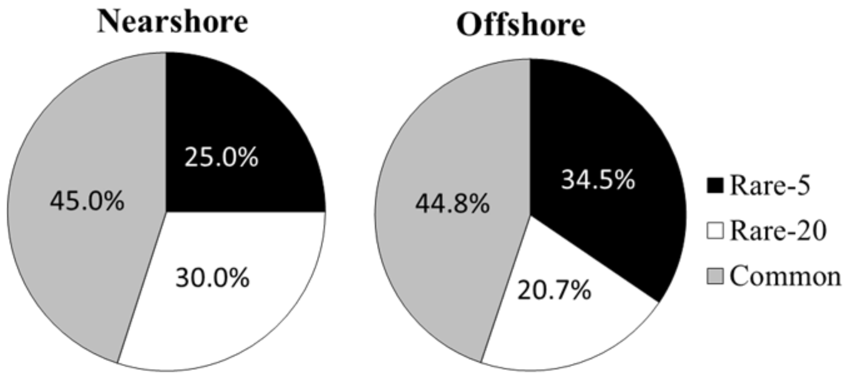

Figure 12: Species incidence rates of diverse fish communities in different zones of Toledo harbor and western Lake Erie during the 2011 sampling season. Fish species incidence was grouped by Common species (>20%), Rare-20 species (<20% and >5%), and Rare-5 species (<5%).

Rare-20 species in nearshore littoral regions in relation to offshore communities (Figure 12).

Determining areas of concern

Analysis of 20 years of complete fish catch data at each ODNR grid sampling location across western Lake Erie showed large heterogeneous distribution in fish species as well as sampling methodology used in cataloging them. Generated maps of the area show large variations in targeted gear type coverage (Figure 13), where only one third of sites were sampled with both trawl and gillnets overlap. Additionally sample sizes varied extensively, with nearly half of all sites in the last 20 years being sampled less than 5 times (Figure 14). Increased cases of gear overlap and high amounts of resampling focused in areas close to the Port of Toledo and the protected island fish sanctuaries north of Sandusky bay. Notably, areas of intensified sampling corresponded with locations of increased fish biodiversity (Figure

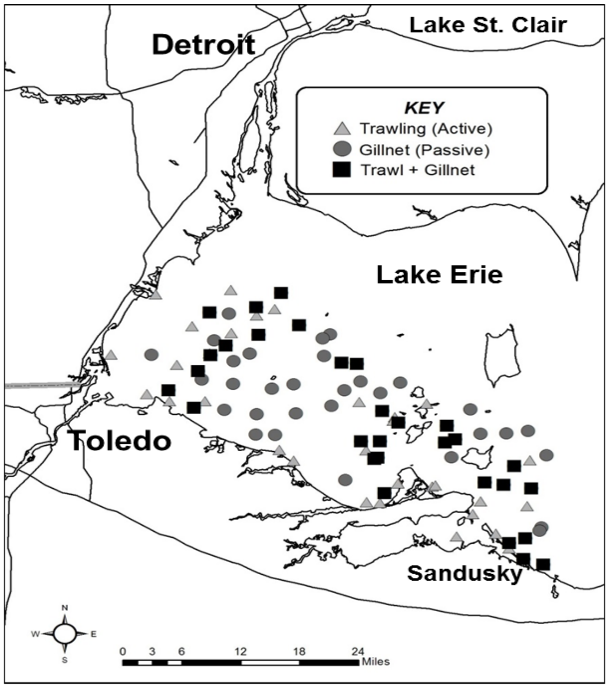

Figure 13: Bathymetric map of Lake Erie listing Ohio Department of Natural Resources grid sampling locations. Gear types used at each sampling grid location are symbolized.

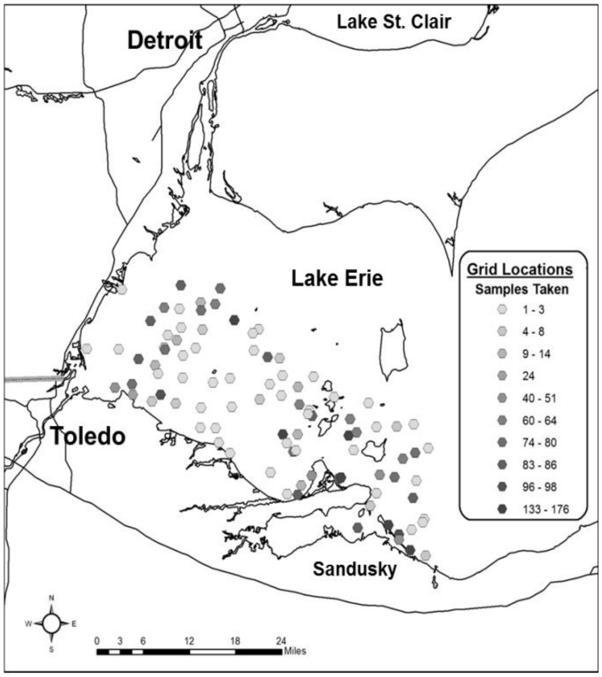

Figure 14: Map of Lake Erie listing Ohio Department of Natural Resources grid sampling locations and total number of samples collected at each location from 1990-2010.

15). Utilizing the species richness values (fish species incidence rates)e; interpolation maps were created of the western basin, which allowed for visualization of the biodiversity gradient of fish species in the region and surrounding the port of Toledo (Figure 16). Identifying sites of high priority for future sampling for the early detection of invasive species was accomplished by utilizing Chao biodiversity calculations to estimate q0 (percent likelihood of new species sampling) at each ODNR grid location. Across the 94 sites sampled by ODNR, the increases in likelihood of a new species being detected at specific grid locations followed trends with decreasing sample sizes. Removing likely under-sampled sites (>20 samples) from q_0 analysis, provided 35 sites of sufficient coverage showing high confidence in biodiversity assessment, and highlighting sites where new species will most likely be found (Figure 17). The probabilities calculated for each

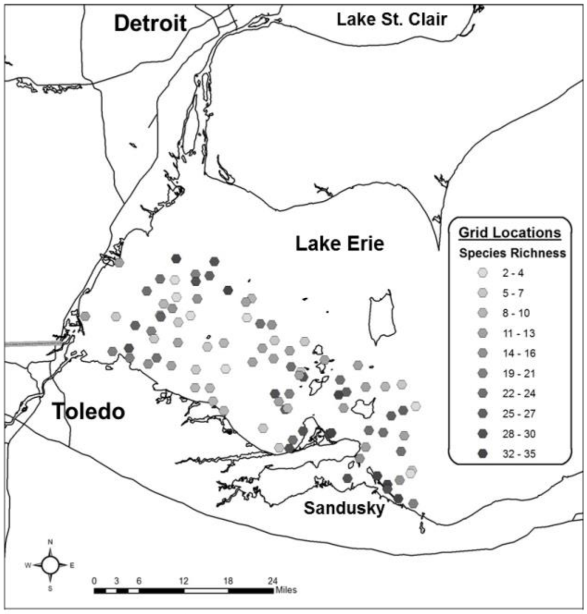

Figure 15: Map of Lake Erie listing Ohio Department of Natural Resources grid sampling locations in western Lake Erie and fish species incidence numbers obtained at each collection site from 1990-2010.

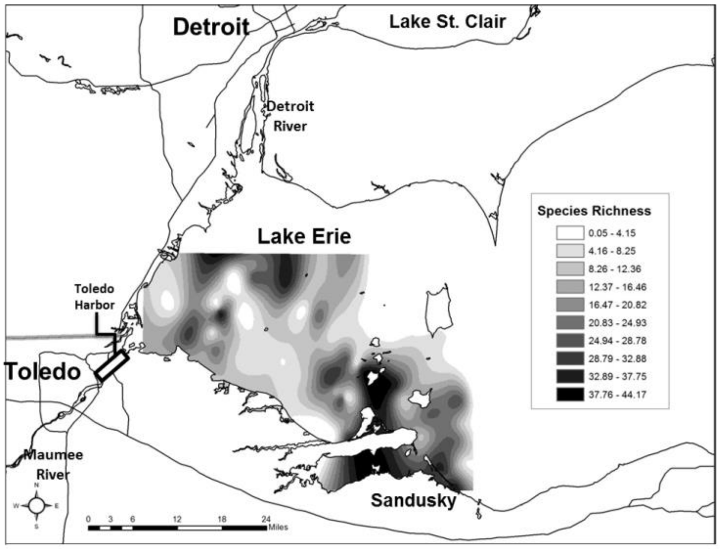

Figure 16: Species richness interpolation heat map of western Lake Erie derived from 94 Ohio Department of Natural Resources grid sampling locations of species incidence numbers obtained between 1990-2010.

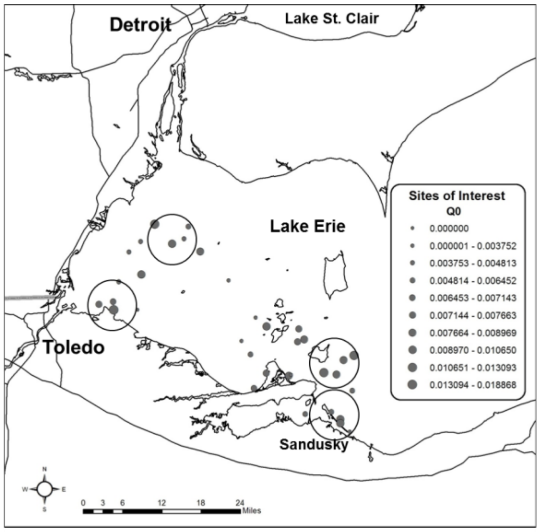

Figure 17: Chao biodiversity analysis for q_0 determination (percent likelihood of sampling a new species at specified location) in western Lake Erie. 35 sites were analyzed, each site was sampled more than 20 times to remove undersampling bias. Increasing size of symbol indicates sites more likely to yield future new species.

grid location (q0) combined with interpolation methods allowed the creation of a gradient map of the entire western Lake Erie basin, which denotes regions of increasing and decreasing likelihood of new species sampling (Figure 18). New q0 values in this figure are based on first and second derivative calculations to produce the interpolated point data, which shifted legend values. This mapping method provides an objective metric for determination of risk across the basin, where future monitoring efforts should focus. Primarily that the ODNR should look to the darkest regions which coincide with tributaries close to Sandusky, as well as the western edge of Lake Erie. Those sites with higher probability of new species detection have a higher likelihood of supporting new potentially rare non-native species. Invasive species incidence tracking showed that 11 non-native species were detected at different times in the western basin of Lake Erie over the 20 year (1990-2010) period of sampling by the ODNR, but as of 2011 only 7 invasive species were recorded. Even populations of

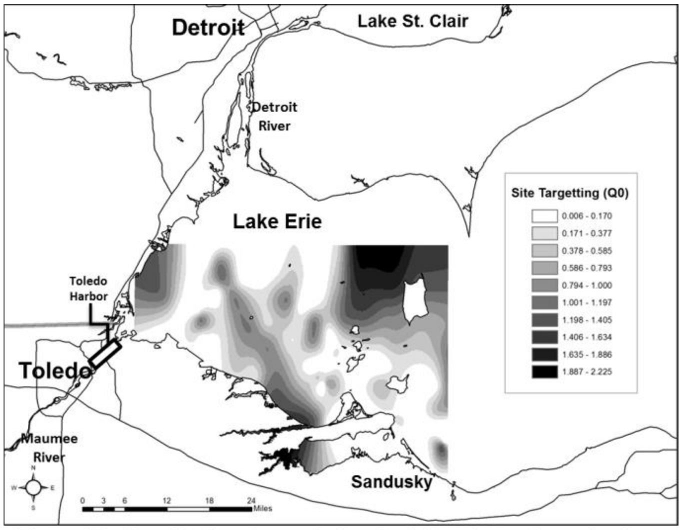

Figure 18: Chao biodiversity analysis calculations for q_0 determination (percent likelihood of sampling a new species at specified location) interpolation heat map of western Lake Erie derived from 94 Ohio Department of Natural Resources grid sampling locations obtained between 1990-2010.

alewife, which were once quite common between the years 1950 and 1980, have largely disappeared since the early 2000's. Additionally, rare invasives like the three-spined stickleback, tubenose goby, chinook salmon, and rainbow trout failed to gain significant incidence ratios and have disappeared from western Lake Erie fish communities currently. Tracking incidence of the currently extant invasive fish species in the region (Figure 19) shows that white perch, common carp, rainbow smelt, and round goby have a broad distribution. Meanwhile earlier invasive distribution analysis showed that rainbow smelt, and round goby were somewhat restricted to offshore habitats. While goldfish, and orange spotted sunfish have been confined to a much narrower windows of habitat distribution centered near the islands north of Sandusky bay.

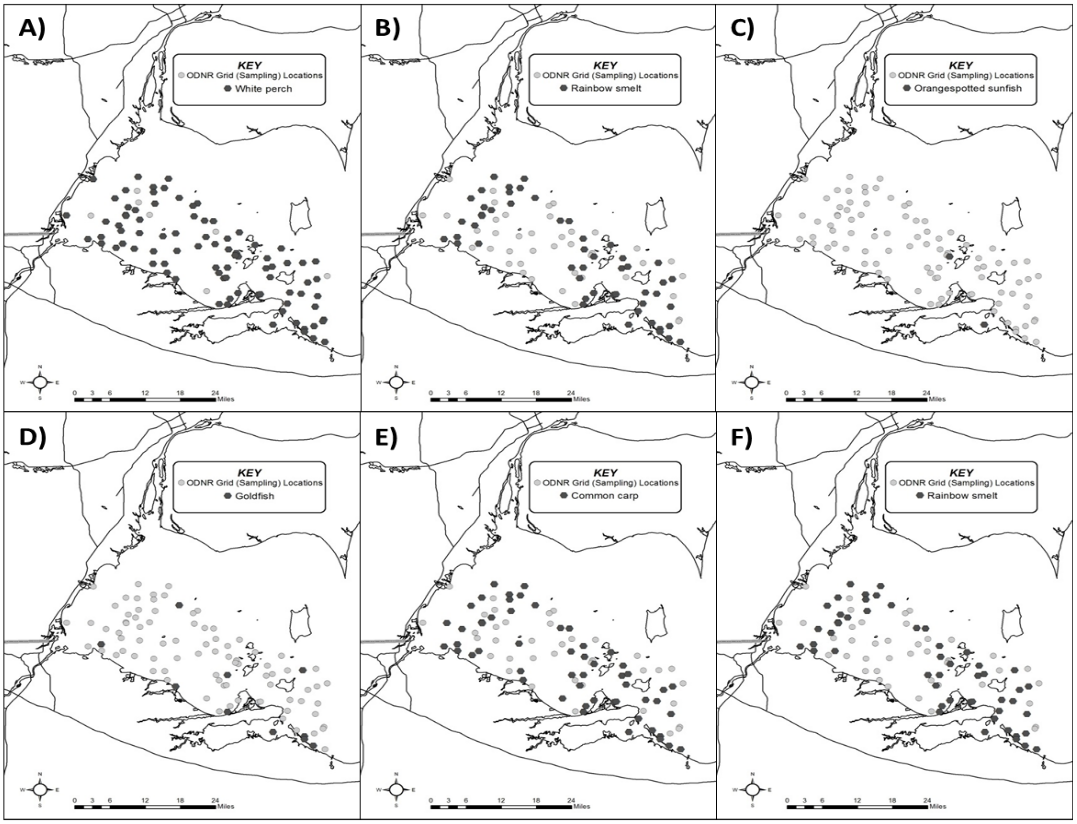

Figure 19A-F: Tracking incidence of current extant non-native species in western Lake Erie ODNR samples from 1990-2010. Species listed for top left to bottom right: A) white perch, B) round goby, C) orangespotted sunfish, D) goldfish, E) common carp, and F) rainbow smelt. Dark grey sites indicate grid locations where these species were found.

Discussion

Fish community assessment and in particular, the tracking of invasive fish species, enables the continued development of more effective monitoring methods to generate an accurate picture of lake-wide fish communities. The early detection of invasives is a challenge as it requires precision collection strategies to sample populations at extremely low abundance during their initial invasion process within a lake when they are at their rarest. General strategy proposed for detecting rare species is to allocate samples widely in space, rather than intensify effort in a small area or over time (Harvey et al. 2009). In western Lake Erie the ODNR through their routine monitoring program, accounted for 29 cataloged species in 2011 of which five were noted invaders (listed in Figure 1). Although ODNR collections do not include near shore sampling in the littoral regions lining western Lake Erie and its tributaries, their use of trawl and gillnet gear types has allowed the agency to cover vast swaths of their study area at a modest expense and with a respectable efficiency of 87.9%. This is in line with the EPA's guidelines that biodiversity collections should approach 90% of fish species incidence (Quoted from the U.S. EPA Great Lakes Restoration Initiative 2010 Request for Applications, p. I-17). By including nearshore electroshocking fish collections, an additional eleven species were sampled, including two invasives not reported by ODNR for this time period (orange spotted sunfish, and ghost shiner). Results from this study indicate that inclusion of near shore sampling can improve species coverage, and thus current agency monitoring strategies can be adjusted if comprehensive coverage and improving early detection become program goals.

The relationship between effort expended and the number and rarity of species detected is well known in ecology (Rosenzweig 1995). Although effort alone is not enough, as each sampling strategy has strengths and weaknesses. Collectively, combining complementary gear can more thoroughly sample a heterogeneous system than any single gear would accomplish alone (Magnuson et al. 1994). Electrofishing as an active process is efficient at targeting all species in a local community, but can only be deployed in limited regions, specifically areas where water does not usually exceed 10 feet of depth. Meanwhile trawl and gillnets do not capture all species in a community and variations in each collection strategy (from depth deployed, and net mesh sizes) can have effects on target species sampled. Goffaux (2005) found that gillnet species selectivity was much higher (species richness was lower), and that electrofishing provided a much more constant species richness. Although electrofishing is not sufficient for a quantitative estimates of entire fish assemblages, and should be combined with at least another sampling strategy (Goffaux 2005). Therefore sample site selection and gear type employed will have a large influence on the resolution of the observable extant fish community and by extension toward the detection and tracking of invasive species.

Aggregation of all the 2011 collection data shows that current extant invasive species occupy a variety of habitat zones, and therefore take advantage of many different ecological niches and food sources. The increase in biodiversity (incident species) in nearshore littoral regions, as well as an increased incidence of present fish species (from Rare-5 to Rare-20), denotes areas of higher productivity and therefore areas with a larger carrying capacity. Such areas provide a more opportune starting point for new invasives to encroach and establish. If monitoring agencies provide an early warning and response to invasives in their management plans then the addition of collection techniques designed to sample nearshore areas should be included in their standard annual fish community assessments.

The distribution of currently extant invasive species in Lake Erie proves that no one collection method will achieve the desired distribution range or target all the species effectively. Of all the currently extant invasive fish species in the region white perch, common carp, rainbow smelt, and round goby have a fairly broad distribution (Figure 19). Meanwhile in this system both goldfish and orange spotted sunfish exhibit a much narrower habitat range with their most frequent occurrence around the islands north of Sandusky bay. Tracking past and current incidence of invasive species in the area allows monitoring agencies to pinpoint the locations most susceptible to infiltration, as well as track their spread over time. During the 2011 season where seven invasive species were documented, no one collection strategy accounted for all the species. Gillnet collections only accounted for 14 species, and only one invasive (white perch) was captured, which is the most abundant and geographically distributed across the western basin. Used to monitor specific species and age classes by the ODNR it's the least suited for comprehensive sampling or early detection (Ohio Department of Wildlife 2012). Trawl collections meanwhile covered a far greater demographic of the fish community (27 species), but only captured five of the documented invaders. Although active trawling is an effective sampling strategy in open water, the diversity of habitat types, fish size, and the geographical limitations of deploying gear behind a boat means that there will be regions inaccessible to coverage (i.e. shallow and/or debris filled water bodies). Trawling is an effective way of monitoring invasives like the invasive rainbow smelt and round goby which enjoy an expansive habitat range, although they are both nearly restricted to offshore areas. Conversely electroshocking while extremely efficient at targeting all organisms within a given range of the electrode source (regardless of debris or obstructions), has restrictions on the depth at which electricity attenuates limiting the effective deployment to nearshore regions and littoral habitat. Even still nearshore electroshocking accounted for 40 distinct fish species, 6 of which were known invasives. The increase in species richness emphasizes the need to expand monitoring strategies to ensure comprehensive coverage, and detection of low incidence species. Positive relationships generally exist between habitat heterogeneity and species diversity (Benson and Magnuson 1992).So utilizing sampling strategies that cross habitat boundaries, especially those denoting prime habitat like those around littoral regions, help show distinct differences in community sizes, the species incidence rates within these communities, and the non-random distribution of invasive species. Current practices miss sampling some habitats and have a lower efficiency of new species collection, reducing the rate at which rare species can be detected.

Utilizing trends in community distribution is a useful practice for management offices to determine where to focus resources and enhance the resolution of existing ecological surveys. Each year small adjustments are made, and sample sites might be added or discarded depending on where management officials determine their time would be best suited. Interpolation maps generated from ODNR data spanning 1990-2010 for both species richness (Figure 16) and q0 values (Figure 18) provide insight into the areas of interest and concern in the western Lake Erie basin by displaying gradients across the basin. Results from this study demonstrate that species richness maps can help to provide information on where concentrations of highest biodiversity are located. Although some confounding effects such as sampling intensity at specific sites will produce higher richness counts. These areas of high diversity have a larger range of niche space and therefore of sampling interest, as invasive species would have more chance to compete for the space and resources needed to subsist and expand. Regions highlighted in this study as having the highest species richness density are close to the two major rivers near the Port of Toledo (Maumee River in the southwest, and the Detroit River in the northwest), which also have one of the highest incidence of invasion in the entire Great Lakes region (Holeck et al. 2004). Additional areas within western Lake Erie that produced high species richness totals were located in the high shipping/boating traffic zones near Sandusky bay, and the islands off the cost of Sandusky Bay, which is a fish habitat conservation area and contains many Ohio state parks. Mapping q0 values provides insight into areas where the likelihood of sampling will produce new species at that location. While there is a correlation between sample size and q0 value, in that lower N sites would be more likely to have missed sampling some species in the area and generate a higher q0 value. Although this also helps to point out sites that could use potentially use additional sampling to ensure accurate species incidence assessment for future analysis, thereby refining the maps every year as the data is aggregated.

Invasive species pose a distinct risk to native fish communities. Improving methods for community assessment and invasive species detection are paramount as the likelihood of success for managing non-native species is higher when detected earlier and at lower abundances (Courchamp et al. 2003). The inclusion of new sampling methods would increase the efficiency of collections and provide coverage to areas not currently sampled. The benefits would provide a much clearer picture of the western Lake Erie fish community for use by monitoring agencies. Fundamental variations in habitat structure, availability, and function create differences in fish community structure across lake systems (Kratz et al. 2005). So that nearshore and offshore ranges require different strategies to effectively sample each. Although these sampling designs are not balanced across categories of interest (habitat, gear, space, and time), which increases complexity and decreases the power of some statistical analysis it’s been shown that the increase in sampling efficiency and the decrease in cost offset these concerns (Peterson and Rabeni 1995, Trebitz et al. 2009)

Invasive species vary like any native species in habitat requirements, feeding preferences, and competitive fitness ensuring sufficient coverage across the region with different sampling techniques is preferable to oversampling only a few sites with less gear. Beyond maximizing efficiency and coverage, utilizing historic catch data to develop predictive methods determining areas of special concern for future sampling should provide further benefits to early detection efforts combating invasive species without requiring huge expenditures of additional resources.

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ABSTRACT

APPROACHES TO IMPROVING DETECTION OF INVASIVE FISH SPECIES IN WESTERN LAKE ERIE THROUGH ANALYSIS OF MONITORING EFFICIENCIES AND METRICS OF COMMUNITY DISTRIBUTION

by

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Efficient monitoring programs are essential for the early detection of invasive species. The Ohio Department of Natural Resources (ODNR) monitoring program encompassing 21 years of fish survey data from western Lake Erie was evaluated using Chao biodiversity analysis to determine the efficiency and precision of collection strategies of trawl and gillnet sampling, at detecting rare or non-native species. Overall, ODNR sampling annually accounted for ~80% of extant fish species, leaving gaps in coverage where rare and invasive species may be overlooked and proliferate.Obtaining 90% efficiency would require an estimated doubling of previous sampling effort. Computer simulations calculating different proportions of trawl and gillnet sampling effort indicate an advantage to mixing collection strategies by reducing effort, and reveals a range of effective proportions concerning the two collection techniques. In addition, population trends for several species were evaluated to better elucidate strengths and weakness of current monitoring programs. These results enable an analysis of maximized sampling efficiency to provide earlier detection of future

introductions, reduce total costs, and facilitate an improved understanding of native community dynamics. Understanding variations in fish community structure across a lake system can improve efficiency of monitoring programs and better prepares responders to invasive species introductions. Analysis of historic fish data to help designate new areas of concern and sites of future sampling interest were developed by utilizing Chao biodiversity statistics to calculate the odds of sampling new species at these ODNR sampling locations across the western basin. Through comparison of offshore ODNR trawl and gillnet samples, and near shore electrofishing surveys conducted by the University of Toledo both in the 2011 season provide proofthat differences in sampling equipment and habitat types lead to variations in sampling efficiency and fish community distribution. Through analysis of spatial trends in species incidence, monitoring programs can selectively target individual species and areas for further study to combat invasive species encroachment into native ecosystems.

AUTOBIOGRAPHICAL STATEMENT

It's not what you do but why you do it that is important. We all stand on the shoulders of giants.