# Optimal Sampling Effort to Inform the Index of Biotic Integrity in the Huron-Erie Corridor Areas of Concern 

Meagan M. Kindree, Jason Barnucz and Nicholas E. Mandrak

Fisheries and Oceans Canada
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, ON
L7S 1A1

2020

Canadian Manuscript Report of Fisheries and Aquatic Sciences 3205

## Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base Aquatic Sciences and Fisheries Abstracts.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers $1426-1550$ were issued as Department of Fisheries and Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

## Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la base de données Résumés des sciences aquatiques et halieutiques.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 900 de cette série ont été publiés à titre de Manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme Manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de Rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de Rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Burlington, ON L5S 1A1

${ }^{2}$ University of Toronto Scarborough<br>Department of Ecology and Evolutionary Biology<br>1265 Military Trail<br>Toronto, ON<br>M1C 1A4

© Her Majesty the Queen in Right of Canada, 2020.
Cat. No. Fs97-4/3205E-PDF ISBN 978-0-660-35744-7 ISSN 1488-5387

Correct citation for this publication:
Kindree, M.M. Barnucz, J. and Mandrak, N.E. 2020. Optimal Sampling Effort to Inform the Index of Biotic Integrity in the Huron-Erie Corridor Areas of Concern. Can. Manuscr. Rep. Fish. Aquat. Sci. 3205: vi + 30 p.

## TABLE OF CONTENTS

ABSTRACT ..... v
RÉSUMÉ ..... vi
INTRODUCTION ..... 1
METHODS ..... 2
FIELD COLLECTION ..... 2
INDEX OF BIOTIC INTEGRITY (IBI) ..... 3
VARIANCE ANALYSIS ..... 4
RESULTS ..... 5
FIELD DATA ..... 5
IBI SCORES ..... 6
VARIANCE WITHIN MEAN IBI ..... 7
DISCUSSION ..... 8
SAMPLING PROTOCOL RECOMMENDATIONS ..... 10
LITERATURE CITED ..... 11
LIST OF TABLES
Table 1. Hamilton adaptation of the IBI classification scheme ..... 14
Table 2. Species assignments for all fishes captured in 2007, 2011 - 2014. ..... 15
Table 3. Edwards adaptation of the Hamilton (1987) IBI classification scheme ..... 17
Table 4. Minns et al. (1994) IBI classification scheme for the Great Lakes littoral fish assemblage. ..... 18
Table 5. IBI scores for the Detroit River based on 2011 and 2013, summer and fall sampling using boat electrofishing (BEF) and benthic trawling (TRL) ..... 19
Table 6. IBI scores for the St. Clair River sires based on 2012, 2014 summer and fall sampling using boat electrofishing (BEF) and benthic trawling (TRL) ..... 20
Table 7. Sampling effort required in the Detroit River to decrease variance by 50\%, 75\%, 90\%,and $95 \%$ where IBI scores for years, seasons, and gears are pooled.21
Table 8. Sampling effort required in the St. Clair River to decrease variance by $50 \%, 75 \%, 90 \%$,and $95 \%$ where IBI scores for years, seasons, and gears are pooled. ...................................... 22
LIST OF FIGURES
Figure 1. Sampling sites on the Detroit River, 2007, 2011, and 2013 ..... 23
Figure 2. Sampling sites on the St. Clair River 2007, 2012, and 2014. ..... 24
Figure 3. Detroit River IBI value variance in response to number of sampling sites for each IBImethod in 2011 and 2013. A) 2011, Hamilton and Edwards.; B) 2011, Minns.; C) 2013, Hamiltonand Edwards; D) 2013, Minns25
Figure 4. Detroit River IBI value variance in response to number of sampling sites for each IBImethod in summer and fall.26
Figure 5. Detroit River IBI value variance in response to number of sampling sites for each IBImethod in BEF and TRL27Figure 6. St. Clair River IBI value variance in response to number of sampling sites for each IBImethod in 2012 and 2014. A) 2012, Hamilton; B) 2012, Edwards.; C) 2012, Minns; D) 2014,Hamilton and Edwards; E) 2014, Minns28Figure 7. St. Clair River IBI value variance in response to number of sampling sites for each IBImethod in summer and fall. A) Summer, Hamilton; B) Summer, Edwards; C) Summer, Minns;D) Fall, Hamilton; E) Fall, Edwards; F) Fall, Minns29
Figure 8. St. Clair River IBI value variance in response to number of sampling sites for each IBImethod in BEF and TRL. A) BEF, Hamilton; B) BEF, Edwards; C) BEF, Minns; D) TRL,Hamilton and Edwards; and E) TRL, Minns30


#### Abstract

Kindree, M.M. Barnucz, J. and Mandrak, N.E. 2020. Optimal Sampling Effort to Inform the Index of Biotic Integrity in the Huron-Erie Corridor Areas of Concern. Can. Manuscr. Rep. Fish. Aquat. Sci. 3205: vi +30 p.

The Great Lakes Water Quality Agreement (GLWQA) provided the basis to identify 43 areas within the Great Lakes basin and international portion of the St. Lawrence River as Areas of Concern (AOC). The Detroit and St. Clair rivers, the riverine portion of the Huron-Erie Corridor (HEC), were designated as AOCs due to the degradation of ecological communities and resulting loss of human benefits. In particular, the loss of fish and wildlife habitat since European settlement in the area raised concerns about the structure and composition of the fish community. Implementation of Remedial Action Plans required aquatic monitoring of AOCs using the Index of Biotic Integrity, a multimetric index using fishes as a proxy for habitat condition. To develop a sampling protocol for future fish community assessment in the HEC, IBIs were calculated for each site in both rivers annually, seasonally, and between gear types (boat electrofishing and trawling). The resulting site IBI scores for each level of organization were then used in a resampling procedure to calculate the corresponding reduction in IBI score variance relative to a maximum value with an increase in the number of sites sampled (from 1 to 100 sites, with replacement). On average sampling 2.5 sites reduce the variance in the IBI score by $50 \%$ relative to the maximum relative variance. The current number of sampling sites in both rivers reduced the variance in the IBI compared to the relative maximum variance by $\sim 75 \%$. On average, an additional two sampling sites in each river would reduce the variance by $90 \%$; therefore, adding two sites to each river is recommended for future monitoring of the HEC AOCs. Finally, the IBI scores in both rivers demonstrate a poor to fair habitat condition, which emphasizes the need for continued monitoring of habitat condition at regular intervals.


## RÉSUMÉ

Kindree, M.M. Barnucz, J. and Mandrak, N.E. 2020. Optimal Sampling Effort to Inform the Index of Biotic Integrity in the Huron-Erie Corridor Areas of Concern. Can. Manuscr. Rep. Fish. Aquat. Sci. 3205: vi +30 p.

L'Accord relatif à la qualité de l'eau dans les Grands Lacs a permis de répertorier 43 zones situées à l'intérieur du bassin des Grands Lacs et de la portion internationale du fleuve Saint-Laurent qui sont considérées comme des secteurs préoccupants. Les rivières Detroit et Sainte-Claire, la portion fluviale du corridor Huron-Érié, ont été déclarées «secteurs préoccupants" en raison de la dégradation des communautés écologiques et de la perte des avantages qu'elle a causée pour les humains. Plus particulièrement, la perte de l'habitat du poisson et de la faune depuis l'établissement des Européens dans la région a soulevé des préoccupations au sujet de la structure et de la composition de la communauté des poissons. Dans le cadre de la mise en œuvre des plans de mesures correctives, il a fallu surveiller les eaux des secteurs préoccupants à l'aide de l'indice d'intégrité biotique, un indice multimétrique qui utilise les poissons comme indicateur de l'état de santé de l'habitat. Afin d'élaborer un protocole d'échantillonnage pour les prochaines évaluations des communautés de poissons dans le corridor Huron-Érié, des indices d'intégrité biotique ont été calculés pour chaque site dans les deux rivières chaque année, de façon saisonnière et selon le type d'engin (pêche électrique par bateau et pêche au chalut). Les résultats de l'indice d'intégrité biotique ayant été obtenus pour chaque site et pour chaque niveau d'organisation ont ensuite été utilisés dans une procédure de rééchantillonnage en vue de calculer la réduction correspondante de la variance relative des résultats de l'indice par rapport à une valeur maximale avec une augmentation du nombre de sites échantillonnés (de 1 à 100 sites, avec remise). En moyenne, l'échantillonnage de 2,5 sites permet de réduire la variance du résultat de l'indice d'intégrité biotique de $50 \%$ par rapport à la variance relative maximale. Le nombre actuel de sites d'échantillonnage dans les deux rivières a réduit la variance de l'indice d'intégrité biotique d'environ $75 \%$ comparativement à la variance relative maximale. En moyenne, l'ajout de deux sites d'échantillonnage dans chaque rivière réduirait la variance de $90 \%$. Il est donc recommandé d'ajouter deux sites à chaque rivière pour surveiller, à l'avenir, les secteurs préoccupants du corridor Huron-Érié. Pour finir, les résultats de l'indice d'intégrité biotique obtenus pour les deux rivières démontrent que l'état de santé de l'habitat est mauvais ou passable, d'où la nécessité de poursuivre les activités de surveillance périodiques.

## INTRODUCTION

Sampling fish assemblages in large rivers presents several logistical and technical challenges due to the diversity of available habitat coupled with deep waters and strong flows (Edwards et al. 2006; Lapointe et al. 2006). Although large rivers are difficult to sample, they often provide key ecosystem services. Degradation of the ecological communities within large rivers has occurred globally through anthropogenic land-use changes, such as urbanization, agriculture, and industry, and often leads to negative impacts on the fish community (Manny et al. 2015). An example of two such rivers experiencing ecological impairment are the St. Clair and Detroit, which function as the riverine portion of the Huron-Erie Corridor (HEC). Both rivers were defined as impaired under the second amendment of the Great Lakes Water Quality Agreement (GLWQA) in 1972 and designated as Areas of Concern (AOC) due to the identification of beneficial-use impairments (BUIs) (Green et al. 2010). The primary objective of the GLWQA was to focus remediation and restoration efforts at specific locations within the Great Lakes basin and international portion of the St. Lawrence River that exhibit severely degraded habitats. Site-specific management and conservation strategies based on BUI targets were developed to reduce the impacts that contributed to the degradation of the ecosystems. Fourteen BUIs were identified as relevant to AOCs, five of which directly relate to fishes: restrictions on consumption, tainting, degradation of habitat, reduction of populations, presence of tumors and other deformities, and loss of habitat (Minns et al. 1994). BUls relevant to the Detroit and St. Clair rivers are the reduction of fish and wildlife habitat due to channelization for industrial, urban, agricultural, and navigational uses (Edwards et al. 2006; Dutz 1998).

The Detroit River and St. Clair River are 52 and 64 km in length, respectively. Both rivers are more than a kilometer wide at the widest points and exhibit fast flow rates (GLIN 2005) with average annual discharges of $5,200 \mathrm{~m}^{3} / \mathrm{s}$ in the Detroit River and $5,150 \mathrm{~m}^{3} / \mathrm{s}$ in the St. Clair River (Green 2010; IJC 2009). Nine BUIs identified in the Detroit River are the result of current and historical industrial, agricultural, and urban land-use activities occurring within the watershed (Edwards et al. 2007). This includes the operation of 50 large industries such as steel mills, electrical power-generating plants, petroleum refineries, and manufacturers of chemicals, automotive parts, rubber products, salts, and plastics (Manny et al. 1988). While in the St. Clair River, eleven beneficial-use impairments were identified. While most of the land use in this AOC is rural ( $78 \%$ in Ontario, $68 \%$ in Michigan), petroleum and chemical industries have a strong shoreline presence (Mayne 2006). Due to the development of large industries and use as shipping channels, the shorelines and riverbeds of both AOCs have been altered. Additionally, population growth has resulted in an increase of sewage outflows into the rivers. The combination of habitat loss and influx of deleterious substances has led to a decline in species richness and abundance of natural communities (Granados 2010). Additional environmental concerns listed for the Detroit and St. Clair rivers include exotic species, fish community structure changes, and a reduction in wildlife populations (Edwards et al. 2007). Programs have been implemented in both rivers to facilitate recovery, such as Remedial Action Plans (RAP) and the Great Lakes Action Plan (GLAP) under Annex 2 of the 1987 GLWQA Protocol. Measuring the biotic integrity of Great Lakes ecosystems has been the primary focus to evaluate the effectiveness of restoration and recovery programs since the inception of the GLWQA (Bhagat et al. 2007). Habitat-recovery studies in the Great Lakes AOCs under RAPs use an ecosystem approach that directly measures the biological community as a proxy for habitat condition (Minns et al. 1994). Habitat recovery in Canadian AOCs has been measured using multimetric Index of Biotic Integrity (IBI) scores over multiple sampling periods to evaluate changes in response to RAPs (Granados 2010). The metrics used in IBI calculations reflect a
broad array of biotic and abiotic factors that influence fishes (Minns et al. 1994). A benefit of using a multimetric method of assessing ecosystem integrity is that it provides a cost-effective method and standardized assessment tool for aquatic environments. Multimetric IBIs allow for standardized long-term monitoring of ecological integrity using community assemblages that have immediate social, economic, and conservation value (De Kerckhove et al. 2008).

In this study, the variance of IBI scores within rivers, corresponding with increasing sampling effort, is assessed to determine the relationship between number of sites samples and the IBI. Biodiversity sampling is resource intensive; therefore, it is important to understand the optimal gear and effort required to characterize fish communities for activities such as calculating IBI scores (Smith and Jones 2005). This information will be used to inform management decisions in developing optimal sampling protocols for this region related to annual, seasonal, and gear requirements. Mean IBI score is a method used by managers to assess the overall ecosystem health; therefore, if mean IBI scores are highly variable, small sample sizes may not accurately reflect the state of the biotic community. Meanwhile, a large sample size may not provide novel information to alter the IBI scores and needlessly increase monitoring costs. Three IBI methods were used in the analysis to determine which IBI score produces the lowest variation using the least number of sites. Conducting sampling over a range of temporal conditions minimizes the variation due to seasonal or diel influences, such as migrations (De Kerckhove et al. 2008). Species richness metrics, used in all IBI methods, are influenced by gear type. All gear types have associated biases and are more efficient at capturing certain species under different habitat conditions, which may influence resulting IBI scores (Jackson and Harvey 1997).

## METHODS

## Field collection

Field sampling, as part of the RAP for Canadian AOCs, was conducted by Fisheries and Oceans Canada (DFO) to monitor the fish communities of the Detroit and St. Clair rivers. Six sites in the Detroit River, sampled as a part of the 1990 RAP fish survey by Ontario Ministry of Natural Resources and Forestry (OMNRF), were re-sampled in 2011 in July, August, September, and October in the Detroit River (Figure 1). These sites were sampled an addition time in 2013 in July, August, October, and November (see Appendix 1 in Kindree and Mandrak 2020 for site descriptions). Eight sites on the St. Clair River, surveyed during the 1994 RAP survey by OMNRF, were re-sampled in 2012 and 2014 (Figure 2). In 2012, fish surveys were conducted in July, August, and October. Community surveys in 2014 only occurred during the July and August (see Appendix 2 in Kindree and Mandrak 2020 for site descriptions). These sampling periods were chosen to represent summer and fall sampling periods. During each sampling period, boat electrofishing and benthic trawling were used to examine potential gear bias on IBI scores for each location. In the St. Clair River, a one km site divided into ten 100 m transects was sampled. Whereas, in the Detroit River two 500 m long parallel transects divided into 100 m sections were sampled to capture nearshore and offshore fish communities. The fish community data from each transect was pooled per site. All sampling was conducted between the hours of 08:00 and 16:00.

Electrofishing was conducted using a 6.35 m Smith-Root dual-boom electrofishing boat equipped with a 7.5 kW Smith-Root generator, a 7.5 GPP control box with two foot pedals, and three kick plates. Sampling data collected at each site included sampling coordinates, sampling effort (see Appendix 9 and 10 in Kindree and Mandrak 2020 for sampling effort site summaries), and electrofishing settings. Sampling was conducted from upstream to downstream, two netters
retrieved stunned fishes as they appeared at the surface and all fishes were transferred into a 300 L live-well. Minimum and maximum lengths were recorded for each species at each sampling location. A subset of fishes were kept as voucher specimens for subsequent laboratory verification. For larger specimens, a photo voucher was taken.

Benthic trawl surveys for each site were conducted using a mini-Missouri Trawl. The Missouri trawl is a dual-mesh trawl which has a 2.4 m head rope and 3.7 m foot rope. The entire trawl is 4.4 m in length. The internal mesh is 19 mm bar mesh and the outer mesh is 3 mm delta heavyduty mesh (Guy et al. 2009). Trawls were deployed from the bow of the survey vessel while travelling downstream in reverse. Each trawl was towed the entire distance of the 100 m survey transect. Trawling speeds were maintained at approximately $2 \mathrm{~km} / \mathrm{h}$. Towlines for the trawl were set according to transect depth following the general rule of seven metres of towline for each metre of water depth (Guy et al. 2009). Captured fishes were processed and vouchered retained using the same methods as the electrofishing surveys.

Habitat characteristics at each of the 2011-2014 sites was recorded upon completion of fish collection at each 100 m transect. Habitat was described by recording air temperature, water temperature, conductivity, dissolved oxygen, pH , turbidity, stream depth, distance from shore, water velocity (at approximately 1 m below the water surface), percent aquatic vegetation, substrate type, riparian vegetation, and floodplain use. For a more detailed description of habitat sampling methods, see Kindree and Mandrak 2020.

## Index of biotic integrity (IBI)

IBI scores for each of the Detroit and St. Clair river sites were calculated using three IBI methods: Hamilton's (1987) adaptation of Karr (1981); Edwards et al. (2006) adaptation of Hamilton's (1987) method; and, Minns et al. (1994) method. For convenience, these methods henceforth will be referred to as the Hamilton, Edwards, and Minns IBI or method. The three methods were calculated to examine the variance in mean IBI score among the three IBI methods. IBI scores were calculated for each site within each river with data pooled from each transect to examine differences among years, seasons, and gear type. The Hamilton and Edwards methods include eight metrics separated into three categories: species richness and composition; trophic composition; and, fish abundance and health (Table 1). Metrics are assigned a ranking of $0,1,3$, or 5 based on predefined thresholds of each metric. Fish species were classified as generalist, specialists, or piscivores based on the number of high-preference food items defined in Coker et al. (2001) (Table 2). Fish species in the dataset where classified as native or exotic to the Detroit and St. Clair rivers using Holm et al. (2009). The eight metrics are summed to a final score and given a narrative ranking from >15=very poor to 40=excellent. The Edwards method modifies one metric in the Hamilton method, from "number of naturally spawned salmonid and coregonine species present in each sample area" to include only "native naturally spawned salmonid and coregonine" individuals captured (Table 3). This method reduces the inflation of that metric score by excluding exotic individuals.

The Minns method is an index based on a continuous scoring system from 0 to 100 (Table 4). This method reduces the variance of individual metric values and gives each metric equal weighting. Twelve metrics are summed including eight positive and four negative metrics (Table 4). This method requires raw metrics $\left(\mathrm{M}_{\mathrm{R}}\right)$ to be standardized $\left(\mathrm{M}_{\mathrm{s}}\right)$ using Equation 1 , to ensure a minimum and maximum metric value of 0 and 10 , respectively.
$M_{S}=A+B \cdot M_{R}$
(Equation 1)

Where, $A$ is the intercept and $B$ is the slope delineated by the minimum and maximum values of the raw metric $\left(M_{R}\right)$. The minimum and maximum threshold of each metric define the floor and ceiling of the standardized metric. The floor should be a zero value for positive metrics (i.e. number of native individuals) and the ceiling is the 95th percentile. When $A$ is a high value and $B$ is a negative number it results in a negative function where large raw metric values indicates low biotic integrity, which produces a low standardized metric score. This would be the case for negative metrics such as those relating to nonindigenous species. Once all standardized metric scores are calculated, the standardized metrics are summed and multiplied by $10 / \mathrm{N}$, where N is the number of metrics, to produce an IBI score between 0 and 100. As in other metrics, total scores are given a narrative rank from $0=$ no fish and $>80=$ excellent. An assumption of the Minns method is that one site within the sampled area is representative of a reference condition. Reference conditions determine the maximum value of raw metrics; however, no acceptable reference condition exists for the Detroit and St. Clair rivers because of ubiquitous anthropogenic disturbance. Therefore, best professional judgement (BPJ) was used to describe expected species compositions for the HEC (Granados 2010) (see Appendix 6 in Kindree and Mandrak 2020). IBI scores using four different expert opinion species lists based on the agreement by $\geq 2$, $\geq 3$, and $\geq 4$ respondents were used to calculate IBI scores based on the Minns method. This will provide a more robust evaluation of species richness by minimizing the effect of inappropriate species selections or omissions by some respondents.

The Minns method uses biomass metrics; however, during DFO surveys, only species abundance, minimum length, and maximum length were recorded. Transformations were required to calculate biomass ( g ) from lengths ( mm ) for each species per site. A geometric mean of the minimum and maximum length of each species at each site was calculated. A more detailed description of length to biomass transformations can be found in Kindree and Mandrak 2020.

IBI scores were calculated for each river site at six levels of data pooling; annual (2011 and 2013 in the Detroit River, 2012 and 2014 in the St. Clair River), seasonally (summer and fall), and gear used (boat electrofishing and trawling). For example, sites 1 through 6 in the Detroit River have an IBI score calculated for 2011, 2013, summer, fall, and each gear type (boat electrofishing and trawling). Finally, IBI scores were calculated for each river at each organization with all sites pooled, for example all fish data from sites 1 through 6 in the 2011 Detroit River survey were pooled to determine the overall IBI score for that year. IBI scores were calculated at each level of organization using the Hamilton, Edwards, and Minns methods.

## Variance analysis

To examine the influence of sampling effort on the IBI score within a river annually, seasonally, and between gear types, the variance between mean IBI scores for 1 to 100 sites sampled was calculated. From each list of IBIs, the scores were selected with replacement 100 times starting with one site randomly chosen from the pool of IBI scores. Then two scores were randomly chosen from the list of IBI scores and averaged. This selection and averaging process occurred until 100 IBI scores were sampled. The variance of each set of IBI scores was calculated and the largest variance was recorded. The absolute difference was calculated between the largest variance and the variance for each number of sites sampled. From this, the change in variance was calculated. The number of sites required to reduce the variance by $50 \%, 75 \%, 90 \%$, and $95 \%$ were determined for each year, season, and gear type in each river. This analysis was
conducted using $R$ version 3.4.3 (R Core Team 2013). This process was repeated for each IBI method and level of data pooling.

## RESULTS

## Field data

A total of 46 and 48 sites were sampled in the Detroit and St. Clair rivers, respectively. A total of 65 species were collected over all sampling periods.

## Detroit River

Six sites in the Detroit River were sampled in 2012 and 2014 during the summer and fall. In 2014, site 5 was omitted from benthic trawling surveys because of several large obstructions (i.e. pilings, submerged docks) had made trawling hazardous at this site. A total of 20,224 individuals, representing 53 species, were captured in the Detroit River. Of these 53 species, 29 were common among years and seasons (see Table 5 in Kindree and Mandrak 2020). The highest number of individuals were captured in 2011 ( $n=11,528$ ) while only 8,696 individuals were collected in 2013 (see Table 4 in Kindree and Mandrak 2020). The highest number of species were captured in 2013 for both summer and fall, 42 and 41, respectively (see Table 5 in Kindree and Mandrak 2020). Between seasons, a higher abundance of fishes was captured in fall, but no substantial difference in species richness between seasons was observed (see Table 5 in Kindree and Mandrak 2020). Benthic trawling surveys captured a higher abundance of fish species in both 2011 and 2013, and a higher species richness in 2013 (see Table 4 in Kindree and Mandrak 2020). Boat electrofishing captured $34 \%(n=6,948)$ of the individuals caught in the Detroit River, while benthic trawling captured 66\%. The most abundant species captured using boat electrofishing were Gizzard Shad (Dorosoma cepedianum) ( $\mathrm{n}=2,266$ ) and Emerald Shiner (Notropis atherinoides)( $\mathrm{n}=2,230$ ). The 40 species collected using boat electrofishing included 11 species unique to that gear type in the Detroit River: Bigmouth Buffalo (Ictiobus cyprinellus), Bowfin (Amia calva), Cisco (Coregonus artedi), Common Shiner (Luxilus cornutus), Goldfish (Carassius auratus), Goldfish X Common Carp hybrid (Carassius auratus X Cyprinus carpio), Sand Shiner (Notropis stramineus), Spotfin Shiner (Cyprinella spiloptera), Striped Shiner (Luxilus chrysocephalus), and Yellow Bullhead (Ameiurus natalis). The most abundant species captured during trawling were Round Goby (Neogobius melanostomus) $(n=2,873)$ and Mimic Shiner (Notropis volucellus) ( $n=2,426$ ). The benthic trawl collected 14 species unique to that gear type including Banded Killifish (Fundulus diaphanus), Channel Catfish (Ictalurus punctatus), Channel Darter (Percina copelandi), Eastern Sand Darter (Ammocrypta pellucida), Green Sunfish (Lepomis cyanellus), Johnny Darter (Etheostoma nigrum), Least Darter (Etheostoma microperca), Northern Madtom (Noturus stigmosus), Orangespotted Sunfish (Lepomis humilis), Pugnose Shiner (Notropis anogenus), Rainbow Darter (Etheostoma caeruleum), Round Goby, Tubenose Goby (Proterorhinus semilunaris), and White Sucker (Catostomus commersonii).There was a higher abundance of native fishes captured using boat electrofishing ( $96.5 \%$ ) compared to benthic trawling. However, benthic trawling resulted in a higher proportion of percid, specialist, and centrarchid species (7,14, and $22.1 \%$, respectively) (see Table 6 in Kindree and Mandrak 2020). Generalists were the most abundance trophic class captured among both gear types, while piscivores were the least abundant.

## St. Clair River

Eight sites were sampled in the St. Clair River in summer and fall of 2012 and the summer of 2014. A total of 16,498 individuals across 47 species were captured between all sampling periods. Of the 47 species, 23 were common among years and sampling seasons (see Table 12 in Kindree and Mandrak 2020). The highest number of fishes were captured in 2012 ( $n=11,592$ ), while in 2014, only 4,906 fishes were collected (see Table 11 in Kindree and Mandrak 2020). The highest abundance of fishes was captured in summer in the St. Clair River when 2012 and 2014 samples were pooled. Boat electrofishing captured $13.7 \%$ ( $n=2,258$ ) of the individuals caught in the St. Clair River, while benthic trawling captured $86.3 \%$ ( $n=14,240$ ) (see Table 13 in Kindree and Mandrak 2020). Yellow Perch (Perca flavescens) ( $\mathrm{n}=613$ ) and Emerald Shiner ( $\mathrm{n}=571$ ) were the most abundant species captured using boat electrofishing. Thirty-four species were captured using boat electrofishing including 12 unique species: Gizzard Shad, Bowfin, Brook Silverside (Culaea inconstans), Common Carp (Cyprinus carpio), Freshwater Drum (Aplodinotus grunniens), Golden Redhorse (Moxostoma erythrurum), Longnose Gar (Lepisosteus osseus), Muskellunge (Esox masquinongy), Pumpkinseed (Lepomis gibbosus), Rainbow Trout (Oncorhynchus mykiss), Silver Lamprey (Ichthyomyzon unicuspis), and Spotted Sucker (Minytrema melanops). The most abundant species captured using the benthic trawl were Round Goby ( $n=6,350$ ) and Hornyhead Chub (Nocomis biguttatus) ( $n=1,924$ ). Thirteen unique species were caught using the benthic trawl including including Black Crappie (Pomoxis nigromaculatus), Bluegill (Lepomis macrochirus), Brook Silverside, Channel Catfish, Channel Darter, Creek Chub (Semotilus atromaculatus), Iowa Darter (Etheostoma exile), Mottled Sculpin (Cottus bairdii), Northern Madtom, Pugnose Shiner, Rainbow Smelt (Osmerus mordax), Slimy Sculpin (Cottus cognatus), and Threespine Stickleback (Gasterosteus aculeatus). Boat electrofishing captured a higher percentage of native individuals (96.9\%) and the only salmonid species in the dataset, Rainbow Trout. Benthic trawling collected 30 native species and 5 exotic species; however, an almost equal proportion of exotic individuals were captured (49\%). There was a high percentage of generalists found in each gear type (see Table 13 in Kindree and Mandrak 2020).

## Habitat data

In the Detroit River, air temperatures ranged from $9.4^{\circ} \mathrm{C}$ to $30.7^{\circ} \mathrm{C}$ during sampling, while water temperatures ranged from $8.5^{\circ} \mathrm{C}$ to $24.8^{\circ} \mathrm{C}$, with the lowest temperatures being recorded in fall 2013. Conductivity ranged from $169.5 \mu \mathrm{~S}$ to $293.5 \mu \mathrm{~S}$. Dissolved oxygen and pH ranged from 6.82 to 15.78 and 8.12 to 9.82 , respectively. All sites were described as having either open water or submerged macrophyte cover. In the St. Clair River, air temperatures ranged from 5.3 ${ }^{\circ} \mathrm{C}$ to $35.1^{\circ} \mathrm{C}$ during sampling, while water temperatures ranged from $13.3^{\circ} \mathrm{C}$ to $31.6^{\circ} \mathrm{C}$, with the lowest temperatures being recorded in fall 2012. Conductivity ranged from $170 \mu \mathrm{~S}$ to 270.1 $\mu \mathrm{S}$. Dissolved oxygen and pH ranged from 0.52 to 13.46 and 8.35 to 10.28 , respectively. All sites were described as having either open water or submerged macrophyte cover.

## IBI scores

## Detroit River

In the Detroit River, all sites within the Detroit River were categorized as "Very Poor" (<15), "Poor" (18-23), or "Fair" (25-29), for all methods, except all sites pooled in 2011 using the Minns method received a score of "Good" (62) (Table 5). The Hamilton and Edwards methods yielded the same scores for all levels of data pooling due to the absence of non-native salmonid species. Kindree (2016) showed that there was no significant difference between IBI scores
inter-annually, seasonally, or among gear types, except between seasons when calculated using the Minns method; IBI scores were consistently higher in fall in the Detroit River. See Kindree and Mandrak (2020) for a more detailed results regarding IBI scores in the Detroit River.

## St. Clair River

In the St. Clair River, the IBI scores from the Hamilton and Edwards methods fell in the categories of "Very Poor" (<15) or "Poor" (18-23). The Hamilton and Edwards IBI scores were not equal in the St. Clair River because Rainbow Trout was captured in Site 1 and 4 in 2012 that reduced the metric score of "native naturally-spawned salmonid species present in the area". The Minns IBI scores ranged from "Poor" (>20-40) to "Fair" (>40-60) (Table 6). Kindree (2016) showed that there was no significant difference between IBI scores inter-annually, seasonally, or among gear types in the St. Clair River. See Kindree and Mandrak (2020) for a more detailed results regarding IBI scores in the St. Clair River.

## Variance within mean IBI

The decrease of variance within the IBI scores in response to the number of sites sampled was calculated using IBI scores calculated from pooling annual, seasonal, and gear type used, respectively. The number of sites needed to reduce the variance in IBI scores in the Detroit River are listed in Table 7. The Hamilton and Edwards methods require the same number of sites to reduce the variance for each year, season, and gear type because no salmonid species were captured in the Detroit River. When IBI score variance is calculated for each year (2011 and 2013) on average, a sample size of 2.5, 4.7, 10.1, and 18.7 sites are needed to reduce the variance in the Detroit's IBI score by $50 \%, 75 \%, 90 \%$, and $95 \%$, respectively (Figure 3). When IBI score variance is calculated for each season (summer and fall) on average, a sample size of $2.8,5.2,9.3$, and 20.7 sites are needed to reduce the variance in the Detroit River IBI score by $50 \%, 75 \%, 90 \%$, and $95 \%$, respectively (Figure 4). When IBI score variance is calculated for each gear type (BEF and TRL) on average, a sample size of 2.2, 4, 8.5, and 13.5 are needed to reduce the variance in the Detroit River IBI score by $50 \%$, $75 \%$, $90 \%$, and $95 \%$, respectively (Figure 5). Sample size for 2014 was lower than 2012 because no trawl sites were conducted in site 5 due to underwater obstructions. This also reduced the sample size in the gear type analysis for TRL variances. The current sampling protocol includes six sites in the Detroit River, which reduced the variance in the IBI scores by $\sim 75 \%$, respective to the maximum relative variance.

The number of sites needed to reduce the variance in IBI score in the St. Clair River are listed in Table 8. The Hamilton and Edwards methods require the same number of sites to reduce the variance because there were no salmonid species captured in the St. Clair River. When IBI score variance is calculated for each year (2012 and 2014) on average, a sample size of 2.5, $4.3,8.7$, and 18.5 sites are needed to reduce the variance in the St. Clair's IBI score by $50 \%$, $75 \%, 90 \%$, and $95 \%$, respectively (Figure 6). When IBI score variance is calculated for each season (summer and fall) on average, a sample size of 2.8, 4.5, 11.7, and 21 sites are needed to reduce the variance in the St. Clair River IBI score by $50 \%, 75 \%, 90 \%$, and $95 \%$, respectively (Figure 7). When IBI score variance is calculated for each gear type (BEF and TRL) on average, a sample size of 2.2, 4.2, 9 , and 15.7 sites are needed to reduce the variance in the St. Clair River IBI score by $50 \%, 75 \%, 90 \%$, and $95 \%$, respectively (Figure 8). Eight sites were sampled in the St. Clair River each year which reduces the variance in the St. Clair River IBI scores by $\sim 75 \%$, respective to the maximum relative variance.

## DISCUSSION

The objective of this study was to determine the variation in mean IBI scores in the Detroit and St. Clair rivers based on gear type and IBI method used. The IBI was calculated annually, seasonally, and for two gear types: boat electrofishing and benthic trawling. Three methods to calculate the IBI score were used to determine the influence of scoring method on IBI scores. The variance within IBI scores for each river showed that for surveys in each year, season, and gear, an increase in the number of sites sampled reduces the variance of the IBI score. Sampling of freshwater fishes is resource intensive; therefore, it is important to identify the optimal sampling protocols to sample fish communities for management activities such as calculating IBI scores (Smith and Jones 2005). Current sampling protocols within both rivers account for $\sim 75 \%$ of the variance in mean IBI score. These results provide the information required to design a standardized sampling protocol in the HEC AOCs.

Throughout the Great Lakes basin, there is a growing need to monitor the effects of urban, agricultural, and industrial land uses on aquatic environments (Steedman 1988). The HEC is exposed to a number of anthropogenic stressors that cause degradation of the aquatic habitat. In particular, the GLWQA identified the HEC as an area of degraded fish and wildlife habitat. The IBI is used as a monitoring tool to represent ecosystem health of AOCs in response to RAPs and has become an integral part of decision making for AOCs (IJC 2005). Monitoring the fish communities within the Detroit and St. Clair rivers is difficult because of the logistical and economic challenges with sampling large rivers and the lack of reference condition. The IBI scores determined in this study are consistent with previous studies in the HEC that have shown no significant increase in IBI scores over time (Edwards et al. 2006; Edwards et al. 2007; Granados 2010; Kindree 2016). Although there is variation in IBI scores among sites between sampling periods, there have been no significant changes interannually, seasonally, or between gear type. The majority of sites within the Detroit and St. Clair rivers are categorized as "Poor" or "Fair", indicating low biotic integrity within this region. The lack of response in the fish community to habitat improvements has been proposed to result from a lagged response of the fish community to improvements, an incomplete fish assemblage dataset (not enough sites sampled), or an IBI not sensitive to changes in the fish community (Granados 2010). Kindree (2016) examined the influence of gear type on IBI scores and found that differences in the fish community captured by different gear types did not influence IBI scores. A high rate of species replacement and metric compensation caused the scores to be similar.

Reliance on a single sampling method has been shown to consistently underestimate the number of species present (Jackson and Harvey 1997). Historically, IBI scores in the Canadian AOCs were calculated using standardized boat electrofishing surveys. In previous studies, boat electrofishing was found to be more efficient in measuring species richness and diversity than other gear types in large river surveys (Mercado-Silva and Escandon-Sandoval 2008; Neebling and Quist 2011). Kindree (2016) found that benthic trawling in the Detroit River captured 64\% of the total individuals and $86.3 \%$ in the St. Clair River, respectively. Trawl nets are not limited by depth; however, they can be obstructed by snags (e.g. woody debris and boulders) that would influence their efficacy. Site 5 in the Detroit River is an example of trawling restrictions as it could not be sampled because of pipelines. Missouri trawls have been shown to be effective at capturing small-bodied species in the lotic environment with a high percentage of rare fishes captured (Neebling and Quist 2011; Fischer and Quist 2014). Benthic fishes, such as darters and sculpins, have been caught in higher abundance in trawling compared to boat electrofishing (Fischer and Quist 2014). It is unrealistic to assume that all species present will be captured using a combination of sampling gears, let alone a single gear, although multiple gears can
provide a more complete characterization of the fish community (Fischer and Quist 2014). However, Kindree (2016) demonstrated that changes in gear type did not significantly influence IBI scores within the HEC AOCs and concluded that either gear type can be used when sampling these rivers. Therefore, standardized sampling can continue using boat electrofishing as the sole gear to collect the fish community dataset. However, fish sampling using boat electrofishing is more costly than trawling because of the cost of the boat and crew training. Therefore, sampling of the Detroit and St. Clair rivers could be completed using only benthic trawling if standardization of sampling across AOCs is not critical to resource managers. If this is the case, sampling protocols within these rivers can be created and modified based on time, budget, relevant research questions, and habitat characteristics.

An important principle in fisheries science is that increasing sampling effort will reduce the inherent natural variability in a sample (Simon and Morris 2014). Determining the number of samples required to reduce the variance in IBI scores is essential to provide accurate assessments of ecosystem health within Canadian AOCs. In this study, the site-level variance of the mean IBI scores in the Detroit and St. Clair rivers was determined. Multimetric indices like the IBI provide a useful tool in assessing ecosystem health but are limited by its dependence on the fish community data collected. Determining the variation in IBI scores based on the number of sites sampled provides a method of determining how many sites should be sampled. The variance in IBI scores within each year, season, and gears decreased when the number of sampling sites increased. Within both rivers, an average sampling effort of 2.5 sites is required to reduce the variance in the mean IBI score by $50 \%$. Current sampling protocols in the Detroit and St. Clair rivers requires sampling six and eight sites, respectively. Based on the results of this study, current sampling protocols reduce the variance of mean IBI scores by $75 \%$ relative to the maximum expected variance, while on average, an additional 2 sites would reduce the variance in the mean IBI score by $90 \%$.

There are several assumptions about using IBIs as a representative measure of ecosystem health. Fish community data and metrics used in the IBI are assumed to be representative of the fish community in an area. Niemela and Feist (2000) found that IBI scores are highly variable for sites in large rivers and suggested that an inability to catch a representative sample of the abundance and richness of fish species contributed to that variability. Failing to capture rare species, which are susceptible to random sampling errors, has been shown to influence IBI scores (Dolph et al. 2010). Metrics that assess richness, rather than abundances, are more sensitive to the presence or absence of rare taxa (Wan et al. 2010). There are no objective methods to determine the number and type of metrics that should be used when developing and applying the IBI score. This leaves room for subjective judgement on which indices best describe each situation (De Kerckhove et al. 2008). Although there is no guideline for creating a robust IBI score, IBI methods with a greater number of metrics can be assumed to have a more robust measure of biological integrity (Angermeir and Karr 1986). Kindree (2016) demonstrated that the three IBls developed for AOCs in southwestern Ontario (Hamilton 1987, Edwards et al. 2006, Minns et al. 1994) were not significantly different when used to calculate IBI scores between year, seasons, and gear type in the HEC. Variance analysis also showed no clear difference between IBI methods.

A reference condition that is used to calibrate IBI metrics, assumed to be an example of a pristine environment, is an assumption of IBI score calculations. The Detroit and St. Clair rivers do not have a reference condition because of long-term disturbance and lack of analogous pristine habitat elsewhere. Since early European settlement in the HEC, the Detroit and St. Clair rivers have been exposed to increasing pollution and sediment load, in addition to near ubiquitous habitat modifications for agriculture, urban, and industrial development (Hartig and

Thomas 1988). Channelization of the HEC for navigational purposes began in the early 1900s causing further reductions in shoreline heterogeneity and fish habitat (Hartig et al. 2009). BPJ condition species list compiled by Granados (2010) uses expert knowledge of the HEC to construct a species list under pre-disturbance conditions. This reference condition was used to determine the expected species richness metrics in the Minns IBI. Several species listed in the reference-condition species list were not collected during sampling. Declines in these species can be directly related to anthropogenic disturbances in the area and sampling bias of the gear types used. Some examples are Blue Pike, Lake Sturgeon, Lake Whitefish, and Silver Lamprey. Lake Sturgeon was abundant in the Detroit and St. Clair rivers until destruction of its spawning habitat reduced their population (Hartig et al. 2009) but current timing and sampling gears bias against capturing this species. RAP habitat-creation initiatives included the reconstruction of spawning beds for Lake Sturgeon (Acipenser fulvescens); however, there has been no evidence since the creation of these artificial spawning beds to support a significant increase in population (Manny et al. 2015). Blue Pike (Sander vitreus glaucus) was listed as a species present in the reference condition but was removed from BPJ list used to calibrate Minns metrics because it has been extinct since the 1960s and no chance of recovery is possible (Jelks et al. 2008). Although there were differences in the level of respondent agreement in the BPJ list created by Granados (2010), BPJ reference conditions are still the most useful tool in bioassessments when no existing reference conditions are available.

## SAMPLING PROTOCOL RECOMMENDATIONS

Based on the results of this study and previous assessments of the fish community in the HEC, the following recommendations are provided to inform assessment and delisting in the AOCs.

## Timing of sampling

Sampling should be completed at regular intervals to determine changes in the fish community. Kindree (2016) demonstrated that bi-annual assessments did not show significant changes in the IBI additionally, Edwards et al. 2006 and 2007 showed no significant difference in the IBI scores between decades. Annual monitoring is not required, as it is expensive and will likely not detect meaningful changes in the fish community. Bi-annual to decadal intervals of sampling are sufficient to continue monitoring fish community change within the HEC. However, if restoration activities are completed within the HEC, sampling should increase in frequency (bi-annually) to detect fish community changes in response to habitat improvements.

Kindree (2016) demonstrated that there were no significant differences between summer and fall sampling seasons; therefore, sampling can occur in either season. Fall sampling may be preferred because of higher IBI scores and larger abundances of fishes captured observed in previous studies (Edwards et al. 2007; Kindree 2016) and seasonal fish movements allow for higher CPUE in the Detroit and St. Clair rivers.

## Number of sites

Current sampling protocols in the Detroit and St. Clair rivers reduced the variance in the mean IBI score by $75 \%$ relative to maximum expected variance. On average, an additional two sites would reduce the variance by $90 \%$; therefore, adding two sites to each river is recommended. These new sites should be selected based on habitat characteristics to increase the level of heterogeneity between sites. Ideal locations for possible sampling sites would be at the mouth
of tributaries, enabling surveys to capture fish movements to possible refuge, and locations that fill in gaps in current site coverage. Maximizing the habitat diversity between sites will maximize the potential community diversity captured within the surveys. Sites were originally selected along the rivers because of their proximity to point sources. Further studies are needed to determine if those point-sources are still relevant and the identification of new locations with increased habitat disturbance.

## Gear type used

Kindree (2016) found there was no significant difference in the IBI scores based on boat electrofishing or benthic trawling. Gear type can be chosen based on time, budget, relevant research questions, and habitat characteristics. Gear used in fish community surveys should be chosen based on individual study questions, combining gear type is not required if the main question is related to the IBI. Boat electrofishing may be preferred as the sole gear to survey the fish community to maintain standardized sampling methods and allow for historical comparisons.

Other trade-offs include processing time, crew training, and financial costs associated with each gear. Boat electrofishing has a large start-up cost compared to trawling, however, has a lower cost associated with processing time. Lower abundances are captured using electrofishing while maintaining high species richness which reduces the processing time associated with each transect. Invasive species are captured more often with trawling which also contributes to longer processing times. Training requirements are higher with boat electrofishing and more expensive compared to trawling because of certifications required for crew leaders.

## IBI method

Kindree (2016) showed no difference between IBI scoring methods that have been developed for use in the Canadian AOCs. However, the Minns method is not ideal unless biomass and length measurements are taken for each fish specimen captured to ensure maximum confidence in the data collected. This will remove error associated with post hoc transformations of lengths. The use of BPJ as a reference condition in this region is also not ideal but is the best available solution in a unique environment of ubiquitous disturbance and impairment.

## LITERATURE CITED

Angermeier, P.L., and J.R. Karr. 1986. Applying an index of biotic integrity based on stream-fish communities: considerations in sampling and interpretation. N. Am. J, Fish. Manag. 6 (3): 418-429.

Bhagat, Y., Ciborowski, J.J., Johnson, L.B., Uzarski, D.G., Burton, T.M., Timmermans, S.T., and M.J. Cooper. 2007. Testing a fish index of biotic integrity for responses to different stressors in Great Lakes coastal wetlands. J. Great Lakes Res. 33: 224-235.
Coker, G.A., Portt, C.B., and C.K. Minns. 2001. Morphological and Ecological Characteristics of Canadian Freshwater Fishes. Can. MS Rpt. Fish. Aquat. Sci. 2554: iv+89p
De Kerckhove, D.T., Smokorowski, K.E., and R.G. Randall. 2008. A primer on fish habitat models. Can. Tech. Rep. Fish. Aquat. Sci. 2817: iv + 65p.
Dolph, C.L., Sheshukov, A.Y., Chizinski, C.J., Vondracek, B., and B. Wilson. 2010. The index of biological integrity andthe bootstrap: can random sampling error affect stream impairment decisions?. Ecol. Indic. 10 (2): 527-537.

Dutz, J. 1998. The St. Clair River area of concern binational habitat management plan.
Available from http://www.friendsofstclair.ca/pdf/hab mgmt plan.pdf. Accessed [01-1214].
Edwards, A., Barnucz, J., and N.E. Mandrak. 2006. Boat electrofishing survey of the fish assemblages of the St. Clair River, Ontario. Can. Manuscr. Rpt. Fish. Aquat. Sci. 2742. v +57 p .
Edwards, A., Torenvliet, E., Barnucz, J., and N. E. Mandrak. 2007. Boat electrofishing survey of the fish assemblages of the Detroit River, Ontario. Can. Man. Rpt. Fish. Aquat. Sci. (unpubl. ms.)
Fischer, J.R., and M.C. Quist. 2014. Characterizing lentic freshwater fish assemblages using multiple sampling methods. Enviro. Monit. Assess. 186 (7): 4461-4474.
Granados, M. 2010. Detecting changes in fish communities in response to habitat rehabilitation: a comparison of multimetric and multivariate approaches. M.Sc. Thesis. Ecology and Evolutionary Biology, University of Toronto. Toronto, ON.
Great Lakes Information Network (GLIN). 2005. Areas of Concerns (AOCs) in the Great Lakes region. Available: http://www.greatlakes.netJenvtJpoliution/aoc.html\#overview. Accessed: October 19, 2016.
Green, N.D., Cargnell, L., Briggs, T., Drouin, R., Child, N., Esbjerg, J., Valiante, M., Henderson, T., McGregor, D., and D. Munro, editors. 2010. Detroit River Canadian Remedial Action Plan: Stage 2 Report. Detroit River Canadian Cleanup, Publication No. 1, Essex, Ontario.
Guy, C.S., Braaten, P.J., Herzog, D.P., Pitlo, J., and R.S. Rogers. 2009. Warmwater fish in rivers in S. A. Bonar, W. A. Hubert, and D. W. Willis, editors. Standard methods for sampling North American freshwater fishes. 59-84pp.
Hamilton, J.G. 1987. Survey of critical fish habitat within International Joint Commission designated areas of concern, August-November, 1986. B.A.R. Environmental, Toronto, ON. Prepared for Ontario Ministry of Natural Resources, Toronto, ON. 119 pp.
Hartig, J. H., and R. L. Thomas. 1988. Development of plans to restore degraded areas in the Great Lakes. Environ. Manag. 12 (3): 327-347.
Hartig, J.H., Zaraull, M.A., Ciborowski, J.J.H., Gannon, J.E., Wilke, E., Norwoord, G., and A.N. Vincent. 2009. Long-term ecosystem monitoring and assessment of the Detroit River and Western Lake Erie. Enviro. Monit. Assess. 158 (1-4): 87-104.
Holm, E., Mandrak, N.E., and M.E. Burridge. 2009. The ROM field guide to freshwater fishes of Ontario. Royal Ontario Museum, Toronto.
IJC (International Joint Commission). 2005. A guide to the Great Lakes Water Quality Agreement: background for the 2006 government review. 23 pp.
IJC (International Joint Commission). 2009. Impacts on Upper Great Lakes Water Levels: St. Clair River Final Report. Accessed from: https://www.ijc.org/en/impacts-upper-great-lakes-water-levels-st-clair-river-final-report
Jackson, D.A., and H.H. Harvey. 1997. Qualitative and quantitative sampling of lake fish communities. Can. J. Fish. Aquat. Sci. 54 (12): 2807-2813.
Jelks, H. L., Walsh, S. J., Burkhead, N. M., Contreras-Balderas, S., Díaz-Pardo, E., Hendrickson, D. A., Lyons, J., Mandrak, N. E., McCormick, F., Nelson, J. S., Platania, S. P., Porter, B. A., Renaud, C. B., Schmitter-Soto, J. J., Taylor, E. B. and M.L. Warren Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries, 33 (8): 372-407.
Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries, 6 (6): 21-27.
Kindree, M.M. 2016. Quantifying the effect of sampling gear and effort on the index of biotic integrity in two Huron-Erie Corridor Areas of Concern. M.Sc. Thesis. Ecology and Evolutionary Biology, University of Toronto. Toronto, ON.

Kindree, M.M. and N.E. Mandrak. 2020. Fish Assemblage Survey of the Detroit and St. Clair rivers: 2007-2014. Can. Manuscr. Rep. Fish. Aquat. Sci. 3204 : x + 77p.
Lapointe, N.W.R., Corkum, L.D., and N.E. Mandrak. 2006. A Comparison of Methods for Sampling Fish Diversity in Shallow Offshore Waters of Large Rivers. N. Am. J, Fish. Manag. 26 (3): 503-513.
Mayne, G. 2006. St. Clair River RAO progress report: synthesis report environmental conditions and implementation actions (1998-2003). Volume 1. North-South Environmental Inc. Campbellville, Ontario. Available from http://www.friendsofstclair.ca/www/pdf/rap/progress.pdf Accessed [09-12-14]
Manny, B.A., Roseman, E.F., Kennedy, G., Boase, J.C., Craig, J.M., Bennion, D. H., Read, J., Vaccaro, L., Chiotti, J., Drouin, R., and R. Ellison. 2015. A scientific basis for restoring fish spawning habitat in the St. Clair and Detroit Rivers of the Laurentian Great Lakes. Restoration Ecology 23 (2): 149-156.
Manny, B.A., Edsall, T.A. and E. Jaworski. 1988. The Detroit River: an ecological profile. U.S. Fish and Wildlife Service Biological Report. 85(7.17). 86 pp.
Mercado-Silva, N., and D.S. Escandon-Sandoval. 2008. A comparison of seining and electrofishing for fish community bioassessment in a Mexican Atlantic slope montane river. N. Am. J. Fish. Manag. 28: 1725-1732.
Minns, C. K., Cairns, V.W., Randall, R.G., and J.E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. Can. J. Fish. Aquat. Sci. 51 (8):1804-1822.
Neebling, T.E., and M.C. Quist. 2011. Comparison of boat electrofishing, trawling, and seining for sampling fish assemblages in lowa's nonwadeable rivers. N. Am. J, Fish. Manag. 31 (2): 390-402.

Niemela S., and M. Feist. 2000. Index of Biotic Integrity (IBI) Guidance for Coolwater Rivers and Streams of the St. Croix River Basin in Minnesota. Minnesota Pollution Control Agency, Biological Monitoring Program, St. Paul, MN.
Simon, T. P., and C.C. Morris. 2014. Relationships among varying sampling distance and the IBI in warmwater, headwater streams of the Eastern Corn Belt Plain. Enviro. Monit. Assess. 186 (10): 6537-6551.
Smith, K. L., and M.L. Jones. 2005. Watershed-level sampling effort requirements for determining riverine fish species composition Can. J. Fish. Aquat. Sci. 62 (7): 15801588.

Steedman, R. J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Can. J. Fish. Aquat. Sci. 45 (3): 492-501.
R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
Wan, H., Chizinski, C.J., Dolph, C.L., Vondracek, B., and B.N. Wilson. 2010. The impact of rare taxa on a fish index of biotic integrity. Ecol. Indic. 10 (4): 781-788.

Table 1. Hamilton adaptation of the IBI classification scheme.

| Section | Description | Scoring criteria |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 0 | 1 | 3 | 5 |
| Species richness and composition | Number of species collected in each sample (as a \% of total collected in the entire AOC) | 0 | 0-25\% | 26-50\% | > 50\% |
|  | Number of percid species present in each sample area | 0 | 1 | 2 | $\geq 3$ |
|  | Number of naturally-spawned salmonid and coregonid species present in each sample area | 0 | 1 | 2 | $\geq 3$ |
| Subtotal: |  |  |  |  |  |
| Trophic composition | Proportion of individuals considered specialist/insectivores/planktivores | 0 | < 20\% | 20-40\% | > 40\% |
|  | Proportion of individuals considered generalists | 0 | > 40\% | 20-40\% | < 20\% |
|  | Proportion of individuals considered top piscivores | 0 | <2\% | 2-5\% | > 5\% |
| Subtotal: |  |  |  |  |  |
| Fish abundance and health | Ratio of CPUE in the sample area to mean AOC CPUE (as \%) | - | < 80\% | 80-120\% | > $120 \%$ |
|  | Occurrence of individuals which are hybrids, diseased, have lamprey scars or are invading species |  |  | 1-5\% |  |
| Subtotal: |  |  |  |  |  |
| Total: |  |  |  |  |  |
| Rating System: | $\begin{aligned} & <15=\text { very poor } \\ & 18-23=\text { poor } \\ & 25-29=\text { fair } \\ & 31-34=\text { good } \\ & 37-40=\text { excellent } \end{aligned}$ |  |  |  |  |

Table 2. Species assignments for all fishes captured in 2007, 2011-2014.

| Common name | Scientific name | Native? | Trophic classification | Tolerance | Taxa |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alewife | Alosa pseudoharengus | N | Spe | Tolerant |  |
| Banded Killifish | Fundulus diaphanus | Y | Spe | Tolerant |  |
| Bigmouth Buffalo | Ictiobus cyprinellus | Y | Gen | Tolerant |  |
| Black Bullhead | Ameiurus melas | Y | Gen | Tolerant |  |
| Black Crappie | Pomoxis nigromaculatus | Y | Pis | Tolerant | Cen |
| Bluegill | Lepomis macrochirus | Y | Gen | Tolerant | Cen |
| Bluntnose Minnow | Pimephales notatus | Y | Gen | Tolerant | NatCyp |
| Bowfin | Amia calva | Y | Pis | Tolerant |  |
| Brook Silverside | Labidesthes sicculus | Y | Spe | Tolerant |  |
| Brook Stickleback | Culaea inconstans | Y | Spe | Tolerant |  |
| Brown Bullhead | Ameiurus nebulosus | Y | Gen | Tolerant |  |
| Burbot | Lota lota | Y | Gen | Tolerant |  |
| Channel Catfish | Ictalurus punctatus | Y | Gen | Tolerant |  |
| Channel Darter | Percina copelandi | Y | Spe | Sensitive | Perc |
| Cisco | Coregonus artedi | Y | Spe | Sensitive | Cor |
| Common Carp | Cyprinus carpio | N | Gen | Tolerant |  |
| Common Shiner | Luxilus cornutus | Y | Gen | Tolerant | NatCyp |
| Creek Chub | Semotilus atromaculatus | Y | Gen | Tolerant | NatCyp |
| Eastern Sand Darter | Ammocrypta pellucida | Y | Spe | Sensitive | Perc |
| Emerald Shiner | Notropis atherinoides | Y | Gen | Tolerant | NatCyp |
| Freshwater Drum | Aplodinotus grunniens | Y | Gen | Tolerant |  |
| Gizzard Shad | Dorosoma cepedianum | Y | Spe | Tolerant |  |
| Golden Redhorse | Moxostoma erythrurum | Y | Gen | Tolerant |  |
| Golden Shiner | Notemigonus crysoleucas | Y | Gen | Tolerant | NatCyp |
| Goldfish | Carassius auratus | N | Gen | Tolerant |  |
| Goldfish X Common Carp | Carassius auratus X Cyprinus carpio | N | Gen | Tolerant |  |
| Greater Redhorse | Moxostoma valenciennesi | Y | Gen | Sensitive |  |
| Green Sunfish | Lepomis cyanellus | Y | Pis | Tolerant | Cen |
| Hornyhead Chub | Nocomis biguttatus | Y | Gen | Sensitive | NatCyp |
| Iowa Darter | Etheostoma exile | Y | Spe | Tolerant | Perc |
| Johnny Darter | Etheostoma nigrum | Y | Spe | Tolerant | Perc |
| Largemouth Bass | Micropterus salmoides | Y | Pis | Tolerant | Cen |
| Least Darter | Etheostoma microperca | Y | Spe | Tolerant | Perc |
| Logperch | Percina caprodes | Y | Spe | Tolerant | Perc |
| Longnose Gar | Lepisosteus osseus | Y | Pis | Tolerant |  |
| Longnose Sucker | Catostomus catostomus | Y | Gen | Sensitive |  |


| Common name | Scientific name | Native? | Trophic classification | Tolerance | Taxa |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Mimic Shiner | Notropis volucellus | Y | Gen | Tolerant | NatCyp |
| Mottled Sculpin | Cottus bairdii | Y | Gen | Sensitive |  |
| Muskellunge | Esox masquinongy | Y | Pis | Tolerant |  |
| Northern Hogsucker | Hypentelium nigricans | Y | Gen | Sensitive |  |
| Northern Pike | Esox lucius | Y | Pis | Tolerant |  |
| Nothern Madtom | Noturus stigmosus | Y | Spe | Sensitive |  |
| Orangespotted Sunfish | Lepomis humilis | N | Gen | Tolerant | Cen |
| Pugnose Shiner | Notropis anogenus | Y | Spe | Sensitive | NatCyp |
| Pumpkinseed | Lepomis gibbosus | Y | Gen | Tolerant | Cen |
| Quillback | Carpiodes cyprinus | Y | Gen | Tolerant |  |
| Rainbow Darter | Etheostoma caeruleum | Y | Spe | Sensitive | Perc |
| Rainbow Smelt | Osmerus mordax | N | Gen | Tolerant | Salm |
| Rainbow Trout | Oncorhynchus mykiss | N | Pis | Sensitive |  |
| River Redhorse | Moxostoma carinatum | Y | Gen | Sensitive |  |
| Rock Bass | Ambloplites rupestris | Y | Gen | Tolerant | Cen |
| Round Goby | Neogobius melanostomus | N | Gen | Tolerant |  |
| Sand Shiner | Notropis stramineus | Y | Spe | Tolerant | NatCyp |
| Shorthead Redhorse | Moxostoma macrolepidotum | Y | Gen | Tolerant |  |
| Silver Lamprey | Ichthyomyzon unicuspis | Y | Spe | Sensitive |  |
| Silver Redhorse | Moxostoma anisurum | Y | Gen | Tolerant |  |
| Slimy Sculpin | Cottus cognatus | Y | Gen | Sensitive |  |
| Smallmouth Bass | Micropterus dolomieu | Y | Pis | Tolerant | Cen |
| Spotfin Shiner | Cyprinella spiloptera | Y | Gen | Tolerant | NatCyp |
| Spottail Shiner | Notropis hudsonius | Y | Gen | Tolerant | NatCyp |
| Spotted Sucker | Minytrema melanops | Y | Gen | Sensitive |  |
| Striped Shiner | Luxilus chrysocephalus | Y | Gen | Tolerant | NatCyp |
| Threespine Stickleback | Gasterosteus aculeatus | N | Gen | Tolerant |  |
| Trout-perch | Percopsis omiscomaycus | Y | Spe | Sensitive |  |
| Tubenose Goby | Proterorhinus semilunaris | N | Spe | Tolerant |  |
| Walleye | Sander vitreus | Y | Pis | Tolerant | Perc |
| White Bass | Morone chrysops | Y | Pis | Tolerant |  |
| White Perch | Morone americana | N | Pis | Tolerant |  |
| White Sucker | Catostomus commersonii | Y | Gen | Tolerant |  |
| Yellow Bullhead | Ameiurus natalis | Y | Gen | Tolerant |  |
| Yellow Perch | Perca flavescens | Y | Pis | Tolerant | Perc |

*Spe-Specialist, Gen-Generalist, , Pis-Piscivore, Cen-Centrarchid, NatCyp- Native Cyprinid, Perc-Percid, Cor- Coregonine

Table 3. Edwards adaptation of the Hamilton (1987) IBI classification scheme.

| Section | Description | Scoring criteria |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 0 | 1 | 3 | 5 |
| Species richness and composition | Number of species collected in each sample (as a \% of total collected in the entire AOC) | 0 | 0-25\% | 26-50\% | > 50\% |
|  | Number of percid species present in each sample area | 0 | 1 | 2 | $\geq 3$ |
|  | Number of native naturally-spawned salmonid and coregonid species present in each sample area | 0 | 1 | 2 | $\geq 3$ |
| Subtotal: |  |  |  |  |  |
| Trophic composition | Proportion of individuals considered specialist/insectivores/planktivores | 0 | < 20\% | 20-40\% | > 40\% |
|  | Proportion of individuals considered generalists | 0 | > 40\% | 20-40\% | < 20\% |
|  | Proportion of individuals considered top piscivores | 0 | <2\% | 2-5\% | > 5\% |
| Subtotal: |  |  |  |  |  |
| Fish abundance and health | Ratio of CPUE in the sample area to mean AOC CPUE (as \%) | -- | < 80\% | 80-120\% | > $120 \%$ |
|  | Occurrence of individuals which are hybrids, diseased, have lamprey scars or are invading species |  | > 5\% | 1-5\% |  |
| Subtotal: |  |  |  |  |  |
| Total: |  |  |  |  |  |
| Rating System: | $\begin{aligned} & <15=\text { very poor } \\ & 18-23=\text { poor } \\ & 25-29=\text { fair } \\ & 31-34=\text { good } \\ & 37-40=\text { excellent } \end{aligned}$ |  |  |  |  |

Table 4. Minns et al. (1994) IBI classification scheme for the Great Lakes littoral fish assemblage. The coefficient intercept (A) and slope (B) in Equation 1 and standardizing the metrics and values for each raw metric.

| Section | Metric description | Metric coefficients |  |
| :---: | :---: | :---: | :---: |
|  |  | A | B |
| Species richness | Natives | 0 | * |
|  | Centrarchids | 0 | * |
|  | Intolerants | 0 | * |
|  | Nonindigenous | 10 | * |
|  | Native cyprinids | 0 | * |
| Trophic structure | \% piscivore biomass | 0 | 0.3 |
|  | \% generalist biomass | 15 | -0.15 |
|  | \% specialist biomass | 0 | 0.3 |
| Abundance and condition | Number of native individuals | 0 | ** |
|  | Biomass of natives (kg) | 0 | ** |
|  | \% nonindigenous numbers | 10 | ** |
|  | \% nonindigenous biomass | 10 | ** |

*Coefficients dependent on best professional judgement reference condition
**Coefficients calculated using the 95th percentile, dependent on scale of analysis Rating System: $0=$ No fish
$>0-20=$ very poor
$>20-40=$ poor
$>40-60=$ fair
$>60-80=$ good
$>80=$ excellent

Table 5. IBI scores for the Detroit River based on 2011 and 2013, summer and fall sampling using boat electrofishing (BEF) and benthic trawling (TRL).

| Method | Year | Season | Gear | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | $\mathbf{6}$ | All |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Hamilton | 2011 | -- | -- | 19 | 23 | 21 | 19 | 25 | 21 | 22 |
| Hamilton | 2013 | -- | -- | 17 | 19 | 21 | 21 | 15 | 26 | 22 |
| Edwards | 2011 | -- | -- | 19 | 23 | 21 | 19 | 25 | 21 | 22 |
| Edwards | 2013 | -- | -- | 17 | 19 | 21 | 21 | 15 | 26 | 22 |
| Minns | 2011 | -- | -- | 47 | 55 | 49 | 39 | 53 | 52 | 62 |
| Minns | 2013 | -- | -- | 44 | 47 | 44 | 41 | 55 | 50 | 60 |
| Hamilton | -- | Summer | -- | 21 | 21 | 19 | 23 | 19 | 25 | 21 |
| Hamilton | -- | Fall | -- | 21 | 21 | 23 | 19 | 29 | 24 | 24 |
| Edwards | -- | Summer | -- | 21 | 21 | 19 | 23 | 19 | 25 | 21 |
| Edwards | -- | Fall | -- | 21 | 21 | 23 | 19 | 29 | 24 | 24 |
| Minns | -- | Summer | -- | 42 | 48 | 43 | 36 | 47 | 46 | 55 |
| Minns | -- | Fall | -- | 48 | 58 | 49 | 45 | 58 | 57 | 67 |
| Hamilton | -- | -- | BEF | 21 | 23 | 21 | 19 | 29 | 18 | 26 |
| Hamilton | -- | -- | TRL | 21 | 19 | 19 | 21 | 21 | 23 | 21 |
| Edwards | -- | -- | BEF | 21 | 23 | 21 | 19 | 29 | 18 | 26 |
| Edwards | -- | -- | TRL | 21 | 19 | 19 | 21 | 21 | 23 | 21 |
| Minns | -- | -- | BEF | 43 | 50 | 49 | 37 | 56 | 53 | 58 |
| Minns | -- | -- | TRL | 44 | 55 | 51 | 49 | 32 | 44 | 57 |

Table 6. IBI scores for the St. Clair River sires based on 2012, 2014 summer and fall sampling using boat electrofishing (BEF) and benthic trawling (TRL).

| Method | Year | Season | Gear | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | $\mathbf{6}$ | $\mathbf{7}$ | $\mathbf{8}$ |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Hamilton | 2012 | -- | -- | 18 | 15 | 23 | 20 | 21 | 19 | 19 | 13 |  |
| Hamilton | 2014 | -- | -- | 17 | 21 | 17 | 17 | 17 | 15 | 19 | 15 |  |
| Edwards | 2012 | -- | -- | 17 | 15 | 23 | 19 | 21 | 19 | 19 | 13 |  |
| Edwards | 2014 | -- | -- | 17 | 21 | 17 | 17 | 17 | 15 | 19 | 15 |  |
| Minns | 2012 | -- | -- | 38 | 27 | 53 | 48 | 49 | 43 | 50 | 28 |  |
| Minns | 2014 | -- | -- | 26 | 32 | 35 | 28 | 29 | 40 | 28 | 31 |  |
| Hamilton | -- | Summer | -- | 21 | 17 | 19 | 20 | 19 | 17 | 19 | 15 |  |
| Hamilton | -- | Fall | -- | 18 | 15 | 23 | 22 | 19 | 19 | 19 | 11 |  |
| Edwards | -- | Summer | -- | 21 | 17 | 19 | 19 | 19 | 17 | 19 | 15 |  |
| Edwards | -- | Fall | -- | 17 | 15 | 23 | 21 | 19 | 19 | 19 | 11 |  |
| Minns | -- | Summer | -- | 32 | 29 | 37 | 36 | 39 | 37 | 40 | 32 |  |
| Minns | -- | Fall | -- | 38 | 33 | 58 | 56 | 44 | 39 | 45 | 15 | 21 |
| Hamilton | -- | -- | BEF | 18 | 19 | 25 | 24 | 27 | 21 | 27 | 15 | 24 |
| Hamilton | -- | -- | TRL | 21 | 17 | 17 | 17 | 17 | 15 | 17 | 13 | 19 |
| Edwards | -- | -- | BEF | 17 | 19 | 25 | 23 | 27 | 21 | 27 | 15 | 23 |
| Edwards | -- | -- | TRL | 21 | 17 | 17 | 17 | 17 | 15 | 17 | 13 | 19 |
| Minns | -- | -- | BEF | 30 | 41 | 43 | 42 | 48 | 44 | 37 | 23 | 52 |
| Minns | -- | -- | TRL | 37 | 29 | 46 | 44 | 36 | 39 | 46 | 34 | 54 |

Table 7. Sampling effort required in the Detroit River to decrease variance by 50\%, 75\%, 90\%, and $95 \%$ where IBI scores for years, seasons, and gears are pooled.

| Level of pooling | IBI method | Number of sites |  |  |  | n |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 50\% | 75\% | 90\% | 95\% |  |
| 2011 | Hamilton | 3 | 5 | 10 | 20 | 24 |
|  | Edwards | 3 | 5 | 10 | 20 | 24 |
|  | Minns | 2 | 4 | 10 | 15 | 24 |
| 2013 | Hamilton | 2 | 4 | 9 | 17 | 22 |
|  | Edwards | 2 | 4 | 9 | 17 | 22 |
|  | Minns | 3 | 6 | 13 | 23 | 22 |
| Summer | Hamilton | 3 | 5 | 12 | 19 | 23 |
|  | Edwards | 3 | 5 | 12 | 19 | 23 |
|  | Minns | 4 | 6 | 13 | 31 | 23 |
| Fall | Hamilton | 2 | 3 | 9 | 16 | 23 |
|  | Edwards | 2 | 3 | 9 | 16 | 23 |
|  | Minns | 2 | 4 | 8 | 16 | 23 |
| BEF | Hamilton | 2 | 4 | 9 | 15 | 24 |
|  | Edwards | 2 | 4 | 9 | 15 | 24 |
|  | Minns | 2 | 4 | 8 | 15 | 24 |
| TRL | Hamilton | 2 | 4 | 8 | 19 | 22 |
|  | Edwards | 2 | 4 | 8 | 19 | 22 |
|  | Minns | 3 | 4 | 9 | 18 | 22 |

Table 8. Sampling effort required in the St. Clair River to decrease variance by $50 \%, 75 \%, 90 \%$, and $95 \%$ where IBI scores for years, seasons, and gears are pooled.

| Level of pooling | IBI method | Number of sites |  |  |  | n |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 50\% | 75\% | 90\% | 95\% |  |
| 2012 | Hamilton | 3 | 7 | 11 | 28 | 32 |
|  | Edwards | 2 | 4 | 8 | 19 | 32 |
|  | Minns | 2 | 4 | 8 | 17 | 32 |
| 2014 | Hamilton | 3 | 4 | 9 | 17 | 16 |
|  | Edwards | 3 | 4 | 9 | 17 | 16 |
|  | Minns | 2 | 3 | 7 | 13 | 16 |
| Summer | Hamilton | 4 | 5 | 12 | 25 | 32 |
|  | Edwards | 3 | 5 | 12 | 20 | 32 |
|  | Minns | 3 | 4 | 12 | 21 | 32 |
| Fall | Hamilton | 3 | 5 | 11 | 20 | 16 |
|  | Edwards | 2 | 4 | 11 | 20 | 16 |
|  | Minns | 2 | 4 | 12 | 20 | 16 |
| BEF | Hamilton | 2 | 4 | 9 | 15 | 32 |
|  | Edwards | 2 | 3 | 9 | 17 | 32 |
|  | Minns | 2 | 4 | 9 | 17 | 32 |
| TRL | Hamilton | 2 | 5 | 10 | 15 | 32 |
|  | Edwards | 2 | 5 | 10 | 15 | 32 |
|  | Minns | 3 | 4 | 7 | 15 | 32 |



Figure 1. Sampling sites on the Detroit River, 2007, 2011, and 2013.


Figure 2. Sampling sites on the St. Clair River 2007, 2012, and 2014.


Figure 3. Detroit River IBI value variance in response to number of sampling sites for each IBI method in 2011 and 2013. A) 2011, Hamilton and Edwards.; B) 2011, Minns.; C) 2013, Hamilton and Edwards; D) 2013, Minns


Figure 4. Detroit River IBI value variance in response to number of sampling sites for each IBI method in summer and fall. A) Summer, Hamilton and Edward; B) Summer, Minns.; C) Fall, Hamilton and Edwards; D) Fall, Minns


Figure 5. Detroit River IBI value variance in response to number of sampling sites for each IBI method in BEF and TRL.
A) BEF, Hamilton and Edward; B) BEF, Minns; C) TRL, Hamilton and Edwards; D) TRL, Minns


Figure 6. St. Clair River IBI value variance in response to number of sampling sites for each IBI method in 2012 and 2014. A) 2012, Hamilton; B) 2012, Edwards.; C) 2012, Minns; D) 2014, Hamilton and Edwards; E) 2014, Minns


Figure 7. St. Clair River IBI value variance in response to number of sampling sites for each IBI method in summer and fall. A) Summer, Hamilton; B) Summer, Edwards; C) Summer, Minns; D) Fall, Hamilton; E) Fall, Edwards; F) Fall, Minns


Figure 8. St. Clair River IBI value variance in response to number of sampling sites for each IBI method in BEF and TRL. A) BEF, Hamilton; B) BEF, Edwards; C) BEF, Minns; D) TRL, Hamilton and Edwards; and E) TRL, Minns

