Fish Community Indices of Ecosystem Health: How does Toronto Harbour Compare to other Lake Ontario Nearshore Areas?

James A. Hoyle[1*], Christine M. Boston[2], Cindy Chu[3], Michael J. Yuille[1], Rick Portiss[4], Robert G. Randall[2]

[1]*Ontario Ministry of Natural Resources and Forestry, 41 Hatchery Lane, Picton, ON K0K 2T0*
[2]*Fisheries and Oceans Canada, 867 Lakeshore Road, Burlington, ON L7R 4A6*
[3]*Ontario Ministry of Natural Resources and Forestry, c/o Trent University, 2140 East Bank Drive, Peterborough ON K9L 1Z8*
[4]*Toronto and Region Conservation Authority, 5 Shoreham Drive, Downsview, ON M3N 1S4*
**Corresponding author: email* jim.hoyle@ontario.ca

Abstract

We assessed fish community status for 16 nearshore areas in Lake Ontario and the upper St. Lawrence River, from 2006 to 2016, using complementary fish sampling gear types and protocols, boat electrofishing and trap nets, and the published aquatic ecosystem health indicators associated with them. Factors influencing Indices of Biotic Integrity (IBI) scores included degree of exposure to the open-waters of Lake Ontario, effective fetch, and land cover and use in surrounding watersheds. Focusing on Toronto Harbour, we determined that IBI scores were lower (45.1 and 45.6 for electrofishing and trap net gear types respectively) than predicted (55.5 and 59.6) based on other Lake Ontario nearshore areas with similar physical/environmental conditions but seemed reasonable given the significant influence of Canada's largest urban area, the City of Toronto. The proportion of fish community biomass comprised of piscivores (0.21 and 0.18 for electrofishing and trap nets respectively) approached target levels (0.20) for the Toronto Harbour fish community, and indicated a balanced trophic structure. On-going aquatic habitat remediation and creation projects on the Leslie Street Spit (including Tommy Thompson Park) and the Toronto Islands, should ensure maintenance or improvement in IBI scores and aquatic ecosystem health generally.

Key words: Toronto Harbour, Lake Ontario, Index of Biotic Integrity, electrofishing, trap netting

Introduction

The Toronto region is a Great Lakes Area of Concern (AOC), one of 43 designated under the 1987 Great Lakes Water Quality Agreement between Canada and the United States (http://www.ec.gc.ca/raps-pas/). Local management agencies, municipalities, and non-government organizations engaged in a Remedial Action Plan (RAP) to restore Toronto's aquatic habitat, are working to complete all restoration actions by 2020 in efforts to delist the AOC status (TRCA 2016). Beneficial use impairments (BUIs) in the Toronto AOC include degradation of local fish populations. The Toronto Harbour area (Fig.1) historical resident fish community was dominated by cool and warmwater species of fish including Northern Pike, Walleye, Largemouth Bass, Yellow Perch, and Sunfish (Whillans 1979)—typical of fish communities in other Lake Ontario embayments and nearshore areas (Hoyle et al., 2012). Recent work indicated that Walleye, Smallmouth Bass, Rock Bass were depressed, and Gizzard Shad and generalist species, Common Carp and Brown Bullhead, were elevated compared to unimpaired embayments (Hoyle and Yuille, 2016; Bowlby and Hoyle, 2017). Fish populations were impaired due to aquatic habitat loss and water quality issues related to the activities of a large urban center, the City of Toronto (population 2.7 million and over 6 million in the Greater Toronto Area in 2016). Efforts to rehabilitate the fish community have included extensive and on-going aquatic habitat restoration and creation projects. In this paper we provide a contribution toward critical evaluation of the contemporary Toronto Harbour fish community status.

To evaluate fish communities specifically and aquatic ecosystem health generally, we employed two published indices of biotic integrity (IBIs). The first IBI was developed by Minns et al. (1994) to assess nearshore fish communities in Great Lakes' AOCs using standard boat electrofishing sampling. The second IBI was developed by Hoyle and Yuille (2016) to assess Lake Ontario/upper St. Lawrence River nearshore fish communities using a Provincial standard trap net sampling protocol. The fish community metrics used to calculate IBIs for these two sampling methods are similar. However, the advantage of using these two different gear types is that fish size and species selectivity influences should be less than with a single gear type, and that this would result in a more robust fish community assessment (Beck and Hatch, 2009).

Our primary objective was to provide a basis for assessment of the contemporary Toronto Harbour area fish community. We used a comparative approach, contrasting Toronto to other Lake Ontario nearshore areas that varied in their: degree of exposure to the open waters of Lake Ontario, fetch within each area, and land cover and use in their respective watersheds. We explored how this variability among nearshore areas related to our IBI measurements with the two gear types and methodologies. A secondary objective was to compare fish community health associated with two major habitat features within the Toronto Harbour area that differ in their degree of human-induced impacts: Tommy Thompson Park and the Toronto Islands.

Methods

Study Areas

Lake Ontario Nearshore Areas—fish community data were collected and reported here for a total of 16 different areas. Six areas were sampled using both electrofishing and trap net gear types: Hamilton Harbour, Toronto Harbour, West Lake, Prince Edward Bay, and the upper and middle Bay of Quinte. Four areas were sampled by electrofishing gear only: Port Dalhousie, Jordon Harbour, Bronte Shore and Frenchman's Bay. Six areas were sampled by trap net gear only: Presqu'ile Bay, Weller's Bay, East Lake, the lower Bay of Quinte, the North Channel and the Thousand Islands. We restricted our analysis to data collected from 2006 to 2016; months sampled included July to October. For electrofishing, only night-time sampling data were used.

Toronto Harbour—our fish community assessments of the Toronto Harbour were focused in the areas of Tommy Thompson Park and the Toronto Islands (Fig. 1). The aquatic habitats afforded by these embayment areas are most directly comparable to those found in the other Lake Ontario embayment and nearshore areas sampled, especially with respect to trap net sampling.

Electrofishing fish community sampling is available for other Toronto area locations and habitat types (i.e., open coastal and river mouth) but these data were not used here.

Tommy Thompson Park (Fig. 1) forms about 50% of a man-made peninsula, known as the Leslie Street Spit. The spit extends five km into Lake Ontario, is over 500 ha in size, and encloses the eastern side of Toronto Harbour. Construction of the spit began in the late 1950s and, since that time, it has been the site for the disposal of dredged material from Toronto Harbour and surplus fill from development sites within the City of Toronto. Rehabilitation of newly filled areas is led by The Toronto and Region Conservation Authority (TRCA), and involves a diversity of functional aquatic and terrestrial habitats (TRCA, 2017).

The Toronto Island complex is a series of islands located offshore of Toronto's city centre, and enclosing the west and southwest sides of Toronto Harbour (Fig. 1). The land mass has gone through extensive land reclamation and development over the past 150 years leading to its current 330 ha configuration. The Toronto Islands consist of a multitude of land use areas including recreational parkland, a commercial airport, and private residences leased from the city. The unique configuration of channels, lagoons, and embayments within the islands provides an important function for the integrity of the lake ecosystem, including the provision of fish spawning, foraging and nursery habitats (TRCA, 2014). Ongoing critical habitat restoration and naturalization projects on the islands are guided by the Toronto Waterfront Aquatic Habitat Restoration Strategy (AHT, 2003; ECCC, 2017).

Sampling Gear and Fish Community Indices

Fish communities were sampled following standardized protocols associated with two gear types—boat electrofishing (Brousseau et al., 2005; transect method developed and used by Fisheries and Oceans Canada (DFO) at the Great Lakes Laboratory for Fisheries and Aquatic Sciences, Burlington ON) and trap netting (Stirling, 1999; developed and used by the Ontario Ministry of Natural Resources and Forestry (MNRF)). Electrofishing involved the use of a 6.1 m Smith-Root electrofishing boat (pulsed DC, 120 pps and about 8 A output) that sampled 100 m line transects at about 1.5 m water depth in nearshore habitat. All fish were identified to species and up to 20 individuals per species were measured for length and weight; after 20, fish were counted and bulk weighed (Brousseau et al., 2005). Nearshore community index netting (NSCIN) is an Ontario provincial standard method for sampling aquatic littoral area fishes using 6 ft (1.83 m) trap nets (Stirling 1999). NSCIN uses a random selection of trap net sampling sites within the geographic area of interest. Sampling occurs in mid to late summer. For each trap net (24 hr set), fish species were identified and enumerated. Either all fish or a random sample of fish, for abundant species, were measured for length and weight. Indices of biotic integrity (IBIs), and the fish community metrics associated with them (Appendix 1), were calculated following Minns et al. (1994) and Hoyle and Yuille (2016) for these two gears. IBI calculations for the two gear types share 10 fish assemblage attribute metrics: the number of native, non-native and centrarchid species, the percent piscivore, generalist and specialist biomass, the number and biomass of native individuals, and percent non-native numbers and biomass. In addition, the electrofishing IBI includes the number of intolerant and native cyprinid species, and the trap net IBI includes the number of piscivore species (Appendix 1).
Toronto Harbour – Electrofishing at the Toronto Harbour was conducted by TRCA following a different sampling protocol (i.e., based on a sampling time of 1000 s) than that of Brousseau et al. (2005; based on a sampling distance of 100 m). Therefore, fish community metric and IBI conversion factors were developed to adjust the TRCA electrofishing results to reflect DFO equivalents. Calibration of fish community metrics comprising the IBI was carried out using data collected during 2011 to 2013. Calibration equations, developed using least squares regression, for each metric were applied to TRCA 1000 s data to convert those data into DFO 100 m equivalents. Metric standardization equations from Minns et al. (1994, Table 3) were subsequently applied to the estimated 100 m fish community metrics, and ultimately used to estimate 100 m IBI values (Hatry et al. In prep).

Physical and Environmental Variables

Land cover and Land Use—Quaternary watershed land cover and land use were used to quantify different human activities in the watersheds surrounding the nearshore sampling areas. All electrofishing and trap net sampling sites within our 16 nearshore areas, were mapped onto Lake Ontario shoreline layers (Wang et al., 2015) using ArcGIS®10.1 (Environmental Systems Research Institute, Redlands, California). Quaternary watersheds (Ontario Ministry of Natural Resources and Forestry (OMNRF, 2010) were chosen because they delineate the major influx of water to the sites via tributaries as well as overland flow draining directly into the nearshore. The watersheds were spatially joined to the Ontario Land Cover Classification V.2 (OMNRF, 2014) shapefile and zonal statistics were used to summarize land cover and use within the watersheds. There were 18 land cover and use variables each representing a proportion of watershed area. Sites were matched to the nearest watershed boundary and land cover and use from the associated watershed were assigned to each sampling site. Sampling sites within the same watershed had the same land cover and land use characteristics. Average values among sites were used to represent land cover and land use conditions within each of our 16 nearshore sampling areas.
Fetch— using the Waves toolbox in ArcGIS (Rohweder et al., 2012), effective fetch was calculated for each sampling site as a weighted average of the distances from a site across the embayment or lake area to

shore given the prevailing winds. Wind data from OMNRFs Renewable Energy Atlas (OMNRF 2017) was used to determine the prevailing winds in Lake Ontario. Wind directions were similar among the different regions of Lake Ontario, therefore an average wind rose was generated and applied to all of the sites to estimate effective fetch.

Exposure Index—The exposure index developed by Bowlby and Hoyle (2017) was used here to quantify the degree of exposure to and potential influence of Lake Ontario (e.g., cold water intrusions) on the aquatic habitats and fish communities of our nearshore sampling areas. For sampling areas at least somewhat sheltered from the open waters of Lake Ontario (14 of 16 nearshore areas sampled), exposure index was calculated as surface area of the embayment divided by the distance across the opening of the embayment exposed to Lake Ontario.

Data Analysis

Analysis of variance (ANOVA) was used to test for differences in IBI scores (arcsine transformed) among geographic areas sampled (StatSoft Inc., 2007). Tukey post-hoc comparisons identified areas with non-significant differences in IBI scores. We explored potential sources of variation among IBIs, due to physical and environmental differences among our sampling areas across Lake Ontario. A principal components analysis (PCA) was used to reduce 18 land cover and use variables to a few principle component factors for use as predictor variables (Quinn and Keough, 2002). General linear models were used to test the effects of land cover and use (first two principle components), fetch, and exposure to Lake Ontario, on IBIs for all geographic nearshore areas sampled. Best models to help explain variation in IBIs were selected based on lowest Akaike Information Criteria values (Quinn and Keough, 2002).

IBIs at sites in and associated with Tommy Thompson Park were compared to those of Toronto Island sites. A two factor ANOVA was used to test the effects of geographic location and sampling year on arcsine transformed IBI scores.

Results

Physical/Environmental Attributes of Study Areas

Fish communities were sampled and assessed in 16 nearshore areas in Lake Ontario and the upper St. Lawrence River and included three AOCs: Hamilton Harbour, Toronto Harbour, and the Bay of Quinte (Table 1). The nearshore areas ranged in their degree of exposure to the open-waters of Lake Ontario. West Lake and East Lake were highly sheltered, while Toronto Harbour and Prince Edward Bay were highly exposed to the open-waters of Lake Ontario. The Lower Bay of Quinte and North Channel represented a vast transitional area from the Bay of Quinte to the Thousand Islands area of the upper St. Lawrence River. Also sampled (electrofishing gear only) were two areas of open-coastal Lake Ontario areas: Port Dalhousie and Bronte Shore. Effective fetch within each nearshore area ranged from 0.63 km for Jordan Harbour to 8.11 km in the North Channel. Land cover and use in the watersheds surrounding nearshore areas also ranged widely. For example, the proportion of the watersheds comprised of built-up infrastructure ranged from 0% for West Lake to 85% for the Toronto Harbour (Table 1).

Sampling and Fish Community Attributes

Ten nearshore areas were sampled with boat electrofishing gear. The number of years sampled ranged from one year in Frenchman’s Bay to 10 years in the Toronto Harbour, and the number of electrofishing samples ranged from seven in Frenchman’s Bay to 469 in Hamilton Harbour. A total of 951 electrofishing samples were taken. Fish species comprising the highest contribution to electrofishing catches were Gizzard Shad, Common Carp, Brown Bullhead, Largemouth Bass and Yellow Perch (Appendix 2). Mean electrofishing IBI ranged from 28.5 at Bronte Shore to 72.5 on the Upper Bay of Quinte, and was 45.1 at the Toronto Harbour. Native species richness ranged from 1.7 at Port Dalhousie and Frenchman`s Bay to 7.9 on the Upper Bay of Quinte, and was 2.9 at the Toronto Harbour. Percent piscivore and specialist species biomass ranged from 5.0 (Bronte Shore) and 28.0 (Toronto Harbour) respectively, to 46.6 (Middle Bay of Quinte) and 83.7 (Frenchman`s Bay). Percent piscivore biomass was 20.9 at Toronto Harbour (Table 2).

Twelve nearshore areas were sampled with trap nets. The number of years sampled ranged from one year in the North Channel and the Thousand Islands to 10 in the Upper Bay of Quinte, and the number of trap net samples ranged from 25 on the Lower Bay of Quinte and North Channel to 360 on the Upper Bay of Quinte. A total of 1014 trap net samples were taken. Fish species comprising the highest contribution to trap net catches were Common Carp, Brown Bullhead, Channel Catfish, White Perch, Pumpkinseed and Bluegill (Appendix 2). Mean trap net IBI ranged from 45.6 at Toronto Harbour to 74.2 on East Lake. Native mean species richness ranged from 5.7 at Toronto Harbour to 9.9 in the Middle Bay of Quinte. Percent piscivore and specialist species biomass ranged from 13.3 (Hamilton Harbour) and 17.2 (Hamilton Harbour) respectively, to 45.2 (Weller`s Bay) and 57.1 (Upper Bay of Quinte). Percent piscivore and specialist species biomass were 17.9 and 29.1 at Toronto Harbour (Table 2).

For the six nearshore areas sampled with both electrofishing and trap nets during the 2006 to 2016 time-period (Table 2), IBI scores were highly correlated ($r = 0.99$, $p < 0.05$). Among IBI metrics, native species richness and percent piscivore biomass were each highly correlated between the two gear types ($r = 0.81$, $p < 0.05$ and $r = 0.88$, $p < 0.05$, respectively but percent specialist biomass was not ($r = 0.39$, $p > 0.05$).

Comparisons among Lake Ontario Nearshore Areas—IBI and community metrics

Significantly different IBIs were observed among nearshore areas for both electrofishing (ANOVA, $F_{(9,941)} = 58.92$ $p < 0.0001$) and trap nets (ANOVA, $F_{(11,987)} = 83.36$ $p < 0.0001$). Fig. 2 summarizes IBI scores for the nearshore areas with significantly different IBIs indicated (Tukey HSD test, alpha = 0.05). For electrofishing, Toronto Harbour IBI was not significantly different than Hamilton Harbour, Jordan Harbour, Frenchman's Bay or Port Dalhousie but was different than all other areas. For trap net gear, Toronto Harbour IBI was not significantly different than Hamilton Harbour but was significantly lower than all other areas (Fig. 2).

ANOVAs were used to test the effects of exposure and effective fetch on IBI scores among the nearshore areas sampled, excluding Hamilton Harbour and Toronto Harbour, the two AOC areas most impacted by urban development. For electrofishing areas, exposure did not have a significant effect on IBI scores. Fetch had a significant effect in the model ($F_{1,6} = 6.96$, $p < 0.04$). Areas with higher fetch had lower IBI scores. This model was then used to predict IBI at Hamilton Harbour and Toronto Harbour given observed exposure and fetch at these areas. Observed and predicted IBIs for Hamilton Harbour were 48.0 and 59.7, respectively, and 45.1 and 55.5 for Toronto Harbour. For trap net areas, both exposure and fetch were significant in the model ($F_{2,7} = 13.63$, $p < 0.004$). Areas with greater exposure or higher fetch had lower IBI scores. This model was then used to predict IBI at Hamilton Harbour and Toronto Harbour given observed exposure and fetch at these areas. Observed and predicted IBIs for Hamilton Harbour were 46.8 and 69.9, respectively, and 45.6 and 59.6 for Toronto Harbour.

Results of the PCA are included in Appendix 3. Land cover or use variables in areas sampled with electrofishing gear and contributing most greatly, were built-up infrastructure and sparse forest for principle component 1 (PC 1) and agriculture and mixed forest for PC 2. For areas sampled with trap nets it was built-up infrastructure and sand for PC 1 and hedge rows and swamp for PC 2.

Models were then developed (including Hamilton Harbour and Toronto Harbour data) to examine the contributions of: 1) exposure (trap net areas only), fetch, and built-up infrastructure; and 2) exposure, fetch, and the first two PCA factors describing land cover and use. Results are presented in Appendices 4 and 5. The highest ranked model (based on AIC) for both electrofishing and trap net gear types included both fetch and built-up infrastructure. Areas with greater built-up infrastructure had lower IBI scores. For trap netting, the second highest ranked model also included exposure (Appendix 4). For models including PC factors, the highest ranking model included fetch and PC 1 for electrofishing and included fetch, PC 1 and PC 2 for trap netting (Appendix 5).

Tommy Thompson versus Toronto Islands

A two factor ANOVA was used to test the effects of geographic location and sampling year on arcsine transformed IBI scores within Toronto Harbour. Neither sampling year nor the interaction between geographic area and sampling year was significant for either electrofishing or trap net IBIs. Geographic area significantly affected IBI scores for both gear types. Electrofishing IBI scores were significantly higher for the Toronto Islands (50.8) than for Tommy Thompson Park (40.2, $F_{(1,198)} = 46.5$ $p < 0.0001$). Similarly, trap net IBI scores were also significantly higher for the Toronto Islands (49.1) than for Tommy Thompson Park (43.5, $F_{(1,126)} = 3.94$ $p = 0.0492$).

Discussion

We now better understand some of the physical/environmental factors influencing electrofishing and trap net IBI scores in Lake Ontario nearshore areas. Variation in IBI scores among the Lake Ontario and upper St. Lawrence River nearshore areas sampled here was significantly related to both exposure to the open-waters of Lake Ontario and to effective fetch within each sampling area. Generally, a greater degree of exposure is associated with lower IBI scores (Hoyle and Yuille 2016). Degree of exposure to Lake Ontario is positively related to the amount of water exchange between the open-lake and embayment and sheltered nearshore areas (Bowlby and Hoyle 2017), and in turn influences water quality and the productivity of the aquatic community including vegetation, zooplankton, benthic invertebrates and fish (Murphy et al., 2011; Murphy et al., 2012). Similarly, higher average effective fetch within our nearshore sampling areas was associated with lower IBI scores. The physical disturbance of wind and wave action influences aquatic habitat in nearshore areas. Nearshore areas with higher fetch are more disturbed with less fine sediments and vegetation (Brousseau et al., 2011; Randall et al., 2012; Chu et al., 2014; Schall et al., 2017). Such areas would tend to have lower IBI scores.

Understanding the factors influencing our IBI scores specifically and aquatic ecosystem health generally, may help to assess human-induced impacts. Above and beyond the influences of physical/environmental factors, human-induced impacts associated with the alteration of shoreline and watershed habitats also influenced our IBI scores. Variables associated with land cover and use, particularly built-up infrastructure, significantly affected IBI scores. Nearshore areas surrounded by urban areas, like the City of Toronto, have lower IBI scores than predicted by a consideration of natural physical/environmental factors alone. Observed contemporary IBI scores at Toronto Harbour were lower (45.1 and 45.6 for electrofishing and trap netting, respectively) than predicted by models that considered the influence of exposure and fetch (IBI = 55.5 and 59.6). The potential of achieving the higher (e.g. predicted) scores at Toronto in the future through on-going remedial actions, given the degree of urban development, is difficult to assess. Of significance however, within the Toronto Harbour area, we found higher IBI scores for the Toronto Islands (50.8 and 49.1 for electrofishing and trap netting respectively) than for Tommy Thompson Park (40.2 and 43.5 respectively)—this is not surprising. Tommy Thompson Park is comprised entirely of re-claimed and restored land and aquatic habitats. Habitat creation projects are on-going and the potential for increased aquatic ecosystem health and IBI scores is high, possibly exceeding those of the Toronto Islands.

The role of piscivores is positively and consistently related to aquatic ecosystem health (Hurley et al., 1986; Brousseau et al., 2011; Hoyle at al., 2012; Boston et al., 2016). Piscivores exert top-down control of prey species, including invasive species such as Alewife (Ridgway et al., 1990) and White Perch (Hurly, 1986), that may otherwise increase to nuisance abundance levels (Hoyle et al., 2016). A proportion of total fish community biomass comprised of piscivores less than 0.2 is associated with degraded aquatic ecosystems (Hurley et al., 1986). A Toronto RAP degraded fish populations BUI target for delisting is to achieve and maintain a proportion of piscivores greater than 0.2 in the Toronto waterfront area. Presently, the Toronto Harbour embayment habitat has proportion of piscivore values that ranged annually over the last decade from 0.15 to 0.46 (annual mean = 0.21) for electrofishing gear and from 0.11 to 0.30 (mean = 0.18) for trap nets. These piscivore levels are very close to achieving the desired 0.2 target level. A similar target was established and achieved on the Bay of Quinte AOC where fostering resurgence of native piscivore levels such as Walleye was considered critical to restore ecosystem health. Walleye abundance is currently very low in the Toronto Harbour and stocking this species is planned (Ontario Ministry of Natural Resources and Forestry, 2015) beginning in summer 2017. Walleye stocking may help advance fish community restoration, in the short to medium term, while the benefits of ongoing wetland and habitat restoration and creation efforts gradually come to fruition. These efforts in the Toronto AOC, including the development and use of carp exclusion barriers (e.g., see Toronto Waterfront Aquatic Habitat Restoration Strategy; http://aquatichabitat.ca/wp/about/twahrs/twahrs-strategy/), are seen as beneficial and may serve to increase the relative proportion of piscivores by decreasing over-abundant Common Carp abundance (Appendix 2 and Bowlby and Hoyle, In press).

Similar to having a piscivore target, the Toronto RAP degraded fish populations BUI target for specialist fish species is 0.4 or greater (proportion of fish community biomass). A high diversity of specialist species is considered to reflect a high diversity of healthy aquatic habitats. Here, we measured specialist proportions that ranged annually over the last decade from 0.16 to 0.43 (annual mean = 0.28) for electrofishing gear and from 0.22 to 0.37 (mean = 0.29) for trap nets. In addition to these specialist species levels being significantly less than the 0.4 target level, they are also inflated by the contribution of non-native specialist species; Alewife and White Perch. Alewife is an offshore pelagic species whose population is not likely dependent on habitat and fish community characteristics of the Toronto Harbour. In addition to being non-native, the White Perch is pollution tolerant and would negatively interact with native species by way of competition and predation, especially if hyper-abundant (Appendix 2 and Hoyle at el., 2012).

Most fish community assessments using IBIs involve a single gear type. The use of two gears types and their associated IBIs should yield more robust assessments (Beck and Hatch, 2009). We found that IBI scores measured by our two gear types were highly correlated for nearshore areas sampled by both gears. One of the differences between the two sampling gears used here is the spatial scale at which the two protocols were designed to sample. The trap net sampling protocol employs a random selection of sampling sites, and nets are set for a 24 hr period. Large and mobile fish can travel a long distance over this time-period and the effective sampling area for the gear is not known but probably on the order of several hundred meters of shoreline. Therefore, the protocol best samples and detects change or differences on the scale of small to medium sized lakes (Stirling 1999) or embayment areas (e.g., several thousand meters of shoreline). That is the scale of sampling and inference that we use for the purposes of the present work. By way of contrast, the boat electrofishing is an active gear sampling, in this case, a 100 m length of shoreline in a few minutes. The gear type can measure and evaluate fish communities and aquatic habitat at a finer spatial scale than the trap nets. Here, we treated the electrofishing sampling the same as the trap net sampling; average IBI values and environmental conditions were used to describe the entire geographic areas rather than individual sampling sites. Also electrofishing can sample a broader range of habitat types including the open-coastal waters of Lake Ontario; areas that are too exposed for the trap nets without risking equipment damage and loss. Studies to further quantify differences between electrofishing and trap net gear types, and thus help define the total breadth of their complementary nature to sample fish communities, are warranted. For example, fish abundance and size structure measured by the two gear types at the same time and locations could be compared. The electrofishing sampling protocol can measure fish density in a defined area; thus the potential exists to calibrate the two gear types to each other and to fish density.

Here we provided a basis for assessment of the contemporary Toronto Harbour area fish community using a comparative approach. The longer-term boat electrofishing monitoring conducted by the TRCA could provide the additional context of trend-through-time changes in the fish community and aquatic ecosystem, for example in response to remedial actions. In addition, this electrofishing monitoring includes broader geographic coverage and additional aquatic habitat types in the Toronto Waterfront area than those sampled here.

Conclusions

We assessed contemporary fish community status in the Toronto Harbour using complementary sampling gear types and protocols, boat electrofishing and trap nets, and the aquatic ecosystem health indicators associated with them. Toronto Harbour IBI scores were lower than predicted for other Lake Ontario nearshore areas with similar environmental conditions but seemed reasonable given the effects of nearby urban development and influences. Piscivore levels in the Toronto Harbour fish community approached target levels indicating a balance trophic structure. On-going aquatic habitat remediation and creation projects on the Leslie Street Spit (including Tommy Thompson Park) and the Toronto Islands, should ensure maintenance or improvement in IBI scores and aquatic ecosystem health generally.

Acknowledgements

We gratefully acknowledge the dedicated staff on DFO and TRCA electrofishing and OMNRF trap netting crews. We also acknowledge the comments and suggestions of two anonymous reviewers. Funding sources included Great Lakes Action Plan (DFO), Great Lakes Sustainability Fund (TRCA), and Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (COA, OMNRF).

References

Aquatic Habitat Toronto (AHT) 2003. Toronto Waterfront Aquatic Habitat Restoration Strategy (http://aquatichabitat.ca/wp/consultants/twahrs-document/).

Beck, M.W., Hatch, L.K., 2009. A review of research on the development of lake indices of biotic integrity. Environ. Rev. 17, 21–44.

Boston, C.M., Randall, R.G., Hoyle, J.A., Mossman, J.L, Bowlby, J.N., 2016. The fish community of Hamilton Harbour, Lake Ontario: Status, stressors, and remediation over 25 years. Aquat. Ecosyst. Health Manag. 19, 206-218.

Bowlby, J.N., Hoyle, J.A., 2017. Developing restoration targets for nearshore fish populations in two Areas of Concern in Lake Ontario. Aquat. Ecosyst. Health Manag. 20, 242-251.

Brousseau, C. M., Randall, R. G., Clark, M. G., 2005. Protocol for boat electrofishing in near shore areas of the lower Great Lakes: transect and point survey methods for collecting fish and habitat data, 1988 to 2002. Fisheries and Oceans Canada, Burlington, Ontario.

Brousseau, C.M., Randall, R.G, Hoyle, J.A., Minns, C.K., 2011. Fish community indices of ecosystem health: How does the Bay of Quinte compare to other coastal sites in Lake Ontario? Aquat. Ecosyst. Health Manag. 14, 75-84.

Chu, C. Koops, M.A., Randall, R.G., Kraus, D., Doka, S.E., 2014. Linking the land and the lake: a fish habitat classification for the nearshore zone of Lake Ontario. Freshw. Sci. 33, 1159–1173.

ECCC (Environment and Climate Change Canada), 2017. Restoring degraded shorelines on the Toronto Islands. Available at: https://www.ec.gc.ca/raps-pas/default.asp?lang=En&n=C9C5AB69-1. Accessed May 2017.

Hoyle, J.A., Yuille, M.J., 2016. Nearshore fish community assessment on Lake Ontario and the St. Lawrence River: A trap net-based index of biotic integrity. J. Great Lakes Res. 42, 687-694.

Hoyle, J.A., 2015. Fish species composition, distribution and abundance trends in the open coastal waters of northeastern Lake Ontario, 1992–2012. Aquat. Ecosyst. Health Manag. 18, 89-100.

Hoyle, J.A., Bowlby, J.N., Brousseau, C.M., Johnson, T.B., Morrison B.J., Randall. R.G., 2012. Fish community structure in the Bay of Quinte, Lake Ontario: The influence of nutrient levels and invasive species. Aquat. Ecosyst. Health Manag.15, 370-384.

Hurley, D.A., 1986. Fish populations in the Bay of Quinte, Lake Ontario, before and after phosphorus control. In: Minns, C.K., Hurley, D.A., Nichols, K.H. (Eds.), Project Quinte: Point Source Phosphorus Control and Ecosystem Response in the Bay of Quinte. Can. Spec. Publi. Fish, Aquat. Sci., Lake Ontario 86, pp. 201–214.

Hurley, D.A., Christie, W.J., Minns, C.K., Millard, E.S., Cooley, J.M., Johnson, M.G., Nicholls, K.H., Robinson, G.W., Owen, G.E., Sly, P.G., Geiling, W.T., Crowder, A.A., 1986. Trophic structure and interactions in the Bay of Quinte, Lake Ontario, before and after point source phosphorus control. In: Minns, C.K., Hurley, D.A., Nichols, K.H. (Eds.), Project Quinte: Point Source Phosphorus Control and Ecosystem Response in the Bay of Quinte. Can. Spec. Pub. Fish. Aquat. Sci., Lake Ontario 86.

Minns, C.K., Cairns, V.W., Randall, R.G., Moore, J.E., 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, 1804–1822.

Murphy, S.C., Collins, N.C., Doka, S.E., 2011. Thermal habitat characteristics for warmwater fishes in coastal embayments of Lake Ontario. J. Great Lakes Res. 37,111–123.

Murphy, S.C., Collins, N.C., Doka, S.E., 2012. The effects of cool and variable temperatures on the hatch date, growth and overwinter mortality of a warmwater fish in small coastal embayments of Lake Ontario. J. Great Lakes Res. 38, 404-412.
OMNRF (Ontario Ministry of Natural Resources and Forestry), 2010. Quaternary Watershed layer. Ontario Ministry of Natural Resources and Forestry - Provincial Mapping Unit. Available at: https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=7a99025f-b894-4b8c-97c4-60f830fa1acc. Accessed January 15 2017.
OMNRF, 2014. Ontario Land Cover Compilation Data Specifications Version 2.0. Peterborough, Ontario. 19 p. Available at: https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/metadata.show?id=14540&currTab=distribution. Accessed Jan 3 2017.
OMNRF, 2015. Lake Ontario fish communities and fisheries. 2014 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario, Canada. Available at: http://www.glfc.org/lakecom/loc/mgmt_unit/index.html Accessed October 28, 2017.
OMNRF, 2017. Renewable Energy Atlas. Available at: http://www.gisapplication.lrc.gov.on.ca/REA/Renewable.html?site=REA&viewer=REA&locale=en-US. Accessed Jan 25 2017.
Quinn, G.P., Keough, M.J., 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge.
Randall, R.G., Brousseau, C.M., Hoyle, J.A., 2012. Effect of aquatic macrophyte cover and fetch on spatial variability in the biomass and growth of littoral fishes in bays of Prince Edward County, Lake Ontario. Aquatic Ecosystem Health & Management 15:385-396.
Ridgway, M.S., Hurley, D.A., Scott, K.A., 1990. Effects of winter temperature and predation on the abundance of Alewife (*Alosa pseudoharengus*) in the Bay of Quinte, Lake Ontario. J. Great Lakes Res. 16, 11–20.
Rohweder, J., Rogala, J. T., Johnson, B. L., Anderson, D., Clark, S., Chamberlin, F., Potter, D., Runyon, K., 2012. Application of Wind Fetch and Wave Models for Habitat Rehabilitation and Enhancement Projects – 2012 Update. Contract report prepared for U.S. Army Corps of Engineers' Upper Mississippi River Restoration – Environmental Management Program. 52 p.
Schall, B.J., Cross, T.K, Katzenmeyer, E., Zentner, D.L., 2017. Use of wind fetch and shoreline relief to predict nearshore substrate composition in a north temperate lake. N. Amer. J. Fish. Manag. DOI:10.1080/02755947.2017.1336135.
Stirling, M., 1999. Manual of Instructions: Fish Community Index Netting (NSCIN). Ontario Ministry of Natural Resources. Lake Simcoe Fisheries Assessment Unit.
TRCA (Toronto and Region Conservation Authority), 2014. Don Mouth Naturalization and Port Lands Flood Protection Project Amended Environmental Assessment Report. Toronto and Region Conservation Authority, 5 Shoreham Drive, Toronto, Ontario M3N 1S4.
TRCA, 2016. Within Reach: 2015 Toronto and Region Remedial Action Plan Progress Report. Toronto and Region Conservation Authority, 5 Shoreham Drive, Toronto, Ontario M3N 1S4.
TRCA, 2017. Tommy Thompson Park: Toronto's Urban Wilderness. Available at: http://www.tommythompsonpark.ca/. Accessed May 2017.
Wang, L., Riseng, C.M., Mason, L.A. Wehrly, K.E., Rutherford, E.S., McKenna, J.E. Jr., Castiglione, C. Johnson, L.B. Infante, D.M., Sowa. S., Robertson, M., Schaeffer, J., Khoury, M., Gaiot, J., Hollenhorst, T., Brooks, C., Coscarelli, M., 2015. A spatial classification and database for management, research, and policy making: The Great Lakes aquatic habitat framework. J. Great Lakes Res. 41(2): 584-596. http://dx.doi.org/10.1016/j.jglr.2015.03.017
Whillans, T. H., 1979. Historic transformations of fish communities in three Great Lakes bays. J. Great Lakes Res. 5, 195–215.

Table 1. Physical attributes of 16 nearshore areas in Lake Ontario and the upper St. Lawrence River. Areas are sorted geographically from Port Dalhousie in southwestern Lake Ontario, north and east to eastern Lake Ontario and the Thousand Islands in the upper St. Lawrence River. AOC=Great Lakes Area of Concern. See text for definitions of "exposure index", "effective fetch", and "built-up infrastructure".

Nearshore area	AOC?	Major habitat type	Surface area (km^2)[1]	Exposure index[1]	Effective fetch (km)	Built-up infrastructure
Port Dalhousie		coastal	n/a	n/a	5.75	36.9%
Jordan Harbour		sheltered	1.2	16	1.82	9.5%
Hamilton Harbour	AOC	sheltered	21	4	1.36	48.0%
Bronte Shore		coastal	n/a	n/a	7.03	19.6%
Toronto Harbour	AOC	exposed	14	137	2.11	85.1%
Frenchman's Bay		sheltered	0.9	46	0.63	41.3%
Presqu'ile Bay		exposed	10	75	1.91	8.3%
Weller's Bay		sheltered	19	5	1.10	2.5%
West Lake		sheltered	19	1.4	1.06	0.0%
East Lake		sheltered	12	1.8	0.84	3.6%

Prince Edward Bay		exposed	102	91	1.61	0.1%
Upper Bay of Quinte	AOC	sheltered	129	8	1.45	2.2%
Middle Bay of Quinte	AOC	sheltered	63	14	0.96	1.1%
Lower Bay of Quinte	AOC	exposed	75	73	2.41	1.5%
North Channel		exposed	189	46	8.11	8.9%
Thousand Islands		riverine	205	25	3.15	3.5%

[1] not applicable (n/a) to open-coastal habitats

Table 2. Sampling (total number of samples and years) and fish community attribute (annual mean and range for IBI, number of native species, piscivore and specialist biomass) statistics for two gear types (boat electrofishing and trap netting) in 16 nearshore areas sampled from 2006 to 2016.

Nearshore area	Number of samples	Number of years	IBI	Native species richness	Piscivore biomass (%)	Specialist biomass (%)
Boat Electrofishing						
Port Dalhousie	19	2	32.7 (32-33)	1.7	5.9	62.3
Jordan Harbour	28	3	41.6 (41-42)	2.6	19.4	58.0
Hamilton Harbour	469	7	48.0 (40-52)	4.7	15.6	40.8
Bronte Shore	37	4	28.5 (22-40)	2.2	5.0	36.2
Toronto Harbour	**200**	**10**	**45.1 (40-49)**	**2.9**	**20.9**	**28.0**
Frenchman's Bay	7	1	41.8	1.7	13.9	83.7
West Lake	26	4	69.8 (67-79)	7.5	35.0	36.7
Prince Edward Bay	24	2	66.6 (64-73)	5.6	44.6	32.7
Upper Bay of Quinte	122	4	72.5 (67-78)	7.9	40.7	43.6
Middle Bay of Quinte	19	2	70.9 (65-83)	7.3	46.6	36.3
Trap netting						
Hamilton Harbour	163	7	46.8 (43-50)	7.2	13.3	17.2
Toronto Harbour	**143**	**6**	**45.6 (41-51)**	**5.7**	**17.9**	**29.1**
Presqu'ile Bay	28	2	64.1 (63-65)	7.2	36.3	27.8
Weller's Bay	48	2	67.6 (67-68)	6.5	45.2	43.3
West Lake	42	2	68.7 (68-70)	7.5	35.9	43.1
East Lake	34	2	74.2 (74-75)	7.8	40.5	39.5
Prince Edward Bay	51	2	61.4 (59-64)	6.5	39.4	23.8
Upper Bay of Quinte	360	10	71.0 (66-75)	8.9	28.2	57.1
Middle Bay of Quinte	59	2	70.8 (68-74)	9.9	31.8	50.1
Lower Bay of Quinte	25	2	66.7 (66-68)	7.2	33.8	53.8
North Channel	25	1	57.1	5.8	26.3	34.7
Thousand Islands	36	1	62.7	8.0	23.7	24.2

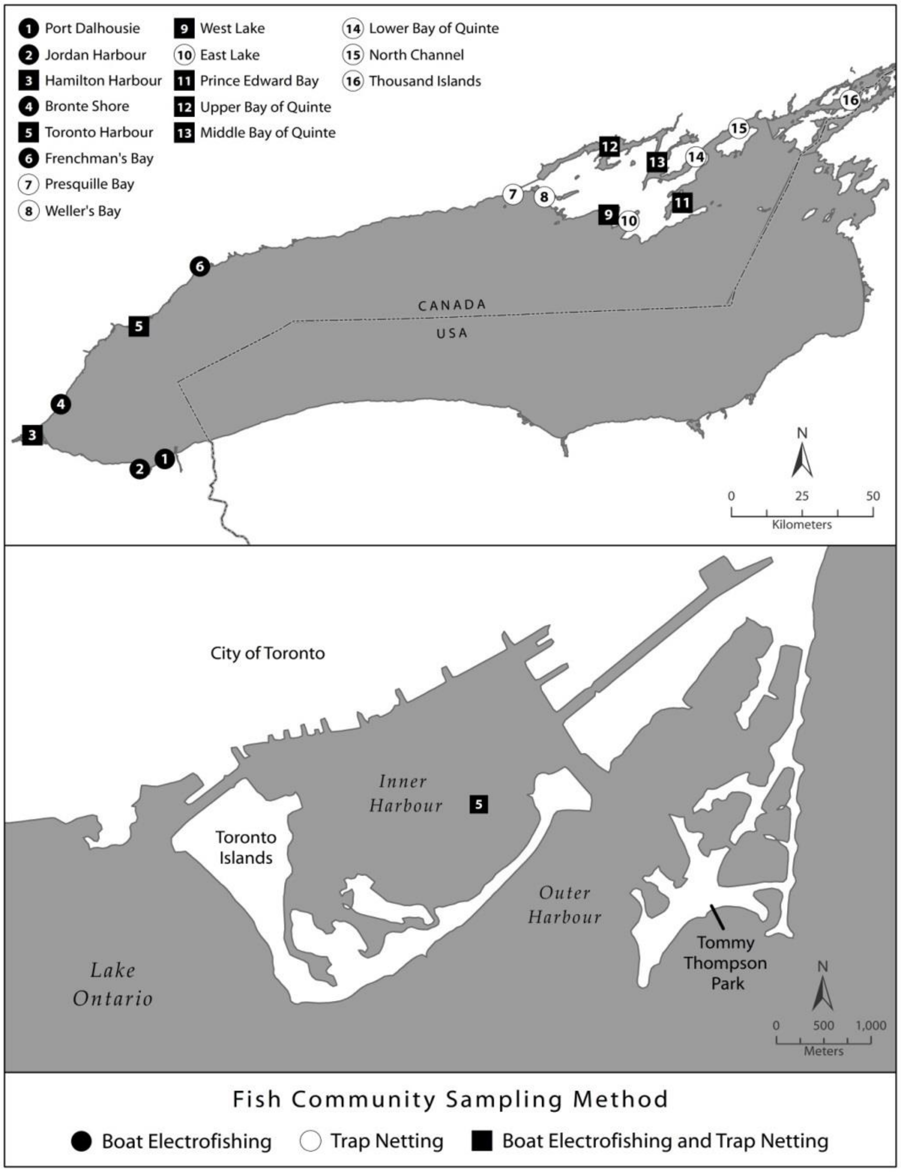

Fig. 1. Map of Lake Ontario and Thousand Islands area of the upper St. Lawrence River (upper panel) and the Toronto Harbour area (lower panel). All nearshore areas sampled with boat electrofishing and/or trap netting gears types are indicated. The lower panel shows the City of Toronto's inner and outer harbour areas, Tommy Thompson Park (southern part of the Leslie Street Spit) and the Toronto Islands.

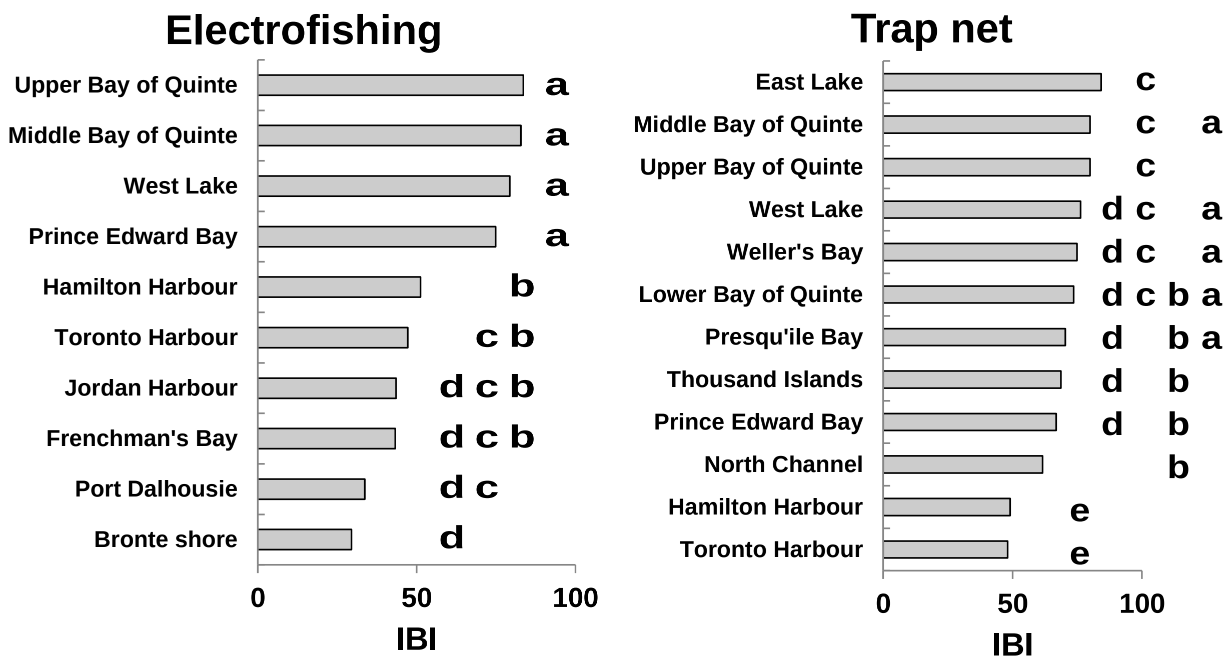

Fig. 2. Index of biotic integrity (IBI) at 16 Lake Ontario nearshore areas sampled with electrofishing (left panel) and/or trap net (right panel) gear types (horizontal shaded bars). Vertical lines of letters group areas that are not significantly different (Tukey test, p>0.05).

Appendix 1. Descriptions of 13 metrics used to calculate IBI for two gear types, electrofishing (12 metrics) and trap nets (11 metrics), grouped by three fish assemblage attributes. Metrics described in detail by Minns et al. (1994) and Hoyle and Yuille (2016).

Fish assemblage attribute		IBI metric description	Gear type: Electrofishing	Gear type: Trap net
Species richness				
	1	Number of native species	x	x
	2	Number of non-native species	x	x
	3	Number of centrarchid species	x	x
	4	Number of intolerant species	x	
	5	Number of native cyprinid species	x	
	6	Number of piscivore species		x
Trophic structure				
	7	Percent piscivore biomass	x	x
	8	Percent generalist biomass	x	x
	9	Percent specialist biomass	x	x
Abundance/biomass				
	10	Number of native individuals	x	x
	11	Biomass of natives	x	x
	12	Percent non-native numbers	x	x
	13	Percent non-native biomass	x	x

Appendix 2. Species-specific catch (number per trap net or electrofishing transect) and biomass (kg) for selected most common species in three AOCs: Hamilton Harbour, Toronto Harbour, and the Upper Bay of Quinte from 2006 to 2016. The 14 and 16 species shown for electrofishing and trap nets respectively, include the top five species (bold) by number and biomass from each AOC.

Species	Hamilton Harbour Catch	Hamilton Harbour Biomass	Toronto Islands Catch	Toronto Islands Biomass	Upper Bay of Quinte Catch	Upper Bay of Quinte Biomass
Electrofishing:						
Bowfin	0.07	140.14	0.43	**929.73**	0.19	378.91
Alewife	1.54	57.95	**17.47**	392.32	1.43	46.79
Gizzard Shad	**2.41**	**873.63**	3.50	**872.97**	0.42	45.13
Chinook Salmon	0.05	109.03	2.09	**1,462.35**	-	-
Goldfish	0.77	**263.46**	-	-	-	-
Common Carp	0.68	**2,444.82**	1.57	**9,362.06**	0.18	**938.10**
Emerald Shiner	**2.84**	7.44	**5.41**	16.94	0.08	0.07
Brown Bullhead	**2.09**	**716.92**	2.15	**662.97**	2.19	**408.91**
Pumpkinseed	0.75	18.94	**9.50**	133.79	**4.12**	106.59
Bluegill	1.22	29.42	-	-	**7.63**	241.13
Largemouth Bass	**1.96**	**364.16**	**8.48**	537.56	**4.28**	**1,295.19**
Yellow Perch	**1.74**	77.83	**13.24**	465.14	**25.42**	**530.03**
Walleye	0.06	36.00	-	-	0.99	**465.38**
Logperch	1.07	9.42	-	-	**2.41**	16.65
Trap net:						
Bowfin	1.31	**3.94**	0.33	1.09	0.81	2.30
Alewife	2.13	0.08	**6.04**	0.14	-	-
Northern Pike	0.69	1.44	1.19	**2.69**	0.46	0.72
White Sucker	0.57	0.23	2.54	**3.35**	0.60	0.61

Common Carp	**2.91**	**6.25**	**3.22**	**12.52**	0.24	0.88
Brown Bullhead	**352.60**	**95.22**	**81.04**	**27.75**	**7.86**	**2.59**
Channel Catfish	**20.53**	**35.64**	0.08	0.29	0.50	1.42
White Perch	**94.19**	**13.06**	0.22	0.05	4.43	0.67
Rock Bass	1.55	0.22	**3.22**	0.40	3.84	0.52
Pumpkinseed	1.28	0.06	**10.45**	0.56	**26.03**	2.31
Bluegill	**9.66**	0.77	1.67	0.13	**81.70**	**6.35**
Black Crappie	0.54	0.09	0.56	0.08	**8.56**	1.89
Largemouth Bass	0.20	0.13	1.65	0.37	**4.53**	1.31
Yellow Perch	1.12	0.14	**6.08**	0.35	4.33	0.32
Walleye	1.50	2.35	0.15	0.31	2.36	**2.62**
Freshwater Drum	1.27	1.80	0.90	**2.22**	1.37	1.70

Appendix 3. Contribution (proportion based on correlations) of each of 18 land cover and use variable to first two principle components for nearshore areas sampled by two gear types, electrofishing and trap nets.

	Electrofishing Areas		Trap Net Areas	
Land cover or use variable	PC 1	PC 2	PC 1	PC 2
Aggregate extraction	0.004	0.200	0.015	0.006
Alvar	0.062	0.051	0.054	0.045
Bog	0.019	0.001	0.021	0.003
Fen	0.094	0.001	0.073	0.025
Marsh	0.072	0.004	0.024	0.122
Agriculture	0.061	**0.184**	0.117	0.050
Built-up infrastructure	**0.123**	0.049	**0.141**	0.080
Swamp	0.002	0.002	0.001	**0.169**
Dense deciduous forest	0.032	0.000	0.035	0.004
Dense coniferous forest	0.025	0.110	0.012	0.041
Mixed forest	0.079	**0.149**	0.074	0.003
Plantations	0.074	0.011	0.009	0.019
Hedge rows	0.042	0.000	0.040	**0.182**
Sand	0.064	0.029	**0.140**	0.031
Open cliff	0.002	0.087	0.000	0.000
Tall grass woodland	0.048	0.052	0.114	0.087
Open water	0.077	0.035	0.005	0.097
Sparse forest	**0.120**	0.034	0.127	0.036

Appendix 4. Models for IBI scores measured by electrofishing and trap net gear types in 16 Lake Ontario nearshore areas to assess the effects of exposure, fetch, and built-up infrastructure. Shown for each model is Akaike's information criterion (AIC), and the difference between each model AIC and that of the model with the lowest AIC (Delta AIC). All models with a Delta AIC less than seven are shown.

Gear type	Model rank	Var. 1	Var. 2	Var. 3	AIC	Delta AIC
Electrofishing						
	1	Fetch	Infrastructure	n/a	76.09	0.00
	2	Fetch		n/a	81.24	5.15
	3	Infrastructure		n/a	82.86	6.77
Trap net						
	1	Fetch	Infrastructure		70.37	0.00
	2	Exposure	Fetch	Infrastructure	71.77	1.39

3	Infrastructure		73.83	3.46
4	Exposure	Infrastructure	74.51	4.14

Appendix 5. Models for IBI scores measured by electrofishing and trap net gear types in 16 Lake Ontario nearshore areas to assess the effects of exposure, fetch, and two PCA factors describing 19 land cover and use variables. Shown for each model is Akaike's information criterion (AIC), and the difference between each model AIC and that of the model with the lowest AIC (Delta AIC). All models with a Delta AIC less than seven are shown.

Gear type	Model rank	Var. 1	Var. 2	Var. 3	Var. 4	AIC	Delta AIC
Electrofishing							
	1	Fetch	PC 1			67.36	0.00
	2	Fetch	PC 1	PC 2		69.15	1.79
Trap net							
	1	Fetch	PC 1	PC 2		76.98	0.00
	2	Exposure	Fetch	PC 1	PC 2	78.95	1.97
	3	PC 1	PC 2			80.06	3.08
	4	Exposure	PC 1	PC 2		81.83	4.85