Mark-Recapture Population Estimates of Piscivores in the Hamilton Harbour Area of Concern

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by

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ABSTRACT

Larocque, S.M., Piczak, M.L., Turner, N.A., Bowman, J.E., Boston, C.M., Midwood, J.D. 2023. Mark-recapture population estimates of piscivores in the Hamilton Harbour Area of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3506: vii + 31 p.

One goal of the remedial action plan in Hamilton Harbour is to re-establish a mesotrophic fish community with healthy populations of top predators. A Capture-Mark-Recapture study assessed population abundances of top predators in Hamilton Harbour from Passive Integrated Transponder tagged fish captured during boat electrofishing surveys and at the Cootes Paradise Fishway. Five species were captured, tagged, and recaptured during 2017 – 2021 to estimate population abundances and growth rates. Walleye (*Sander vitreus*) and Largemouth Bass (*Micropterus salmoides*) population abundance estimates were the largest of the five species; however, Walleye emigration reduced estimate accuracy. Bowfin (*Amia calva*) had high use of Cootes Paradise, yet intermixing between sampling methods suggests harbour-wide movements. Both sampling methods captured different portions of the Northern Pike (*Esox lucius*) population. Lastly, Smallmouth Bass (*Micropterus dolomieu*) revealed a small, highly localized population within the harbour. For all species, the estimated density of fish within the harbour was lower than documented in other systems. Growth rates of Bowfin (except in 2020), Largemouth Bass, and Northern Pike were lower than published growth rates within the Great Lakes region. These results provide critical information regarding the health and abundance of current piscivore populations.

RÉSUMÉ

Larocque, S.M., Piczak, M.L., Turner, N.A., Bowman, J.E., Boston, C.M., Midwood, J.D. 2023. Mark-recapture population estimates of piscivores in the Hamilton Harbour Area of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3506: vii + 31 p.

Un des objectifs du plan d'action pour l'assainissement du port d'Hamilton est de rétablir une communauté de poissons mésotrophes avec des populations saines de prédateurs de niveau trophique supérieur. On a procédé à une étude de capture-marquage-recapture pour évaluer l'abondance des populations de prédateurs de niveau trophique supérieur dans le port de Hamilton, en se basant sur le marquage par transpondeur passif intégré des poissons capturés dans le cadre des relevés par pêche à l'électricité à bord d'un navire et à la passe migratoire de Cootes Paradise. On a capturé, marqué et recapturé cinq espèces entre 2017 et 2021 dans le but d'estimer l'abondance et le taux de croissance des populations. Les estimations de l'abondance des populations de doré jaune (*Sander vitreus*) et d'achigan à grande bouche (*Micropterus dolomieu*) étaient les plus importantes des cinq espèces; toutefois, l'émigration du doré jaune a réduit la précision des estimations. On a observé une forte utilisation de Cootes Paradise par des poissons-castors (*Amia calva*), mais le mélange entre les méthodes d'échantillonnage semble indiquer des mouvements à l'échelle du port. Les deux méthodes d'échantillonnage ont permis de capturer différentes parties de la population de grands brochets (*Esox lucius*). Enfin, on a observé une petite population très localisée d'achigan à petite bouche (*Micropterus dolomieu*) dans le port. Pour toutes les espèces, la densité estimée de poissons dans le port était inférieure à celle documentée dans d'autres systèmes. Les taux de croissance des poissons-castors (sauf en 2020), de l'achigan à grande bouche et du grand brochet étaient inférieures aux taux de croissance publiés dans la région des Grands Lacs. Ces résultats fournissent des renseignements importants concernant la santé et l'abondance des populations actuelles de piscivores.

INTRODUCTION

A remedial action plan has been implemented for the Hamilton Harbour Area of Concern (AOC). One of the goals of this plan is to improve fish habitat within Hamilton Harbour to encourage the re-establishment of a mesotrophic fish community with healthy populations of top predators [e.g., Northern Pike (*Esox lucius*), Largemouth Bass (*Micropterus salmoides*), Walleye (*Sander vitreus*)]. As such, there is a need to assess the condition of fish communities in the Hamilton Harbour AOC in support of Beneficial Use Impairment #3b (Degradation of Fish Populations). Tracking the success of these efforts can be challenging since the current abundance of top predators in the harbour is unknown. Previous efforts to estimate abundance have been based on the use of active or passive sampling gear and extrapolated to infer species population status. While these types of data can provide an indication of the trajectory of populations of top predators in the harbour (i.e., changes in abundance, tracking movement of a recruitment class through the population through time) and allow for an assessment of individual condition, they do not allow for a direct estimate of population size.

Capture-mark-recapture (CMR) methods and models are common approaches for estimating population abundance. The basis of CMR approaches is that animals are initially captured and marked, sampling occurs at a later time period with marked individuals being recaptured, and the number of animals caught in each time step relative to the number of marked individuals are used to estimate population abundances. CMR methods can also measure individual growth rates to help assess fish population health. Like most modelling approaches, there are assumptions when developing CMR models. For example, CMR modelling approaches can differ by whether or not populations demonstrate closure. A closed population does not change in size during the course of the field experiment such that births, deaths, emigration or immigration are negligible (Krebs 1999). In addition to the assumptions about closure, CMR models assume equal catchability (Chao 1987; Amstrup et al. 2005) and survival rates of all animals, and that markings are not lost or missed between sampling events (Pollock 2000). Understanding what assumptions cannot be met and how this might affect the interpretation of population abundance estimates is critical for evaluating the results of CMR models.

One approach to marking freshwater fishes when implementing a CMR study while limiting the violation of assumptions is the use of Passive Integrated Transponder (PIT) tags. PIT tags have been used to estimate population sizes for a variety of fish species (e.g., van Winkle et al. 1993; Juanes et al. 2000; Thompson 2003; Cooke et al. 2013) and have been shown to have minimal effects on growth and survival of tagged individuals (Gries and Letcher 2002; Zydlewski et al. 2003). Generally, tag retention rates have been shown to be relatively high (e.g., Largemouth Bass; Harvey and

Campbell 1989) such that marks are not lost between sample periods. Moreover, given the procedure of manually scanning individuals, imperfect detection of tagged fish is a non-issue. Thus, the use of PIT tags is a favourable approach for generating CMR population estimates in fish.

The objective for this project was to estimate the abundance of common piscivore populations in Hamilton Harbour based on mark-recaptures of PIT tagged fish. Fishes were captured during boat electrofishing community surveys along the shorelines of Hamilton Harbour and at the Royal Botanical Garden's (RBG) Cootes Paradise Fishway. Fish sampling was a multi-year effort and this report presents five years of tagging (2017 – 2021). Annual sampling effort varied based on the overall spatial coverage and frequency of monitoring programs, and was influenced by restrictions related to the COVID-19 pandemic. Summary information (i.e., numbers, size) of fish captured and tagged is provided. Population abundance estimates and growth rates for adult species with recaptures are also presented. Overall, this work provides a contemporary assessment of the piscivorous fish community occupying Hamilton Harbour AOC in support of the Beneficial Use Impairment #3b (Degradation of Fish Populations).

METHODS

STUDY AREA AND SAMPLING

Fish were captured as part of standardized boat electrofishing surveys in Hamilton Harbour that occurred during the ice-free season (March-November; Table 1). Sampling was performed along major harbour shorelines (East, North, West) with suitable habitats (i.e., <2.0 m depth), excluding the industrialized south shore where it was too deep (Brousseau et al. 2005; Boston et al. 2016) as shown in Figure 1. PIT tagging of piscivores occurred from 2017 to 2021 during all standardized electrofishing surveys, with some variation in the months that surveys were conducted (Table 1).

Fish were also captured at the Cootes Paradise Fishway in the Desjardin Canal located between Hamilton Harbour and Cootes Paradise Marsh (Figure 1). The Fishway is a 2-way barrier equipped with a series of baskets to capture fish entering or leaving the marsh. It is used by the RBG to: 1) prevent the movement of Common Carp (*Cyprinus carpio*) into Cootes Paradise, and 2) move native fish species (including piscivores) into and out of the marsh during migration (Royal Botanical Gardens 1998). The Fishway operates from March to August to support fish migration in and out of Cootes Paradise while blocking access to non-native carp. In-bound piscivores were all checked for PIT tags at the Fishway from 2018 to 2021 between March and July (Table 1). During periods of high captures of Bowfin (*Amia calva*), not all individuals were PIT tagged; otherwise, all untagged piscivores were PIT tagged upon first encounter at the Fishway.

Although out-bound fish were also monitored, fish could go undetected and, therefore, only in-bound fish were included in the analyses.

TAGGING

The most common piscivores in the system were targeted for tagging: Bowfin, Largemouth Bass, Northern Pike, Smallmouth Bass (*Micropterus dolomieu*) and Walleye. Captured fish were processed for fork length (±1 mm) and wet mass (±1 g), and each fish was scanned for an existing PIT tag with a handheld reader (Biomark HPR Lite). If a tag was located, the tag ID was recorded and the fish was released back into the harbour. If the fish was untagged, it was placed ventral side down in a trough with fresh water and, specifically during electrofishing surveys, fish handling gloves (Smith-Root 2019) were used to immobilize the fish. Gloves were positioned on the head (anode) and caudal peduncle (cathode) of the fish. The gloves were turned on to the lowest current setting (4 mA) and increased in a step-wise manner (6.3 mA, 10 mA, 16 mA, and 25 mA) until immobilization was observed (as per the manufacturer's instructions). A 12-mm PIT tag (Biomark APT12) was injected into the dorsal musculature posterior to the head of the fish using a Biomark gun implanter. Immediately following insertion, the gloves were removed and the fish were released back into the harbour near their location of capture. PIT tagging protocols were completed under the Great Lakes Laboratory for Fisheries and Aquatic Sciences animal use permits #1745, 1845, 1945, 2045, and 2145.

ANALYSIS

Captures from standardized electrofishing surveys and at the Fishway were used to derive separate and combined population abundance estimates (i.e., an estimate for electrofishing surveys and the Fishway independently, and an estimate using pooled data). Both methods used relatively consistent effort within each survey period (e.g., similar number of electrofishing surveys conducted or number of days the Fishway was monitored) to reduce any biases based on changes in effort. Each monthly electrofishing survey from 2017 to 2021 (i.e., seasonal community assessments) was treated as a separate sampling event for the mark-recapture analysis. This approach, herein referred to as "event-based", yielded 19 month-year sampling events (Table 1). Given low recapture rates for most species, mark-recapture numbers were also aggregated to year, which resulted in five sampling events and is herein referred to as "year-based". Similarly, Fishway mark-recaptures between ~March to August of 2018-2021 had 17 "event-based" and four "year-based" sampling events (Table 1).

Data were summarized and population abundances were estimated using both event-based and year-based datasets from standardized electrofishing surveys or tagging at the Fishway. Only the year-based estimates were used when pooling electrofishing and Fishway data (2017 – 2021). Results based on the separate sampling methods are restrictive in the sense that they only sample a certain area but are still informative towards population abundance estimates within the harbour and use of certain areas. A multi-census population estimate approach based on Schnabel (1938) was applied using the ‘mrClosed’ function in the FSA package (Ogle et al. 2020) in R version 4.0.2 (R Core Team 2020). This approach assumes that: 1) populations are closed (spatially and demographically), 2) there is an equal chance of capture across all individuals within sampling events, and, 3) tags do not affect catchability, are retained, and are always detected. Consideration of the appropriateness of these assumptions for each species is provided in the discussion. Population abundance estimates were reported as the mean and 95% confidence interval (CI).

The annual growth rates of freshwater fishes can provide insight into the health of populations, particularly if compared to similar or nearby areas. Annual growth for recaptured individuals was estimated based on observed differences in fork length (mm) over time using data from both capture methods. If a fish was recaptured within the same year, it would not be used to determine an annual growth rate. Only Bowfin, Largemouth Bass and Northern Pike had a sufficient number of recaptures to determine annual growth rates. Individuals who had a negative growth rate were removed as it was likely an error (N = 21). As the majority of tagged fish were deemed adults, growth rates based on size classes were not considered. An analysis of variance (ANOVA) was used to determine whether annual growth rates for each species changed over time based on the initial year of capture. For Bowfin, a non-parametric Kruskal-Wallis test was used as the assumption of normality was not met for an ANOVA, and was followed by a post-hoc Dunn test. Significance was assessed at $\alpha = 0.05$.

RESULTS

ELECTROFISHING POPULATION ABUNDANCE ESTIMATES

From 2017 to 2021, 415 individuals were PIT tagged during boat electrofishing surveys (Table 2). The majority of these fish were Largemouth Bass (N = 241) followed by Walleye (N = 110), with fewer individuals of Bowfin, Northern Pike, and Smallmouth Bass (N = 30, 20, and 14, respectively). Based on measured fork lengths and mass, most tagged fish were classified as adults, although a few smaller Largemouth Bass and Walleye (minimum fork lengths of 125 mm and 185 mm, respectively) were also tagged (Table 2). Thus, the population abundance estimates reported here represent adult populations.

The total number of individuals recaptured was low (<20%) for each species, with a maximum of two recaptures of the same individual occurring between 2017 and 2021 (two Largemouth Bass and one Northern Pike). Largemouth Bass had the most recaptures, with 6% (15 individuals) being recaptured over the duration of the study (Tables A1 and A2). Bowfin had a 3% recapture rate (one individual) with one event-based recapture, but 0% for year-based recaptures (i.e., the individual was recaptured in the same year they were tagged). As a result, no year-based population abundance estimates were calculated for Bowfin. Smallmouth Bass had a 14% recapture rate (two individuals) with two event-based recaptures and one year-based recapture. There were no differences in the number of event-based and year-based recaptures for the other species, with 15% (three individuals) of tagged Northern Pike recaptured for four event- and year-based recaptures, and 2% (two individuals) recaptured (with similar numbers of event-based and year-based recaptures) for Walleye (Tables A1 and A2).

Given the overall low recapture numbers, population abundance estimates are preliminary and should be interpreted with caution. Mean adult Largemouth Bass event-based and year-based abundance estimates were 1791 (95% CI = 1113 – 3049) and 2615 (95% CI = 1404 – 5284), respectively (Table 3). Mean adult Walleye population abundance estimates were higher than Largemouth Bass for the event-based analysis (1901, 95% CI = 694 – 4592) but lower for the year-based analysis (1534, CI = 559 – 3704; Table 3). Abundance estimates for both Largemouth Bass and Walleye had large confidence intervals (Table 3). Mean population abundance estimates for Bowfin (event-based = 212, 95% CI = 64 – 414), Smallmouth Bass (event-based = 28, 95% CI = 10-67; year-based = 34, 95% CI = 10 – 65) and Northern Pike (event-based = 43, 95% CI = 19 – 103; year-based = 38, 95% CI = 17-91; Table 3) were low due to the lower number of tagged individuals of each species and few recaptures (1 – 4 recaptures).

FISHWAY POPULATION ABUNDANCE ESTIMATES

From 2018 to 2021, 306 individuals were PIT tagged at the Fishway moving into Cootes Paradise (Table 4). The majority of these fish were Bowfin (N = 204), followed by Northern Pike (N = 73), Largemouth Bass (N = 27), and Smallmouth Bass (N = 2). No Walleye were captured and tagged at the Fishway. Based on measured fork lengths and mass, fish tagged were classified as adults and population abundance estimates therefore relate to the adult population (Table 4).

Recapture rates of individuals at the Fishway moving into Cootes Paradise were higher than electrofishing surveys for some of the species. Some individual Bowfin and Northern Pike were recaptured up to a maximum of four and two times, respectively, between 2018 and 2021. Recaptures were primarily from Bowfin, with 68% (139 individuals) being recaptured at least once, for a total of 277 event-based recaptures and 274 year-based recaptures (Table A3 and A4). Northern Pike had more recaptures at the Fishway than during electrofishing surveys with 26% (19 individuals) being recaptured at least once; there were 22 event-based and year-based recaptures of Northern Pike. Largemouth Bass had half as many Fishway recaptures relative to electrofishing but with fewer overall marked fish. There was a 30% recapture rate with 8 individuals being recaptured over the study period for Largemouth Bass, and a total of 8 event-based and year-based recaptures. The two Smallmouth Bass tagged at the

Fishway were not recaptured and therefore no abundance estimates were calculated (Table A3 and A4).

Data from the Fishway provided local population abundance estimates for a very specific area that some fish species and individuals may use more often than others, and as such, extrapolation to the harbour-wide population should be done with caution. Bowfin had the highest population abundance estimates at the Fishway, with mean event-based and year-based estimates of 226 (95% CI = 201 – 259) and 208 (95% CI = 175 – 258), respectively (Table 3). Bowfin population abundance estimates at the Fishway were relatively similar to electrofishing surveys (Table 3). Northern Pike had the next highest population abundance estimates with mean event-based and year-based estimates of 131 (95% CI = 88 – 204) and 115 (95% CI = 77 – 179), respectively (Table 3). Population abundance estimates of Northern Pike at the Fishway were approximately three times as large as from electrofishing surveys. Finally, Largemouth Bass mean event-based and year-based population abundance estimates at the Fishway were 47 (95% CI = 25 – 95) and 35 (95% CI = 19 – 71), respectively (Table 3), approximately 1 – 2% of the estimates from electrofishing surveys (~1800 – 2600).

COMBINED POPULATION ABUNDANCE ESTIMATES

Instances of fish being tagged and later recaptured using a different sampling method (specifically between the Fishway and electrofishing surveys, and vice versa) occurred 11 times; eight Bowfin and three Largemouth Bass were recaptured when using an alternate survey approach. Four of these occurrences for Bowfin and two occurrences for Largemouth Bass were when the fish was originally tagged at the Fishway, whereas four Bowfin and one Largemouth Bass were originally tagged during electrofishing. Capture or recapture of two of the eight Bowfin during electrofishing surveys were along the northeast shore of Hamilton Harbour, suggesting extensive spatial movement by Bowfin. All three Largemouth Bass that were captured or recaptured during electrofishing surveys were found along the western shoreline or at Bayfront Marina/Park area and thus were within close proximity to the Fishway.

When both electrofishing and Fishway datasets were combined, there were some differences in the mean year-based population abundance estimates compared to the separate datasets (Table 3). Specifically, both Bowfin and Smallmouth Bass had slightly higher combined population abundance estimates of 232 (95% CI = 199 – 278) and 48 (95% CI = 14 – 93), respectively. The combined Largemouth Bass mean population abundance estimate of 1547 (95% CI = 998 – 2518) was intermediate to the large electrofishing and small Fishway year-based estimates. The combined mean population abundance estimate for Northern Pike of 166 (95% CI = 115 – 250) was approximately the sum of both dataset estimates.

GROWTH RATE ESTIMATES

The annual growth rates of Largemouth Bass (N = 16), and Northern Pike (N = 21) did not change based on the initial year of capture ($F_{2,14} = 1.136$, $p = 0.349$; and $F_{2,19} = 0.159$, $p = 0.854$, respectively; Figure 2). Largemouth Bass had a mean (± 1 SD) annual growth rate of 16 ± 18 mm per year, and Northern Pike had a mean annual growth rate of 39 ± 21 mm per year. Annual growth rates of Bowfin (N = 105) were higher in 2020 (50 ± 32 mm per year; N = 4) than in 2018 (11 ± 14 mm per year; N = 72) and 2019 (12 ± 12 mm per year; N = 29; $\chi^2_2 = 12.598$, $p = 0.002$; Figure 2).

DISCUSSION

Five species of top predators were PIT tagged in Hamilton Harbour during boat electrofishing fish community surveys (2017 – 2021) and at the Cootes Paradise Fishway (2018 – 2021) with a goal of estimating adult population abundances based on mark-recaptures. Annual growth rates for adult Bowfin, Largemouth Bass, and Northern Pike in Hamilton Harbour were also estimated through these sampling events. There were some discrepancies regarding population abundance estimates based on the location and method of sampling, which are likely related to fish use of the harbour, differential movement into and out of Cootes Paradise, as well as their catchability. Given the limited recapture numbers and small sample sizes, and potential violation of model assumptions (i.e., whether a closed population or equal catchability of individuals), the accuracy of the population abundance estimates is unclear, but can still provide insight into the top predator populations of Hamilton Harbour. Ricker (1975) noted that there is a negative bias in population abundance estimates when recaptures are low, therefore the estimates presented at this time are likely underestimates; this is particularly true for species other than Largemouth Bass from electrofishing surveys and Bowfin from the Fishway.

Differences in the population abundance estimates derived from electrofishing and the Fishway provides species-specific information regarding fish movements, residency, and general catchability. Sampling by boat electrofishing covered a much wider area of the harbour than the Fishway and estimates may be more representative of the whole harbour, or at the very least the portions of the harbour that were effectively sampled with electrofishing (i.e., littoral zone at < 2.0 m depth). In contrast, the Fishway is a passive capture method that only captures fish as they move through the narrow channel that connects Cootes Paradise Marsh with the harbour. Although smaller individuals can be captured, all larger individuals will be captured as the ability of larger individuals to pass through the bars in the Fishway cages was limited (approx. 5 cm gap between bars). As the only entrance into Cootes Paradise, the Fishway provides solely estimates of abundance for adult fishes that use the wetland itself or the canal that connects it to the harbour, which are areas not sampled by the DFO boat electrofishing surveys. As a result, population abundance estimates from each dataset may represent different areas of use or behaviours among individuals and between species.

Population abundance estimates from electrofishing surveys were nearly 60 times the size of Fishway estimates for Largemouth Bass. In a previous study, Largemouth Bass were captured more frequently within the harbour during boat electrofishing compared to other passive capture techniques like trap nets (Boston et al. 2016). Largemouth Bass are not known to move large distances and typically have a small home range (around 2 – 8 ha with a max of 30 ha) but can have general movements upwards of 100 ha (Sammons and Maceina 2005; Hunter and Maceina 2008; Harris 2013). This lack of larger scale movements may reduce the susceptibility of Largemouth Bass to be captured in passive gears, such as at the Fishway. Largemouth Bass may also have suitable spawning habitat within their home ranges and do not undertake migrations into Cootes Paradise for spawning like some of the other species. Thus, the population abundance estimates from electrofishing are likely more representative of the harbour for Largemouth Bass relative to the Fishway based on the lower likelihood of capture and more expansive sampling. The adult population of Largemouth Bass is likely between 1000 – 3000 individuals, which could be verified with additional recapture data. Similarly, Smallmouth Bass population abundance estimates from electrofishing are likely more representative of the harbour population; however, they are also likely an underestimate due to low recapture rates (Ricker 1975). Our observations suggest the distribution of Smallmouth Bass in the harbour appears to be restricted to only a few areas along the southwest shore and, as such they likely do have a small overall population, but we have not confirmed their full distribution. The combined population abundance estimate was also similar, suggesting a small population of ~50 adults.

Northern Pike population abundance estimates derived from the Fishway were twice as large as estimates from electrofishing surveys. Previously, sampling of Northern Pike indicated that the species were captured more frequently during passive trap netting than electrofishing in Hamilton Harbour (Boston et al. 2016). This result suggests that Northern Pike may be captured more often at the passive Fishway. Northern Pike captures and recaptures at the Fishway primarily occurred from March – May (Table A3), which is consistent with movement to and from spawning grounds located within Cootes Paradise. The frequency of catches at the Fishway likely provided an accurate population abundance estimate of the larger Northern Pike that use Cootes Paradise for spawning. The repeated recaptures of some of the same individuals at the Fishway (29%) indicates that these movements into and out of the wetlands were recurring. Given the lack of recapture of Fishway-tagged Northern Pike during electrofishing (and vice versa), it is possible that each dataset is capturing a different component of the population of Northern Pike in the harbour. There are other potential spawning areas including in the marshes of Grindstone Creek and Red Hill, where harbour-tagged individuals may be aggregating and thus access to Cootes Paradise is not essential for all Northern Pike. Furthermore, boat electrofishing is limited to specific areas and depths within the harbour and Northern Pike can exhibit a variety of behavioural types (Kobler et al. 2009) such that the estimates of ~120 individuals in Cootes Paradise and

~40 individuals via electrofishing may reflect distinct components of the Northern Pike population that has yet to be fully assessed within the harbour. Thus, the combined population abundance estimate of ~160 individuals was an aggregate of the two sampling methods; however, incorporating additional sampling techniques (e.g., trap netting) into the mark-recapture program may help refine the current estimate.

Bowfin population abundance estimates from the two sampling methods were relatively similar at approximately 220 individuals and a slightly larger combined estimate of 230 individuals, which is less than the 234 total tagged Bowfin across both methods (Table 2 – 4). Some Bowfin were repeatedly recaptured at the Fishway confirming movements in and out of the wetland on an annual basis. The majority of these movements occurred between April – May, which coincides with the start of their spawning period (Table A3). However, 9% of all tagged Bowfin were only captured and recaptured during electrofishing, suggesting some Bowfin do not move into Cootes Paradise and may spawn elsewhere. Unlike Northern Pike, 3% of the 234 tagged Bowfin were captured using both sampling methods, which suggests some level of movement between the areas where fish were sampled. Of the fish captured using both methods, two were captured during electrofishing surveys that were ~6 km from the Fishway indicating larger movements of this species and supporting the smaller overall population abundance estimate in the harbour. Larger, short-term movements (5 – 10 km) of acoustic tagged Bowfin have been observed in Toronto Harbour, Ontario (Midwood et al. 2018), so moving across Hamilton Harbour (~7 km) is possible for the species. However, of the few (N = 4) acoustic tagged Bowfin in Hamilton Harbour, none have been detected in Cootes Paradise (Larocque et al. in prep), suggesting that some Bowfin are using areas other than Cootes Paradise during spawning. Although Bowfin are fairly mobile and some intermixing between sampling methods occurred, the resulting combined population abundance estimate of ~230 Bowfin in Hamilton Harbour is likely an underestimate.

Lastly, Walleye were only captured during electrofishing surveys and, despite considerable tagging effort (N = 110), there were few recaptures (N = 2). The lack of captures at the Fishway suggests that Walleye are not using Cootes Paradise nor the tributaries that flow into Cootes Paradise. Within the harbour, population abundance estimates were quite high (~1700, Table 3), which is likely driven by provincial stocking efforts (OMNRF 2021). The low recapture rate and violations of the assumption of a closed population is also likely biasing population abundance estimates. Acoustically tagged Walleye in Hamilton Harbour have been shown to leave the harbour for periods of time (Brooks et al. 2019) and it is unknown if all individuals repeatedly return, suggesting potential emigration. Thus, the current population abundance estimate is to be interpreted with caution. Had recapture rates been higher, information on the proportion of individuals that were resident or non-resident could have been incorporated into an open population mark-recapture model. Therefore, documenting the timing and duration of emigration into Lake Ontario is important for supporting future assessment of population sizes within the harbour.

The annual growth rates of freshwater fishes can provide insight into the health of populations. The age of captured fish were unavailable to compare length at age curves (e.g., von Bertalanffy curves) from nearby regions, but we were able to determine individual growth rates based on recaptures and compare to estimates of changes in lengths across ages of similar sized fish. Adult Bowfin from the Montréal region, Québec that were a similar size as individuals in this study (minimum fork lengths ranging from 500 to 650 mm) generally grew at triple the rate (mean of 32 mm per year; Cartier and Magnin 1967 in Scott and Crossman 1998) of individuals in this study from 2018 and 2019; however, Bowfin from 2020 had a higher growth rate. Adult Largemouth Bass in Lake Opinicon, Ontario grew at approximately 27 mm per year (Lewis 1965 in Scott and Crossman 1998), which is nearly double the mean annual rate observed from Hamilton Harbour. Finally, mean annual growth rates of Northern Pike in Hamilton Harbour were lower than growth rates of individuals in Georgian Bay, Ontario (fish with minimum fork lengths ranging from 450 to 750 mm grew at approximately 58 mm per year; Wainio 1966 in Scott and Crossman 1998). Although the ages of fish were not collected in Hamilton Harbour, it appears that growth rates of Bowfin (except in 2020), Largemouth Bass, and Northern Pike are lower than nearby locations within the Great Lakes watershed. These nearby locations vary in habitat features compared to Hamilton Harbour that influence the differences in growth rates. Lower growth rates may be caused by reduced habitat quality due to high contamination in Hamilton Harbour relative to other regions of Ontario (Amara et al. 2007). Moreover, reduced growth rates may relate to different forage base and/or reduced abundance, limited foraging opportunities, high levels of resource competition, water temperature, or more generally reduced habitat quality (Przybylski 1996; Bohlin et al. 2002; Gilliers et al. 2006; Searcy et al. 2007).

The derivation of population estimates using more complex statistical approaches (e.g., Cormack-Jolly Seber models), requires not only more recaptures, but also additional information on rates of residency and/or emigration for species, and estimates of species-specific birth and mortality rates in the harbour (both natural and as a result of angling). The concurrent acoustic telemetry project underway in Hamilton Harbour (see Brooks et al. 2017) has also tagged the same species and should be able to inform residency, as was discussed with Walleye (Brooks et al. 2019). Unpublished results suggest the other four species assessed in this study are resident within Hamilton Harbour (with corroborating evidence from works in Toronto Harbour; Midwood et al. 2018, 2019) and therefore better meet the assumption of a closed population. Unfortunately, with such low recapture rates, using more complex statistical approaches is not yet feasible.

The assumption of equal catchability within sampling events poses challenges due to sampling bias. Violations of this assumption will have a limited effect that will yield lower than expected population abundance estimates for Schnabel CMR models (e.g., Carothers 1973). Electrofishing may not be the most effective method for capturing some piscivores in Hamilton Harbour, and as a result may lead to underestimates of population abundances. Spatially, the lack of sampling along the south shore of the harbour may also be excluding portions of the population; however, the south shore could not be effectively sampled by boat electrofishing due to greater depths. A previous study found that electrofishing surveys had lower capture rates of Bowfin, Northern Pike and Walleye relative to trap nets in Hamilton Harbour (Boston et al. 2016). This suggests capture efficiency may be low for Bowfin, Northern Pike, and Walleye using electrofishing, although if this bias is constant for all individuals in the population it may not represent a violation of the catchability assumption. Nevertheless, there is a risk that the whole population may not be sampled, as noted in the discrepancy between Fishway and electrofishing population abundance estimates for Northern Pike, and thus careful interpretation of abundance estimates is required. For Northern Pike in particular, it is possible that electrofishing surveys are only capturing one portion of the population [possibly the more sedentary behavioural morph described by Jepsen et al. (2001)], while the Fishway sampling was limited to only Northern Pike that use Cootes Paradise Marsh for spawning. Although the combined estimate suggests a larger population, further tagging and tracking of fish in the system, and using different gears, will help resolve this challenge of unequal catchability within sampling events.

Seasonal variation in fish behaviour, movements and habitat use can also violate the assumption of equal catchability within sampling events. For example, the catch rates during the month-year sampling events at the Fishway showed some seasonal variation between spring and summer months. This is presumed to reflect congregated fish movements into Cootes Paradise for spawning or foraging in the spring, with later movements back into the harbour for most species to support overwintering in deeper waters. Thus, the Fishway is more likely to sample fish that spawn in or use Cootes Paradise, therefore violating assumptions of equal catchability of the population. Due to COVID-19 restrictions, electrofishing did not have equal sampling events across years and occurred in different months (specifically missing the spring surveys), which could also impact the catchability of fish during these times. Changes in fish behaviour based on seasonal influences will alter the fish composition captured when sampling at different times of year (Pope and Willis 1996). In Hamilton Harbour, some fish move to shallower habitats during the spring and summer months and deeper habitats during the fall and winter (Larocque et al. 2020), which would influence their ability to be captured during electrofishing surveys. For example, our historic data suggests that Walleye are more likely to be captured during spring surveys than any other season and if spring sampling did not occur, it would influence the number of recaptures and potentially positively bias abundance estimates to be larger for this species in particular. These shifts in seasonal habitat use by fishes could lead to violations of the assumption of equal catchability; however, if all individuals of the same species show similar seasonal patterns, the effect of these changes in catchability on final population abundance estimates is likely minimal.

The population abundance estimates in this study give a better indication of the number of adult fish in the harbour than typical assessments based on relative abundance from fish community sampling; however, contrasting our derived estimates with other systems that are considered to be healthy is an important next step. While direct comparisons of population estimates among different systems is challenging due to confounding variables such as the amount and composition of available fish habitat within a waterbody, the regional species pool, or system productivity, we were able to find some estimates for comparison. To account for different sized waterbodies, we compared density estimates (fish/ha) using our population abundance estimates by the estimated surface area of Hamilton Harbour (2150 ha; Barica 1989). It is important to note that this includes areas likely uninhabited by our selected fish species (e.g., depths > 12 m, areas without aquatic vegetation), which would negatively skew our density estimates. For Bowfin, Mundahl et al. (1998) estimated Bowfin populations post-reintroduction in a Minnesota lake to be 3.2 fish/ha which was much higher than our estimate of 0.1 fish/ha. Adult Largemouth Bass densities in Minnesota have been estimated at 3.5 – 4.9 fish/ha (Ebbers 1987) and in Wisconsin at 5.7 fish/ha (Kubisiak 2005) which were much higher than our estimates of 0.5 – 1.4 fish/ha. For Northern Pike, Pierce and Tomcko (2005) used a single mark-recapture event to estimate populations in Wisconsin lakes and found on average estimates for fish > 600 mm total length had a density of 1.6 fish/ha, approximately double our estimate of 0.7 fish/ha. However, Northern Pike densities varied across lakes depending on the amount of littoral habitat and shoreline length (Pierce and Tomcko 2005). Lastly, for Walleye, Lydon et al. (2008) estimated 3.8 fish/ha in Lake Otsego, New York (the lowest among other central New York lakes), and Kubisiak (2005) estimated 2.2 fish/ha in a Wisconsin lake, which were still four or two times higher than our estimates of 0.9 fish/ha, respectively. Overall, Hamilton Harbour density estimates of adult piscivores, although with significant caveats, appear to be much lower than in other lakes for all species. Using acoustic telemetry derived habitat use within Hamilton Harbour could improve estimates of the area focal species inhabit (as opposed to using the whole area of the harbour) and would improve the accuracy of derived density estimates. While such adjustments would act to increase our density-based estimates, our density compared to other studies would still likely be low.

Despite the potential violations of assumptions, the results provide insight into the status of adult piscivore populations in Hamilton Harbour. An increased understanding of piscivore ecology in Hamilton Harbour was gained by comparing population abundance estimates from different sampling methods. For example, recapture results indicated that some species do not use Cootes Paradise (e.g., Walleye and Smallmouth Bass), but also that there are potentially distinct portions of other species' populations using Cootes Paradise that were not sampled or estimated from electrofishing (e.g., Northern Pike). Understanding differences among sampling methods (like the Fishway vs electrofishing) and combining the datasets can improve population abundance estimates for these species. Similarly, comparing our density estimates to other lakes highlighted how low the adult piscivore populations were in Hamilton Harbour.

The population abundance estimates of piscivores in Hamilton Harbour are informative for management of these species. With continued sampling and integration of other datasets, the Hamilton Harbour mark-recapture efforts will serve as a useful approach for assessing the condition of fish communities in the Hamilton Harbour AOC as part of Beneficial Use Impairment #3b (Degradation of Fish Populations). More specifically, mark-recapture estimates can help determine whether populations are increasing or decreasing over time, whether predictions on the amount of suitable habitat for a species align with observed production, whether further stocking is required for a species, and which species may require targeted rehabilitation or restoration efforts. Expanding PIT tagging to other species, like invasive species (e.g., Common Carp), may also be useful for determining whether active management measures are required and understanding their efficacy. Overall, PIT tagging in Hamilton Harbour has provided some unique information regarding current piscivore populations and continued efforts and expanding to more species will provide metrics to assess and monitor the recovery of the fish community.

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TABLES AND FIGURES

Table 1. Sampling events between 2017 and 2021 when tagging during electrofishing or at the fishway in Hamilton Harbour. Note, spring electrofishing surveys were not conducted during 2020 and 2021 due to COVID-19 restrictions.

Sampling Method	**Year**	**Month**											
		1	2	3	4	5	6	7	8	9	10	11	12
Electrofishing	2017						X				X		
	2018				X	X	X		X		X	X	
	2019					X	X	X	X		X		
	2020							X		X	X		
	2021							X	X		X		
Fishway	2017												
	2018			X	X	X	X	X					
	2019			X	X	X	X						
	2020			X	X	X	X						
	2021			X	X	X	X						

Table 2. Summary information on all fish that were tagged during electrofishing surveys from 2017 to 2021. Where appropriate, results are presented as mean with standard deviation.

Species	Year	# Tagged	Fork Length (mm)	Fork Length Range (mm)	Wet Mass (kg)	Wet Mass Range (kg)
Bowfin	2017	5	676 ± 44	627 - 711	2.9 ± 0.7	1.9 - 3.5
	2018	4	690 ± 38	638 - 725	2.5 ± 1.5	0.3 - 3.6
	2019	5	599 ± 55	526 - 676	2.1 ± 0.5	1.4 - 2.7
	2020	11	624 ± 116	365 - 757	3.1 ± 1.3	0.6 - 4.5
	2021	5	600 ± 64	533 - 670	2.7 ± 1.0	1.7 - 3.7
Largemouth Bass	2017	44	358 ± 58	199 - 450	1.0 ± 0.4	0.2 - 2.0
	2018	64	289 ± 121	140 - 485	0.7 ± 0.7	0.0 - 2.7
	2019	70	294 ± 120	137 - 478	0.8 ± 0.9	0.0 - 3.5
	2020	37	257 ± 85	125 - 474	0.7 ± 1.0	0.1 - 4.3
	2021	26	245 ± 128	150 - 622	0.5 ± 1.0	0.1 - 3.7
Northern Pike	2017	8	697 ± 110	532 - 878	2.7 ± 1.2	1.0 - 4.9
	2018	4	641 ± 44	590 - 669	1.9 ± 0.1	1.9 - 2.0
	2019	1	350	350	0.3	0.3
	2020	4	617 ± 66	535 - 675	1.9 ± 0.4	1.4 - 2.4
	2021	3	697 ± 88	596 - 756	1.1 ± 0.7	0.3 - 1.8
Smallmouth Bass	2017	3	399 ± 9	392 - 409	1.2 ± 0.1	1.1 - 1.3
	2018	3	455 ± 28	435 - 475	1.6 ± 0.1	1.5 - 1.7
	2019	7	422 ± 14	397 - 438	1.4 ± 0.2	1.1 - 1.7
	2020	0	-	-	-	-
	2021	1	440	440	1.8	1.8
Walleye	2017	7	531 ± 60	416 - 591	2.2 ± 0.7	1.0 - 3.0
	2018	31	468 ± 159	185 - 657	2.0 ± 1.1	0.1 - 3.8
	2019	40	455 ± 135	200 - 650	1.5 ± 1.0	0.1 - 3.7
	2020	14	556 ± 110	363 - 702	2.7 ± 1.1	0.9 – 4.8
	2021	18	495 ± 163	189 - 658	2.1 ± 1.3	0.1 - 3.9

Table 3. Event-based and year-based population abundance estimates derived from electrofishing surveys and Fishway surveys for species with at least one recapture. All estimates were made using the Schnabel method and the ranges represent the upper and lower 95% confidence intervals for these estimates.

Electrofishing Population Abundance Estimates

Species	Event–Based Estimate	Event-Based Range	Year-Based Estimate	Year-Base Range
Bowfin	212	64 - 414		
Largemouth Bass	1791	1113 - 3049	2615	1404 - 5284
Northern Pike	43	19 - 103	38	17 - 91
Smallmouth Bass	28	10 - 67	34	10 - 65
Walleye	1901	694 - 4592	1534	559 - 3704

Fishway Population Abundance Estimates

Species	Event–Based Estimate	Event-Based Range	Year-Based Estimate	Year-Base Range
Bowfin	226	201 - 259	208	175 - 258
Largemouth Bass	47	25 - 95	35	19 - 71
Northern Pike	131	88 - 204	115	77 - 179

Combined Population Abundance Estimates

Species	Year-Based Estimate	Year-Base Range
Bowfin	232	199 - 278
Largemouth Bass	1547	998 - 2518
Northern Pike	166	115 - 250
Smallmouth Bass	48	14 - 93
Walleye	1534	559 - 3704

Table 4. Summary information on all fish that were captured and tagged moving in-bound to Cootes Paradise at the RBG Fishway from 2018 to 2021. Where appropriate, results are presented as the mean with standard deviation.

Species	Year	# Tagged	Fork Length (mm)	Fork Length Range (mm)	Wet Mass (kg)	Wet Mass Range (kg)
Bowfin	2018	119	632 ± 74	440 - 785	2.5 ± 0.8	0.9 - 4.4
	2019	60	604 ± 78	352 - 750	2.5 ± 0.9	0.9 - 4.4
	2020	13	637 ± 88	453 - 762	2.4 ± 0.9	0.8 - 3.6
	2021	12	583 ± 93	374 - 720	2.4 ± 1.1	0.5 - 4.2
Largemouth Bass	2018	14	385 ± 35	337 - 445	1.2 ± 0.3	0.8 - 1.9
	2019	12	418 ± 27	370 - 470	1.6 ± 0.4	1.0 - 2.4
	2020	1	420	420	1.5	1.5
	2021	0	-	-	-	-
Northern Pike	2018	45	716 ± 83	504 - 872	3.2 ± 1.2	0.7 - 6.5
	2019	21	731 ± 96	570 - 905	3.6 ± 1.2	1.7 - 5.3
	2020	4	664 ± 41	623 - 720	2.5 ± 0.6	2.0 - 3.4
	2021	3	766 ± 44	716 - 799	3.7 ± 1.0	2.6 - 4.7
Smallmouth Bass	2018	0	-	-	-	-
	2019	0	-	-	-	-
	2020	2	403 ± 41	374 - 432	1.3 ± 0.2	1.1 - 1.4
	2021	0	-	-	-	-

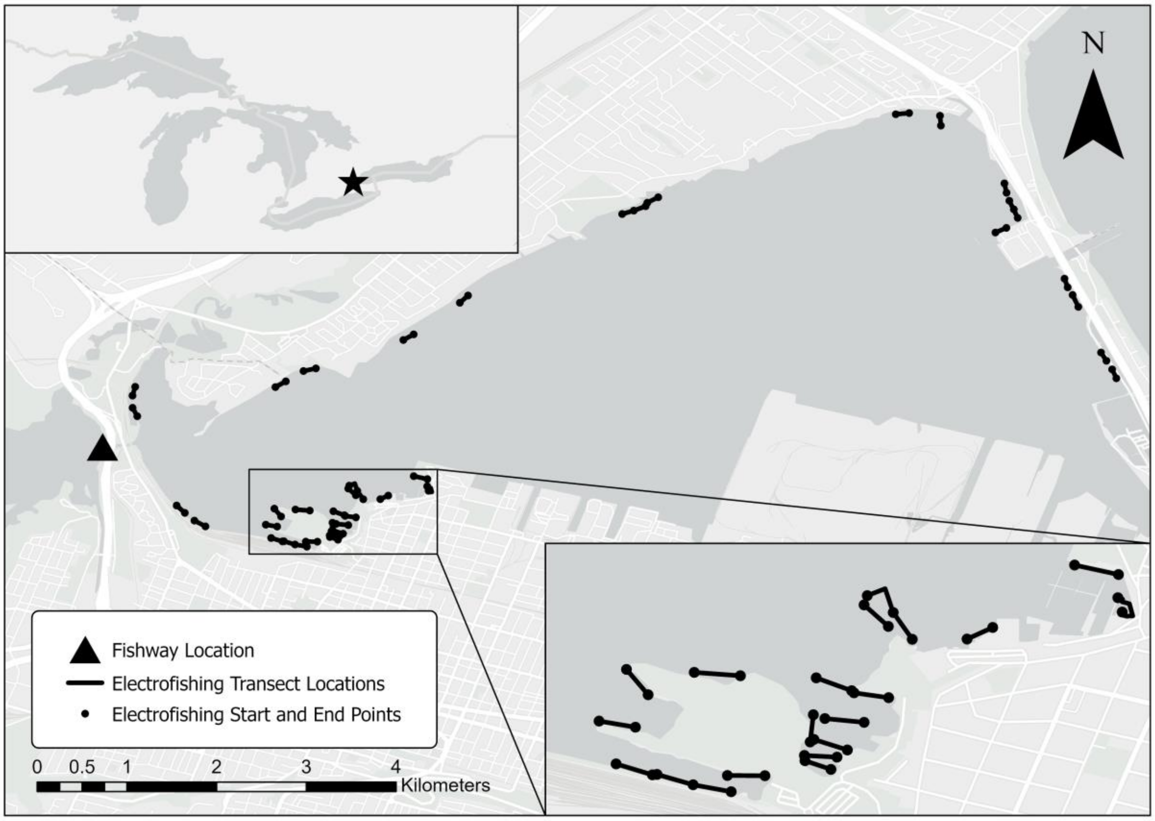

Figure 1. Location of electrofishing surveys and fishway surveys in Hamilton Harbour, Ontario, Canada.

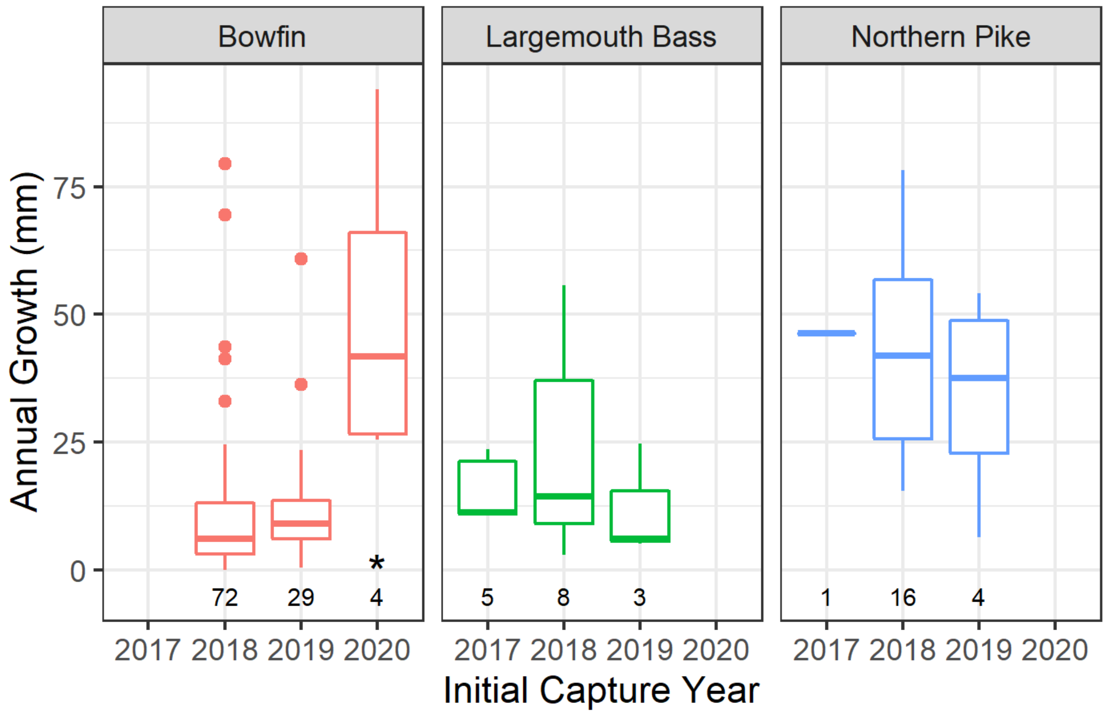

Figure 2. Box plots of PIT tagged Bowfin, Largemouth Bass, and Northern Pike annual growth in fork length (mm) at different initial years of capture until recapture in following years. Sample sizes are indicated above each year. Asterix (*) indicates a significant difference from other years within that species. Lower and upper box boundaries are the 25th and 75th percentiles, respectively. The line inside box is the median, and the lower and upper whiskers are the smallest and largest values (no further than 1.5 x inter-quartile range). Filled circles are data falling outside the whiskers.

APPENDIX

Table A1. Event-based summary of the number of each species that were captured during electrofishing surveys including: the number that were recaptured, the number that were tagged (marked) during that event, the number of tagged fish that were at large during that event (Tagged at Time), and the cumulative number of tagged fish overall. Note that event-based and year-based (Table A2) recapture totals differ because individuals were recaptured multiple times within an event or year.

Species	Event	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
Bowfin	2017-06	2	0	2	0	2
	2017-10	3	0	3	2	5
	2018-04	0	0	0	5	5
	2018-05	0	0	0	5	5
	2018-06	3	0	3	5	8
	2018-08	0	0	0	8	8
	2018-10	1	0	1	8	9
	2018-11	0	0	0	9	9
	2019-05	0	0	0	9	9
	2019-06	1	0	1	9	10
	2019-07	0	0	0	10	10
	2019-08	2	0	2	10	12
	2019-10	2	0	2	12	14
	2020-07	4	0	4	14	18
	2020-09	6	1	5	18	23
	2020-10	2	0	2	23	25
	2021-07	1	0	1	25	26
	2021-08	3	0	3	26	29
	2021-10	1	0	1	29	30
Largemouth Bass	2017-06	10	0	10	0	10
	2017-10	34	0	34	10	44
	2018-04	0	0	0	44	44
	2018-05	5	0	5	44	49
	2018-06	22	2	20	49	69
	2018-08	3	1	2	69	71
	2018-10	31	0	31	71	102
	2018-11	6	0	6	102	108
	2019-05	11	0	11	108	119
	2019-06	17	1	16	119	135
	2019-07	1	1	0	135	135
	2019-08	22	1	21	135	156
	2019-10	28	6	22	156	178
	2020-07	6	1	5	178	183

Species	Event	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
	2020-09	21	0	21	183	204
	2020-10	12	1	11	204	215
Largemouth Bass (con't)	2021-07	4	1	3	215	218
	2021-08	4	0	4	218	222
	2021-10	19	0	19	222	241
Northern Pike	2017-06	3	0	3	0	3
	2017-10	5	0	5	3	8
	2018-04	0	0	0	8	8
	2018-05	0	0	0	8	8
	2018-06	2	1	1	8	9
	2018-08	0	0	0	9	9
	2018-10	3	0	3	9	12
	2018-11	0	0	0	12	12
	2019-05	1	1	0	12	12
	2019-06	1	1	0	12	12
	2019-07	0	0	0	12	12
	2019-08	0	0	0	12	12
	2019-10	2	1	1	12	13
	2020-07	0	0	0	13	13
	2020-09	3	0	3	13	16
	2020-10	1	0	1	16	17
	2021-07	1	0	1	17	18
	2021-08	1	0	1	18	19
	2021-10	1	0	1	19	20
Smallmouth Bass	2017-06	3	0	3	0	3
	2017-10	1	1	0	3	3
	2018-04	0	0	0	3	3
	2018-05	0	0	0	3	3
	2018-06	1	1	0	3	3
	2018-08	1	0	1	3	4
	2018-10	2	0	2	4	6
	2018-11	0	0	0	6	6
	2019-05	0	0	0	6	6
	2019-06	5	0	5	6	11
	2019-07	0	0	0	11	11
	2019-08	1	0	1	11	12
	2019-10	1	0	1	12	13
	2020-07	0	0	0	13	13
	2020-09	0	0	0	13	13
	2020-10	0	0	0	13	13
	2021-07	1	0	1	13	14
	2021-08	0	0	0	14	14

Species	Event	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
Smallmouth Bass (cont'd)	2021-10	0	0	0	14	14
Walleye	2017-06	7	0	7	0	7
	2017-10	0	0	0	7	7
	2018-04	12	0	12	7	19
	2018-05	6	0	6	19	25
	2018-06	2	0	2	25	27
	2018-08	0	0	0	27	27
	2018-10	11	0	11	27	38
	2018-11	0	0	0	38	38
	2019-05	11	0	11	38	49
	2019-06	4	0	4	49	53
	2019-07	7	0	7	53	60
	2019-08	15	0	15	60	75
	2019-10	4	1	3	75	78
	2020-07	3	0	3	78	81
	2020-09	8	0	8	81	89
	2020-10	4	1	3	89	92
	2021-07	2	0	2	92	94
	2021-08	4	0	4	94	98
	2021-10	12	0	12	98	110

Table A2. Year-based summary of the number of each species that were captured during electrofishing surveys from 2017 – 2021 including: the number that were recaptured, the number that were tagged (marked) during that year, the number of tagged fish that were at large during that year (Tagged at Time), and the cumulative number of tagged fish overall. Note that event-based (Table A1) and year-based recapture totals differ because individuals were recaptured multiple times within an event or year.

Species	Year	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
Bowfin	2017	5	0	5	0	5
	2018	4	0	4	5	9
	2019	5	0	5	9	14
	2020	11	0	11	14	25
	2021	5	0	5	25	30
Largemouth Bass	2017	44	0	44	0	44
	2018	66	2	64	44	108
	2019	73	3	70	108	178
	2020	39	2	37	178	215
	2021	27	1	26	215	241
Northern Pike	2017	8	0	8	0	8
	2018	5	1	4	8	12
	2019	4	3	1	12	13
	2020	4	0	4	13	17
	2021	3	0	3	17	20
Smallmouth Bass	2017	3	0	3	0	3
	2018	4	1	3	3	6
	2019	7	0	7	6	13
	2020	0	0	0	13	13
	2021	1	0	1	13	14
Walleye	2017	7	0	7	0	7
	2018	31	0	31	7	38
	2019	41	1	40	38	78
	2020	15	1	14	78	92
	2021	18	0	18	92	110

Table A3. Event-based summary of the number of each species that were captured at the Cootes Paradise Fishway including: the number that were recaptured, the number that were tagged (marked) during that event, the number of tagged fish that were at large during that event (Tagged at Time), and the cumulative number of tagged fish overall. Note that event-based and year-based (Table A4) recapture totals differ because individuals were recaptured multiple times within an event or year.

Species	Event	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
Bowfin	2018-03	0	0	0	0	0
	2018-04	88	0	88	0	88
	2018-05	29	0	29	88	117
	2018-06	1	0	1	117	118
	2018-07	3	2	1	118	119
	2019-03	1	0	1	119	120
	2019-04	105	63	42	120	162
	2019-05	31	14	17	162	179
	2019-06	2	2	0	179	179
	2020-03	18	16	2	179	181
	2020-04	71	65	6	181	187
	2020-05	17	14	3	187	190
	2020-06	6	4	2	190	192
	2021-03	38	33	5	192	197
	2021-04	61	54	7	197	204
	2021-05	5	5	0	204	204
	2021-06	5	5	0	204	204
Largemouth Bass	2018-03	0	0	0	0	0
	2018-04	8	0	8	0	8
	2018-05	6	0	6	8	14
	2018-06	0	0	0	14	14
	2018-07	0	0	0	14	14
	2019-03	0	0	0	14	14
	2019-04	6	2	4	14	18
	2019-05	12	5	7	18	25
	2019-06	1	0	1	25	26
	2020-03	0	0	0	26	26
	2020-04	2	1	1	26	27
	2020-05	0	0	0	27	27
	2020-06	0	0	0	27	27
	2021-03	0	0	0	27	27
	2021-04	0	0	0	27	27
	2021-05	0	0	0	27	27
	2021-06	0	0	0	27	27
Northern Pike	2018-03	4	0	4	0	4
	2018-04	40	0	40	4	44
	2018-05	1	0	1	44	45

Species	Event	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
Northern Pike	2018-06	0	0	0	45	45
(con't)	2018-07	0	0	0	45	45
	2019-03	17	6	11	45	56
	2019-04	15	5	10	56	66
	2019-05	0	0	0	66	66
	2019-06	0	0	0	66	66
	2020-03	12	8	4	66	70
	2020-04	1	1	0	70	70
	2020-05	0	0	0	70	70
	2020-06	0	0	0	70	70
	2021-03	5	2	3	70	73
	2021-04	0	0	0	73	73
	2021-05	0	0	0	73	73
	2021-06	0	0	0	73	73
Smallmouth Bass	2018-03	0	0	0	0	0
	2018-04	0	0	0	0	0
	2018-05	0	0	0	0	0
	2018-06	0	0	0	0	0
	2018-07	0	0	0	0	0
	2019-03	0	0	0	0	0
	2019-04	0	0	0	0	0
	2019-05	0	0	0	0	0
	2019-06	0	0	0	0	0
	2020-03	0	0	0	0	0
	2020-04	0	0	0	0	0
	2020-05	2	0	2	0	2
	2020-06	0	0	0	2	2
	2021-03	0	0	0	2	2
	2021-04	0	0	0	2	2
	2021-05	0	0	0	2	2
	2021-06	0	0	0	2	2

Table A4. Year-based summary of the number of each species that were captured at the Cootes Paradise Fishway from 2018-2021 including: the number that were recaptured, the number that were tagged (marked) during that year, the number of tagged fish that were at large during that year (Tagged at Time), and the cumulative number of tagged fish overall. Note that event-based (Table A3) and year-based recapture totals differ because individuals were recaptured multiple times within an event or year.

Species	Year	# Captured	# Recaptured	# Marked	Tagged at Time	Cumulatively Tagged
Bowfin	2018	119	0	119	0	119
	2019	139	79	60	119	179
	2020	112	99	13	179	192
	2021	108	96	12	192	204
Largemouth Bass	2018	14	0	14	0	14
	2019	19	7	12	14	26
	2020	2	1	1	26	27
	2021	0	0	0	27	27
Northern Pike	2018	45	0	45	0	45
	2019	32	11	21	45	66
	2020	13	9	4	66	70
	2021	5	2	3	70	73
Smallmouth Bass	2018	0	0	0	0	0
	2019	0	0	0	0	0
	2020	2	0	2	0	2
	2021	0	0	0	2	2