Assessment of long-term trends in the littoral fish community of Hamilton Harbour using an Index of Biotic Integrity

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ABSTRACT

Brousseau, C.M., and Randall, R.G. 2008. Assessment of long-term trends in the littoral fish community of Hamilton Harbour using an Index of Biotic Integrity. 2811: ii + 85 p.

An Index of Biotic Integrity (IBI) was used to assess the status of the littoral fish community in Hamilton Harbour, Lake Ontario (1988-2008), in comparison to two other Areas of Concern, the Bay of Quinte (Lake Ontario) and Severn Sound (Georgian Bay). Average IBI scores in Hamilton Harbour increased significantly during this time period but remained lower than at the other areas. Although the fish community composition still resembles the catch from 1988-1990 (ictalurids, non-native cyprinids and clupeids), progress has been made. Species richness indices, including native, native cyprinid, and turbidity intolerant, have increased significantly over time while the percentage of non-native species in the catch has declined. Despite the positive changes in richness indices, the current trophic composition continues to reflect a degraded fish community. The biomass of generalist fish species such as Common Carp (*Cyprinus carpio*) and bullheads was high while the average biomass of piscivores was low, averaging less than 10% of total biomass in most years. Despite restoration of fish habitat at many locations around the harbour, there was no significant difference between IBI scores at areas before and after restoration. IBI scores at Hamilton Harbour were 1.5 to 2 times lower than scores from the Bay of Quinte and Severn Sound.

RÉSUME

Brousseau, C.M., and Randall, R.G. 2008. Assessment of long-term trends in the littoral fish community of Hamilton Harbour using an Index of Biotic Integrity. 2811: ii + 85 p.

On a utilisé un indice d'intégrité biotique (IIB) pour évaluer la situation des communautés de poissons de la zone littorale au havre Hamilton, sur le lac Ontario, entre1988 et 2008, et ensuite la comparer à celle dans deux autres secteurs préoccupants, soit la baie de Quinte (sur le lac Ontario) et le bras Severn (dans la baie Georgienne). La valeur moyenne de l'IIB au havre Hamilton a augmenté de façon marquée au cours de cette période, bien qu'elle soit demeurée inférieure à ce qui a été mesuré dans les autres secteurs. Même si la composition des communautés de poissons ressemble à ce qu'elle était entre 1988 et 1990 (ictaluridés, cyprinidés non indigènes et clupéidés), on constate une certaine amélioration. Les indices de diversité des espèces, incluant les espèces indigènes, les cyprinidés indigènes et les espèces intolérantes à la turbidité, ont nettement augmenté au fil du temps, alors que le pourcentage d'espèces non indigènes a diminué. Malgré ce changement pour le mieux des indices de diversité, on constate que le réseau trophique actuel continue de refléter la dégradation de la communauté de poissons. La biomasse des espèces de poissons « généralistes », comme la carpe commune (*Cyprinus carpio*) et les barbottes, était élevée, alors que la biomasse moyenne des espèces piscivores demeurait basse, représentant, la plupart des années, moins de 10 % de la biomasse totale. En dépit de la restauration de l'habitat des poissons en de nombreux endroits du havre, on n'a constaté aucune différence notable entre les valeurs de l'IIB des sites non altérés et des sites restaurés. Ainsi, les valeurs de l'IIB au havre Hamilton étaient de 1,5 à 2 fois plus basses que les valeurs de la baie de Quinte et du bras Severn.

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INTRODUCTION

Hamilton Harbour was identified by the International Joint Commission in 1985 as an Area of Concern (AOC) due to extensive aquatic habitat loss, cultural eutrophication, and high levels of contaminants found in the sediment (Smokorowski et al. 1998). As part of the restoration program, Fisheries and Oceans Canada (DFO) conducted a nearshore fish survey and monitoring program in the harbour. The field program was initiated in 1988 and involved sampling of the fish community, physical habitat and water quality parameters before (1988 and 1990) and after (1992-2008) habitat restoration projects at specific sites. Smokorowski et al. (1998) summarized the results of the survey program for the period 1988 to 1997, and identified delisting targets for the fish community based on an Index of Biotic Integrity (IBI). This report will summarize the most recent survey data (1998, 2002, 2006 and 2008) with goals to update progress towards meeting the fish community delisting targets since 1997, and to assess the response of the fish populations to restoration efforts. In addition, the Index of Biotic Integrity scores from Hamilton Harbour were compared to those from the Bay of Quinte and Severn Sound. Four specific objectives were set.

1. Describe and interpret trends in the fish community using individual IBI metrics and the progress towards meeting quantitative fish community delisting targets
2. Examine trends of individual fish species and how they influence IBI metrics
3. Compare the trends of IBI metrics in the vicinity of habitat restoration sites to adjacent unaltered sites
4. Compare IBI metrics at Hamilton Harbour with the Bay of Quinte and Severn Sound, both annually and seasonally

Historically, Hamilton Harbour was a productive wetland area and supported a coldwater fishery for Cisco (*Coregonus artedi*) stocks in western Lake Ontario (Holmes and Whillans 1984). Over time, human population and industrial growth perturbed the harbour ecosystem and, by 1988, it was considered one of the most degraded ecosystems in the Great Lakes (COA 1992). Today, non-native species (e.g. Alewife, *Alosa pseudoharengus;* Common Carp, *Cyprinus carpio*) dominate the nearshore zone (0 to 2

m) rather than native species such as Northern Pike (*Esox lucius*), Largemouth Bass (*Micropterus salmoides*), or Yellow Perch (*Perca flavescens*). An imbalance in the trophic structure, with too many benthic generalists and too few piscivores, is a reflection of the degraded state of the harbour (Smokorowski et al. 1998). While other AOCs in the lower Great Lakes (Severn Sound and Bay of Quinte) have shown positive changes in their fish communities as a result of improved water quality and increased macrophyte growth (Leisti et al. 2006), progress in Hamilton Harbour has been slow (Smokorowski et al. 1998; Boston and Randall 2001; Brousseau and Randall 2003; Brousseau et al. 2004; and Bowlby et al. 2007).

HABITAT IMPAIRMENTS, RESTORATION AND MONITORING

In the Great Lakes Water Quality Agreement (GLWQA), beneficial use impairments (BUI) emphasize the importance of healthy, functioning fish and wildlife populations (IJC 1987). As part of Canada's commitment to the Binational GLWQA, a Remedial Action Plan (RAP) was implemented and delisting targets were developed for BUI (HH RAP 2003). In Hamilton Harbour, 14 BUI were identified, nine of which related directly or indirectly to fish habitat and populations. Quantitative, nearshore fish community targets were identified as a priority for effective monitoring. DFO Science addressed this priority by developing an Index of Biotic Integrity (IBI) designed specifically to evaluate nearshore fish assemblages as an indicator of ecosystem health and habitat quality in the lower Great Lakes (Minns et al. 1994).

The IBI is a quantitative measure that integrates a number of biological factors into a single value of ecosystem integrity. Four main factors that influence the condition of the Great Lakes littoral fish assemblages were incorporated either directly or indirectly into the IBI: 1) non-native species, 2) water quality, 3) physical habitat supply and 4) piscivore abundance (Minns et al. 1994). Using the IBI values, spatial and temporal trends in the status of the fish assemblage can be assessed to monitor the response of the fish community to positive (habitat restoration) or negative (non-native species) variables.

Quantitative fish targets for the harbour were developed by comparing fish assemblage measures (trophic structure and species composition) at four reference areas to values from Hamilton Harbour (Randall et al. 1993; Minns et al. 1994; Smokorowski et al. 1998). Electrofishing data from surveys conducted from May to August 1990 in the Bay of Quinte and Severn Sound (Penetang Bay, Hog Bay, and Matchedash Bay) were used as a reference to Hamilton Harbour data despite their AOC status; according to the IBI analysis, bays in these areas were far less degraded than Hamilton Harbour (Randall et al. 1993; Minns et al. 1994; Smokorowski et al. 1998). Additional information on the harbour fish targets and reference data can be found in Minns et al. (1994) and Smokorowski et al. (1998).

Numerous attempts have been made to restore fish and wildlife habitat in the harbour by the RAP team (HH RAP 2003). For fishes, the RAP team identified six areas within the harbour suitable for physical fish habitat restoration: north shore, Fisherman's Pier, Windermere Basin, Bayfront Park, LaSalle Park and the northeast shoreline (Fig. 1). Four of the six areas have undergone habitat restructuring and improvement to address RAP goals (HH RAP 2003).

- Bayfront Park (completed spring 1992)
- LaSalle Park (completed spring 1996)
- Northeastern shoreline (completed spring 1996)
- Bayfront Park to Desjardins Canal/West Harbour Waterfront Trail (completed 2000)

Other remedial efforts to enhance fish populations in the harbour include the Cootes Paradise/carp barrier (March 1996), the Grindstone Creek pike spawning marsh (1993-1994), and lower Grindstone Creek restoration (1999-2002).

At Bayfront Park, habitat restoration measures involved the construction of underwater structures (artificial reefs), shoreline alterations (armour stones, points and headland structures) and the addition of substrates (pea gravel, sand, rock and rubble) for spawning, nursery and adult fish habitat. At LaSalle Park, restoration involved a promontory and reef at the west end of the site, a restored pebble beach, emergent shoals and a variegated shoreline at the eastern end of the site. These shoreline modifications doubled the riparian edge through a complex of wetlands and small islands. Along the northeast shoreline, three islands were built to provide colonial bird nesting habitat but also provided rock reefs, shoals and sheltered fish habitat behind the islands. In the newly protected areas behind the islands, aquatic macrophytes have become established where formerly there were none. Between the Straughan Channel and the Desjardins Canal, small islands, reefs, coarse substrate and shoreline vegetation were also added to enhance fish habitat. Since 1997, many other small habitat projects have been initiated to further address RAP goals.

METHODS

Hamilton Harbour (N43.2912 W79.8332) is located at the western end of Lake Ontario between the cities of Burlington and Hamilton, Ontario. The harbour has a surface area of about 2,150 hectares, an east-west axis of 8 km, and a north-south axis of 5 km (COA 1992a). Mean water depth in the harbour is 13 m with a maximum depth of 26 m. The harbour connects to Lake Ontario via the Burlington shipping canal.

Fish and Habitat Surveys

Electrofishing surveys were conducted in Hamilton Harbour between 1988 and 2008 using a standardized protocol (Valere 1996; Brousseau et al. 2005). Surveys were conducted at 31 transects grouped into 11 areas (A-KB) around the Harbour (Fig. 1). In each area, two to five 100 m transects were surveyed, depending on the year. In nine out of ten years, 25 transects were sampled at areas A through K (Table 1). An additional six transects were sampled at restoration area KB (Bayfront Park, Fig. 1) since 1993. Data collected between May and August were included in the analyses. Autumn samples from a subset of transects and years were also used to compare seasonal trends in IBI (spring, summer and autumn) at Hamilton with the Bay of Quinte and vicinity (see section on ‘Comparison of the Index of Biotic Integrity at Hamilton Harbour with other Areas of Concern’ below).

Sampling locations were chosen to represent different habitat types, with ranges in degree of exposure/fetch, substrate composition and macrophyte abundance. Survey sites provided good spatial coverage of the harbour along the east, north and west shoreline areas (Fig. 1). The south shoreline was not surveyed because it is heavily industrialized (steel mills), the water is deep, and the sediments in this area are contaminated. Freighter traffic is also heavy along the south shore.

Fish surveys were designed to determine fish community composition, abundance, biomass (kg) and species richness in the near shore zone. A Smith-Root electrofishing boat (length=6.1 m, beam=1.9m) was used to collect fishes at 100 m transects parallel to the shoreline at 1.5 m water depth. A 16 hp gas motor driving a 7.5 kW generator produced the electrical current. Output was standardized at about 8 amperes. The electrode configuration consisted of two anodes, each with a terminal six wire umbrella array, extended out from the bow at approximately 25°, with the aluminum hull acting as the cathode. The 100 m transects were surveyed at dusk and continued into the night; each transect sample took about five minutes. Fishes were retained in a live well, identified to species and individually measured (length in mm, weight in g) before being returned to the water after the transect survey was completed. If more than 20 individuals of one species were captured, they were counted and batch weighed. Voucher specimens were kept when necessary for verification of species identification.

Water quality and habitat information were collected in the evening immediately prior to fish sampling. Floats marked the start and end of transects identified by shore markers and a global positioning system. Water characteristics recorded at the time of survey included dissolved oxygen (± 0.3 mg/L), conductivity (± 0.5% µS/cm), water temperature (± 0.1°C) and Secchi depths (m) taken at the middle of each transect (Table 2). A petite Ponar grab was used to sample fine substrates at each transect end; large substrates (e.g., gravel to cobble) were assessed visually. Substrate was classified texturally as silt (0.0039 mm to 0.0625 mm), sand (0.0625 mm to 2 mm), gravel (2 mm to 16 mm), pebble (16 mm to 64 mm), cobble (64 mm to 256 mm) or boulder (>256 mm). Other substrate classes included flat bedrock, organic and woody debris and zebra mussels. Dominant (>50 %), sub-dominant (10 to 50 %) and trace (<10 %) components of substrate were assigned and recorded.

Macrophyte density (percent bottom cover) was visually assessed at each transect as: none (0 %), sparse (1 to 19 %), moderate (20 to 70 %) or dense (>70 %) (Table 3). Dominant macrophytes were identified to genus (Newmaster et al. 1997).

Index of Biotic Integrity (IBI)

Indices of Biotic Integrity (Minns et al. 1994) were calculated using software developed by Stoneman (1998). Both an unadjusted IBI score (based on all species captured) and an adjusted IBI score (IBI*; offshore species excluded) were calculated for each transect. IBI scores were calculated from 12 separate assemblage metrics based on the diversity and trophic characteristics of the fish community (Minns et al. 1994; Table 4). Positive metrics (8) included species richness (native, centrarchid, turbidity intolerant and native cyprinid), trophic composition (percent piscivore and specialist biomass) and abundance (number and biomass of native fish species). Negative metrics (4) included the occurrence of non-native species, percent generalist biomass and percent number and biomass of non-native fish species (Table 4). IBI metrics were standardized and summed to produce an IBI score that ranged between 0 and 100. Further details of the Great Lakes IBI are given by Minns et al. (1994).

Quantitative fish community targets were developed for the harbour (Randall et al. 1993; Minns et al. 1994; Smokorowski et al. 1998) to aid in BUI delisting. Delisting targets, listed below, were used as a reference for comparing the status of the fish assemblage in different years and at different locations.

Fish measure	Target for Hamilton Harbour
Species richness	6 to 7 species
Biomass	6 to 7 kg
% piscivore biomass	20 to 25%
% generalist biomass	10 to 30%
% specialist biomass	50 to 60%
% native biomass	80 to 90%
IBI	55 to 60
Adjusted IBI (IBI*)	50 to 60

IBI scores are rated as very poor (0-20), poor (20-40), fair (40-60), good (60-80) and excellent (>80) (Minns et al. 1994). The IBI delisting targets for Hamilton Harbour are at the upper end of the fair category.

Statistical Analysis

Following the format of Smokorowski et al. (1998), a series of figures were prepared to show annual trends in catch statistics and IBI metrics for the Harbour, both overall and for the individual areas (A-KB). For comparing average catch statistics and IBI indices among years, a one-way analysis of variance (ANOVA) was used on square-root transformed IBI and IBI* data (Minns et al. 1994) and log (x+1)-transformed catch data (biomass and numbers). The Tukey multiple comparisons test (Zar 1984; p.186) was used to determine which pairs of means differed significantly. F-statistics were considered significant at $\alpha \leq 0.05$. The non-parametric Kruskal-Wallis (KW) one-way analysis of variance and the Mann-Whitney U test statistic were used on the individual IBI metric scores. All statistical analyses were performed using SYSTAT (SPSS 2000).

In addition to IBI, and the individual metrics of IBI, the patterns of catches of individual species were examined to help interpret trends over time in the IBI metrics.

Habitat Restoration

IBI trends were compared at restoration sites (C and E only) and unaltered sites (A, B, D, F, G, H, and K) before and after restoration work. For statistical analyses, the years 1988 and 1990 (before) were chosen to represent the period before restoration work while post restoration work was represented by the years 1996 to 1998, 2002, 2006 and 2008 (after). A two-factor ANOVA was used to test for significant differences between year and habitat (altered or not). Data from areas KB and J were excluded from the restoration analysis because habitat alterations were not completed until the spring of 1992 and 2000, respectively. However, for area J, a one-way ANOVA was used to test for a temporal change in IBI after restorations were completed.

Comparison of the Index of Biotic Integrity at Hamilton Harbour with other Areas of Concern

Average annual IBI values at Hamilton Harbour were compared to those from two areas in Severn Sound (Penetanguishene Harbour and Hog Bay), the upper Bay of Quinte and West Lake. Data from three areas of the upper Bay of Quinte (Trenton, Belleville, and Big Bay) were pooled because results from the analysis from each area indicated that the IBI values were not different from each other. In Severn Sound, Penetanguishene Harbour was initially (1990) more degraded than Hog Bay (Minns et al. 1994) and, hence, the two areas were kept separate in the comparison. West Lake, a coastal wetland connected to Lake Ontario near the Bay of Quinte, was selected as a reference area for Quinte (Hurley et al. 1986). Surveys were conducted within the same time period (June to September) in each area between 1988 and 2007. Statistical comparisons could not be made between the different locations because not all areas were surveyed within the same year.

- Hamilton Harbour (1988, 1990, 1995, 1996, 1997, 1998, 2002, 2006, 2008)

- Penetanguishene Harbour (1990, 2002)
- Hog Bay (1990, 1995, 2002)
- Bay of Quinte (1990, 1999, 2007)
- West Lake (1998, 1999, 2007)

The IBI score and five IBI metrics were selected to illustrate the magnitude of the differences between Hamilton Harbour and the other areas. Selected metrics included species richness, trophic composition metrics and percent biomass of non-indigenous species.

Seasonal trends in IBI and IBI* metrics were examined from Hamilton Harbour and were compared to two of the other areas: upper Bay of Quinte and West Lake. Seasonal data were grouped into spring (May and June), summer (June and July) and fall (September and October) periods. Seasonal data was pooled from years in which fall data were collected.

RESULTS

Habitat

Average water temperature at the time of survey ranged from 20.7 °C to 25.8 °C between 1988 and 2008 (Table 2). Mean water temperatures were highest in 1988, 1990, 2002 and 2006 (Table 2) and were lower in the years 1995 to 1998 and 2008. Secchi depth, not recorded in all years, varied between 1.3 m and 1.7 m (Table 2). In 2006, water clarity was low due to an algal bloom that lasted from mid-July to September. In 2008, mean water conductivity and dissolved oxygen values were 622.4 µS/cm and 11.7 mg/L, respectively.

Substrate at sampling sites was predominantly sand (Table 3). Sites on the northeast shoreline were the most exposed as the prevailing winds are from the southwest. In 2008, most of the electrofishing transects in Hamilton Harbour were characterized by sparse vegetation comprised almost exclusively of *Vallisneria americana* (water celery) (Table 3, Fig. 2). *Potomageton richardsonii* was also abundant in some locations (e.g., eastern shoreline) but restoration sites in the Straughan Channel (K) and around Bayfront Park supported the most diverse macrophyte assemblages (e.g. *V. americana*, *M. spicatum*, *Certaophyllum* sp., *Elodea* sp. and *Nuphar* sp.).

Sites along the western shoreline (K, KB) and northern shoreline (LaSalle Park -E and area G -between Willow and Carrolls Point) had the highest macrophyte densities ranging from no macrophytes to dense cover. Transects in the bay at the mouth of Grindstone Creek (H) had the lowest Secchi depth and were devoid of macrophytes (Fig. 2). Visual observations indicated that median macrophyte densities were slightly lower in 2006 and 2008 than in 2002 at most individual areas (Table 3, Fig. 2). However, macrophyte densities were higher in post-restoration years (2002, 2006 and 2008) than before (e.g. 1993) at areas A, B, C, D, K and KB (Fig. 2). Prior to the construction of the northeast wildlife islands (C), no submerged macrophytes were found along that shoreline. In 2006 and 2008, macrophyte densities were also lower at area J along the Waterfront Trail where finer substrates had recently (2000) been removed and replaced by cobble substrates and rock islands.

Catch Statistics and IBI

Catches: Cumulatively (1988-2008), 41 species of fishes were captured by electrofishing in the harbour, but the number of species captured in any one year was less (e.g. 21 species in 2006). Average species richness at transects varied significantly among years (KW = 52.9, $p<0.001$; Fig. 3). In 2008, a mean richness value of 6.1 met the delisting target of 6 to 7 species per transect. Less than half of the individual areas (A to KB) fell within the richness delisting targets (Fig. 3) but in 2008, average species richness improved at all three areas around Bayfront Park. Average biomass (kg) varied significantly among survey years (ANOVA, $F_{9,858} = 3.9$, $p< 0.001$). Biomass exceeded delisting targets in 1988, 1990, 1996, 1997 and 2006; biomass was lowest in 1995 (Fig. 4). The spike in biomass observed in 1996 was coincident with the opening and operation of the Cootes Paradise fishway that held Common Carp at the barrier, which would normally reside or move into Cootes Paradise, and force them to return to the harbour. Mean total biomass (kg) has declined since 1996 and in 2008, it was below (5.4) the delisting target of 6 to 7 kg/transect (Fig. 4). Biomass (kg) of individual fish species is listed in Appendix 1.

Over time, mean numbers of fishes have decreased significantly (ANOVA, $F_{9,858}$= 10.8, $p<0.001$). Average catches in 2002, 2006 and 2008 were significantly lower ($p<0.001$, Tukey) than what they were in 1988 and 1990 (Table 5). Individual species that contributed to the decline in total numbers included Alewife in particular (Fig. 17, Appendix II) but also Common Carp, Emerald Shiner (*Notropis atherinoides*), Brown Bullhead (*Ameiurus nebulosus*), Pumpkinseed (*Lepomis gibbosus*), Largemouth Bass, Yellow Perch and Logperch (*Percina caprodes*) (Figs. 15-20). An increase in biomass, and a subsequent decrease in numbers, created a maximum average weight of individual fish per transect in 2006.

IBI Scores: The IBI score in Hamilton Harbour has changed significantly (ANOVA, $F_{9, 858} = 7.40$, $p<0.001$) over time and, in general, has increased (Fig. 5). In 2008, an IBI score of 44.3 was the highest average IBI score to date; IBI scores in 2006 and 2008 were significantly higher ($p<0.001$, Tukey) than scores from 1988 (30) or 1990 (30). Also, the average 2008 IBI score was significantly higher than IBI scores from 1992, 1996 and 2002 ($p<0.05$, Tukey). Only two individual areas (K and KB) met the IBI delisting targets in 2008 despite visible improvements in many areas (Fig. 5). Similarly, the adjusted IBI (IBI*) score increased (ANOVA, $F_{9,858} = 11.0$, $p<0.001$) over time (Fig. 7); IBI* scores were significantly higher ($p<0.05$, Tukey) in post-restoration years (1996-2008) than in earlier years (1988-1995). IBI* scores improved at about half of the areas in 2008(Fig. 6).

Native Species: Native species richness varied over time (KW= 94.4, $p<0.001$). Mean native species richness dropped to 3.0 species per transect in 2002 but increased to 4.3 species per transect in 2008 (Table 5), the highest mean value for native species richness since 1998. More native species were caught in 2008 than in 2002 except at area H (Carrolls Bay) (Fig. 1).

Numbers of native fishes declined significantly after 1998 (KW= 48.1, $p<0.001$). The average catch per transect ranged from 19 to 36 between 1988 and 1998 (Table 5). After 1998, native fish catches averaged between 13 and 17 individuals per transect. Examples of native fishes that declined in numbers since 1998 were Pumpkinseed and Logperch. Conversely, native fish biomass has increased since 1988 and was higher in 2002, 2006 and 2008 (KW= 45.4, $p<0.001$) than the four previous surveys (Table 5). Native species that have made greater contributions to total biomass in recent years (2002-2008) included Gizzard Shad (*Dorosoma cepedianum*), Rock Bass (*Ambloplites rupestris*), Bluegill Sunfish (*Lepomis macrochirus*), Largemouth Bass and Yellow Perch. The mean percentage of native fish between 2002 and 2008 was greater than 60% compared to 35% and 25% in 1988 and 1990, respectively (Fig. 11). Fewer but larger native fish (e.g. Largemouth Bass, Yellow Perch) have been caught since 1998.

Centrarchids: The number of centrarchid species changed significantly over time (KW= 95.1, $p<0.001$). Centrarchid species have been more abundant in the harbour since 1995 but richness has declined in recent years (Fig. 7). For predatory centrarchids, numbers of Largemouth Bass declined significantly (KW=91.6, $p=0.001$)) since 2002 but biomass has increased to maximum values (Fig. 15). Smallmouth Bass (*Micropterus dolomieu*) biomass peaked in 1992 and since 1995 they have rarely been caught during electrofishing (Fig. 15). Other common centrarchid species included Rock Bass, Pumpkinseed and Bluegill sunfish. Prior to 2008, Pumpkinseed were the most abundant sunfish in the harbour, ranging from 0.5 to 7.6 individuals and 0.01 kg to 0.14 kg per transect, respectively (Appendices 1-2). Pumpkinseed numbers and biomass have declined significantly (KW= 122.8 and 74.8 respectively, $p<0.001$) since 1998 (Fig. 18) and in 2006 and 2008, both Rock Bass and Bluegill surpassed Pumpkinseed in numbers and biomass. Pumpkinseed was rare in the catch prior to 1995 but have since formed between 3% and 20% of the annual catch despite recent declines. The decrease in average centrarchid species richness per transect in recent years (Fig. 7) was largely due to the decline in Pumpkinseed.

Rock Bass were common in the catch but contributions to total biomass on average were less than 1%, except for in 2008. In 2008, Rock Bass biomass comprised 2% of the total biomass; Rock Bass numbers and biomass increased significantly (Fig. 18; KW= 155.8 and 92.2 respectively, $p<0.001$). In 1995, Bluegill began to appear frequently in the electrofishing samples (Appendices 1-2). Other centrarchids, Green Sunfish (*Lepomis cyanellus*) and Black Crappie (*Pomoxis nigromaculatus*), were rare (Appendices 1-2).

Native Cyprinid and Turbidity Intolerant Species: Native cyprinid and turbidity intolerant species richness both changed significantly during the survey period (KW= 123.8 and 81.3 respectively, $p<0.001$). In general, both turbidity intolerant and native cyprinid species richness averaged less than one species per transect (Table 5). The number of native cyprinid species captured per transect was lower in 2002 than previous years but increased to a maximum of 1.2 cyprinids per transect in 2008. Six species of cyprinids were caught by electrofishing between 1988 and 2008, but only Emerald Shiner and Spottail Shiner (*Notropis hudsonius*) were common. Emerald Shiner abundance averaged from 1% to 23% of the total catch annually (Fig. 20, Appendix 2). Emerald Shiner numbers averaged 11.9 per transect in 1990 but have since declined in abundance. Spottail Shiner was not as abundant as Emerald Shiner and contributed from less than 1% to 5% (1998) of the total annual catch. Small cyprinids were more abundant in 2006 and

2008 than 2002 (Fig. 20). The mean catch of turbidity intolerant species per transect has increased since 1996 (Table 5). In 2008, a marked increase in turbidity intolerant species was due to the significant increase in the catches of Spottail Shiners (KW= 57.2, $p<0.001$) and Rock Bass (KW= 84.4, $p<0.001$).

Non-native Species: The number of non-native species in the catch changed significantly during the survey period (KW= 49.3, $p<0.001$). Average non-native species richness was between 1.4 and 2.2 species per transect in any given year, but increased at most individual areas in 2008. Catches of Goldfish (*Carassius auratus*) were higher in 2006 than in any other year but declined again in 2008 as did catches of Common Carp (Fig. 16). Round Goby (*Neogobius melanostomus*) numbers and biomass have increased in the harbour since their first appearance in the 2002 catch. Round Goby was caught at 52% of the 31 transects sampled in 2008 compared to 42% in 2002.

Both percent number and biomass (Fig. 12) of non-native fishes have decreased significantly (KW= 122.9 and 85.7 respectively, $p<0.001$) over time. Between 1988 and 1998, the biomass of non-native species averaged between 57% and 70% of the total catch. The average percent biomass in 2006 and 2008 was 36 % and 39%, respectively (Table 5). Despite a significant decline in 2008 of the dominant White Perch (KW=18.5, $p<0.001$), the percent number of non-natives fishes increased to 36% in 2008 from 32% in 2006 (Table 5). The increase in non-native fishes contributing to total numbers was seen at most individual areas around the harbour. However, the greatest increases in the mean number of gobies captured was found at the restoration sites with large, rock substrates in the west end of the harbour around Bayfront Park.

Piscivores: Top predators have made small contributions to total mean biomass in the harbour (2.5 to 12.1%) annually (Fig. 8). The percentage of piscivore biomass in the catch changed significantly during the survey period (KW= 32.7, $p<0.001$) and remains below the current delisting targets (20-25%). Percent piscivore biomass was highest in 1995 and lowest in 1988 (Table 5). Piscivores averaged 8.7 % of the total biomass per transect in 2008 (Fig. 8). Piscivores were most abundant at areas K and KB (Bayfront Park). Largemouth Bass and Northern Pike were the key contributors to mean biomass and numbers in most years (Fig. 15; Appendices 1-2). Largemouth Bass was rare prior to 1995 but became more abundant recently (Fig. 15). Numerically, Largemouth Bass have been the harbour's top predator comprising between 4% and 13% of total catch in any year (Appendix 2); in biomass, Largemouth Bass comprised between 5% and 6 %, 0.3 kg to 0.4 kg/transect annually (Appendix 1). Northern Pike comprised about 4% of total biomass in 1990 (0.3 kg) but were less in other years.

Bowfin (*Amia calva*) and Smallmouth Bass were a small (<1 %) but constant component of the catch in most years (Fig. 15; Appendices 1-2). Walleye (*Sander vitreus*) was only caught in 1998 and 2008. American Eel (*Anguilla rostrata*) was caught between 1988 and 1998; eel biomass averaged between 0.1 kg and 0.3 kg per transect in that period (Appendix 1). Eels were not captured in recent surveys. Small seasonal catches of salmonids contributed little to piscivore biomass (Appendices 1-2).

Generalists: Generalist species (Common Carp, Brown Bullhead and others) made the largest contribution to total mean biomass (up to 60%) (Fig. 9; Appendix 1) and exceeded the delisting targets (10-30%) in every year. The percentage of generalists in the catch varied significantly among years (KW= 31.2, $p<0.001$) and remained high in the catch from 1996 to 2006 until 2008, when a significant decline was noted. In 2008, generalist biomass dropped to 42.3 % of total biomass (Fig. 8) which is the lowest value on record since 1992.

Common Carp biomass averaged between 2.3 kg and 8.0 kg per transect and formed from 73% to 84% of total mean biomass in peak years (1996-7). The high carp biomass in the mid-1990s was largely responsible for the peak in percent generalist's biomass (Fig. 9). The average number of Common Carp per transect was high in 1988 and 1990 (Fig. 16) but was replaced by fewer, larger fish in later years. Common Carp was the key contributor to biomass annually despite significant variation among years (KW= 39.7, $p<0.001$). Average Common Carp biomass reached a minimum in 2008 (Fig. 16), comprising only 42% of total biomass (Appendix 1). Goldfish, another non-native cyprinid, comprised less than 1% of total biomass in most years, but increased numerically (KW= 53.1, $p< 0.001$) in 2006 (Fig. 16, Appendix 2).

Brown Bullhead was the other key contributor to generalist biomass. Bullhead biomass averaged between 0.4 kg (1995) and 2.8 kg (1988) per transect (Fig. 16). Biomass (kg) was significantly higher (KW= 69.5, $p < 0.001$) in 2002 and 2006 forming between 17% and 23 % of the total catch but declined in 2008 (Fig. 16).

Specialists: The percentage of specialists in the harbour catch varied significantly over time (KW= 28.8, $p < 0.001$); specialists in the catch decreased between 1995 and 2002 (32-33%) but increased again to 48% in 2008 (Fig. 10). The specialist catch in 2008 was close to the delisting target of 50-60% (Fig. 10). Specialists are classified as planktivores, invertivores, or insectivores and include species such as Alewife, Gizzard Shad, White Sucker (*Catostomus commersonii*) and Yellow Perch.

Yellow Perch and Logperch are native percids and specialists. Yellow Perch was the dominant percid in the nearshore zone. Numbers and biomass of Yellow Perch were significantly higher (KW= 147.1 and 170.4 respectively, $p < 0.001$) in the period between 1998 and 2008 than before, forming between 4% and 13% of the total catch (Fig.19). Since 1995, Logperch have been a key component of the catch but due to their small size contribute only a small percentage (<1%) to total biomass. Both percid species peaked in numbers and biomass in 1998 (Fig. 19) and then declined in 2002. Yellow perch, not Logperch, increased in biomass in 2008 close to values recorded back in 1998 (Appendices 1-2). Non-native and offshore species (below) form the largest percentage of specialist biomass in Hamilton Harbour.

Offshore species: Offshore fish species that frequent the nearshore zone in the harbour made up a large proportion of overall total numbers and biomass (Fig. 13, 14); both metrics varied significantly over time (KW= 83.0 and 61.9 respectively, $p < 0.001$). The average percentage of offshore fish by number varied between 31% and 63% from 1988 to 2008. Average percent numbers and biomass of offshore species increased in 2008 (Fig. 14). Three key species made up the offshore biomass in Hamilton Harbour: two non-native species (Alewife, White Perch- *Morone americana*) and one native species (Gizzard Shad). Alewife was the most abundant species in any given year and comprised between 20% and 62% of the total catch (Fig. 17). Between 1988 and 1996, Alewife biomass averaged between 0.5 kg and 1.0 kg per transect. Since 1997, Alewife has made up a smaller component of the near shore biomass (0.1 kg to 0.4 kg/transect). Alewife numbers declined significantly (KW= 161.0, $p<0.001$) in 2006 but rose again in 2008, accounting for the increase in the percent number of offshore species (Figs. 13, 17). The sharp decline in percent biomass of specialists and offshore species after 1995 (Figs. 10 and 13) was coincident with the decline of Alewife.

Gizzard Shad was a key component of the harbour's offshore fish assemblage forming between 0.5% and 4.0 % of the total mean biomass in most years (Fig. 17). Gizzard Shad biomass increased significantly (KW= 61.8, $p<0.001$) in 2006 and comprised 18% of the total biomass reflecting an average biomass per transect of 1.3 kg; Gizzard Shad biomass decreased to 0.5 kg per transect in 2008. An increase in Gizzard Shad biomass positively affected several IBI metrics, including percent specialists, the biomass of native fish and the overall IBI.

White Perch was a constant and significant contributor to offshore fish biomass (0.12 to 0.46 kg/transect) and total numbers (1.7 to 5.5 fish/transect) (Fig. 17). Annually, White Perch comprised between 3% and 17% of the total catch. In recent years (2002-2008), offshore species have formed between 36% and 42% of the nearshore electrofishing catch (numbers) compared to 63% in 1988 (Table 5).

Habitat Restoration

No significant differences were found in the overall IBI scores between the restoration (1996-2008) and unaltered (1988, 1990) sites (Figs. 21-27). The IBI and IBI* scores were not significantly different between the two habitat types (ANOVA, $F_{1,606}$= 1.4, P=0.24 and $F_{1,606} = 0.72$, p=0.4, respectively). However, as noted below, there were differences in a few individual metrics between habitats, both positive and negative. Most metric scores from both unaltered and restoration areas increased over time; positive changes in IBI scores from both types of habitat (Figs. 21-22) between 1988 and 2008 were significant (IBI $F_{1,606} = 6.4$, p=0.012; IBI* $F_{1,606} = 32.4$, p <0.001).

For the years immediately following restoration in 1996 and 1997, IBI scores and individual metrics at restoration sites increased. However, the values declined again in the two subsequent studies before increasing again in 2006. Since then, centrarchid species richness (Fig. 23), the proportion of piscivores (Fig. 25) and the number of native species have declined; some metrics have declined back to pre-restoration values. Native species richness remained stable with similar values in 2006 and 2008 to post-restoration (1996 and 1997) values. The percent biomass of specialists showed a positive trend at both non-altered and restorations sites (Fig. 27); in contrast, the percent biomass of generalists declined to lows at both types of habitat (Fig. 26). Metrics that showed similar patterns among years regardless of habitat type included total biomass, total numbers, non-indigenous species richness, turbidity intolerant species richness (Fig. 24), native cyprinid species richness, numbers and biomass of native fish and the percentage of offshore fish biomass.

Transects at area J (Figs. 1) were analyzed separately because habitat alterations occurred in 2000, later than the restorations elsewhere. The IBI and IBI* scores were significantly higher post restoration (ANOVA, $F_{1,90} = 9.53$, $p=0.003$ and IBI*, $F_{1,90} = 16.4$, $p<0.001$, respectively) than before (1988-1998).

Comparison of Hamilton Harbour with Other AOCs

IBI scores in Hamilton Harbour were generally poor (>20-44) compared to the other study areas (>60-80), (Fig. 28). Key differences between Hamilton Harbour and the other areas in species richness and trophic groups were apparent (Figs. 29-33). Species richness in Hamilton Harbour was on average lower than the other areas (Fig. 29) with the exception of Penetanguishene Harbour. Centrarchids increased during the survey period in the other study areas but have remained low in Hamilton Harbour. For example, mean centrarchid species per transect from the most recent surveys in each of the five areas were as follows: Hamilton Harbour (0.9, 2008), upper Bay of Quinte (4.0, 2007), West Lake (4.6, 2007), Penetanguishene Harbour (2.6, 2002), and Hog Bay (2.8, 2002).

The trophic composition of the Hamilton Harbour fish community was different from that of the Bay of Quinte, West Lake and Severn Sound. With the exception of 1995, the mean percentage of piscivore biomass per transect in Hamilton Harbour was less than 10%, well below the delisting targets of 20% to 25%. In the other areas, piscivores were a key component of the fish community and in most cases comprised ≥ 20-25% of the total biomass (Fig. 30). For example, in 2007 the average percentage of piscivore biomass per transect was 36% and 44% for the upper Bay of Quinte and West Lake, respectively, compared to 8.7% in Hamilton Harbour (2008). In contrast, the percentage of generalist biomass, which was largely comprised of non-native species, was higher in the harbour than in the other areas. Mean percent biomass of generalist species per transect at the other AOCs ranged between 10% and 30% but, in Hamilton, the average value was about 60% annually (Figs. 31) until 2008 when the average value dropped to 42%. The biomass of specialist species per transect in Hamilton Harbour in 2008 was comparable to percent specialist by biomass scores from the other areas in recent years (Fig. 32). Despite significant declines in non-native species biomass since 2002 (KW= 85.7, p<0.001), the biomass of non-native species in Hamilton Harbour has remained high. In 2008, the average percent biomass of non-native species was 39% compared to less than 10% in the Bay of Quinte and West Lake in 2007 (Fig. 33).

Despite the difference in the magnitude of the IBI scores among the areas, seasonal trends in IBI scores were similar. IBI scores were significantly higher in the summer or fall than in the spring at the three areas: Hamilton Harbour ($F_{2, 652}$= 11.2, p<0.001; Bonferroni; p≤ 0.05), Bay of Quinte ($F_{2,161}$= 8.4, p<0.001; Bonferroni; p=0.002) and West Lake ($F_{2,32}$= 6.1, p=0.006; Bonferroni; p<0.02).

Season	Mean IBI Scores (SE)		
	Hamilton Harbour	Bay of Quinte	West Lake
Spring	37.1 (1.3)	56.8 (3.1)	70.7 (3.0)
Summer	36.5 (1.0)	69.9 (2.0)	74.2 (2.0)
Fall	46.4 (1.4)	74.6 (2.7)	83.6 (2.3)

However, the reasons why IBI scores increased at Hamilton were different from the reason that IBI scores increased in the Bay of Quinte and West Lake. Seasonal increases in the IBI scores were linked to an increase in species richness in the Bay of Quinte and West Lake; increases in the IBI scores at Hamilton from spring to fall were linked to seasonal decreases in non-indigenous species richness, numbers, and biomass. For example, at Hamilton, species richness remained unchanged from spring through autumn (KW=4.5, p=0.11), (Fig. 34), but species richness was significantly higher in the summer or fall in the upper Bay of Quinte (KW=23.7, p<0.001) and West Lake (KW=5.6, p=0.05). Also, in Hamilton, the average non-indigenous species richness, percent numbers and biomass per transect were all significantly higher in the spring than the fall (KW= 89.8, 111.2, and 33.3 respectively, p<0.001). No pattern in non-indigenous species richness metrics was found in the other areas.

DISCUSSION

The Index of Biotic Integrity (IBI) developed for the Great Lakes' littoral fish assemblages integrates the effects of four main factors, non-native fishes, water quality, physical habitat supply and the abundance of piscivores, and is an indicator of ecosystem health (Minns et al. 1994) and habitat quality (Randall and Minns 2002). All four of these factors continue to negatively affect the fish populations in Hamilton Harbour.

Delisting IBI targets for the fish assemblages in Hamilton Harbour are conservative as they were based on values from other less degraded AOCs (Smokorowski et al. 1998). In 1990, the poor state of the harbour fish community was reflected in the low IBI scores. Compared to the Bay of Quinte and Severn Sound, the IBI and average species richness scores were lower in Hamilton Harbour. Additionally, the ratio of native to non-native species was significantly lower in Hamilton Harbour than in the Bay of Quinte or Severn Sound. In 1990, fish biomass was highest in Hamilton Harbour, largely because of the relatively high abundance of large Common Carp; Randall et al. (1993) found that fish biomass within the three AOCs was positively correlated with total phosphorus concentrations and they suggested that eutrophication was a factor affecting fish biomass.

After more than 15 years of restoration activities and improved water quality management (Hall et al. 2006), the state of the fish community in Hamilton Harbour has improved, but IBI values are still lower than at other AOCs and the fish community continues to reflect an unhealthy ecosystem. The differences that existed in 1990 between Hamilton Harbour and the other AOCs still prevail. The rate of change in the harbour has been slow, and positive changes over time in the other AOCs magnify the differences between them. Habitat restoration efforts have been numerous but localized; differences between restored and non-altered sites in Hamilton Harbour were minimal.

The delisting of Hamilton Harbour as an AOC is considered achievable by 2015 (Hall et al. 2006). Once an important spawning, nursery, and rearing location for native fishes, the aquatic ecosystem in the harbour became degraded after decades of industrial and cultural contamination, eutrophication and extensive losses of fish habitat. Other major occurrences within the last century have also affected fish community dynamics, aquatic ecosystem structure, and function in the harbour.

- A decrease in phosphorous concentrations in the Harbour since the early 1970s (Johannsson et al. 1998; Mills et al. 2003; Munawar and Munawar 2003) because of water quality management
- The introduction of non-native species including Common Carp-1900s (Holmes and Whillans 1984), dreissenid mussels-1980s (Mills et al. 1993, 1999, 2003) and the Round Goby-mid 1990s (Jude et al. 1995; Jude 1997)
- An increase in the abundance of a top avian predator, the double-crested cormorant, late 1980s to 2000s (Burnett et al. 2002; Lantry et al. 2002; Weseloh et al. 2002)
- Climate change and its effects on water temperatures and native fish distributions (Casselman 2002; Casselman et al. 2002)

The latter three factors (non-native species, cormorant abundance and climate change) all affect the Great Lakes as a whole, not just Hamilton Harbour. Progress or lack thereof, in achieving the IBI delisting targets for littoral fish assemblages in Hamilton Harbour are discussed below in the context of changes in habitat (macrophytes and physical habitat restoration), water quality, and the occurrence of non-native species. Trends in the Index of Biotic Integrity are also considered in the context of localized (within harbour) and whole-lake stressors.

Changes in Habitat - Macrophytes

Most of the fish habitat at sampling locations in the harbour was classified as medium suitability (i.e. dominant sand substrate with sparse vegetation) (Minns et al. 1999). A few areas of high quality habitat (i.e. fine substrates and dense macrophytes), which support a wide diversity of species including piscivores, are limited to the south western end of the harbour in the vicinity of Bayfront Park. Although macrophyte density was high in other areas (e.g. LaSalle Park), plant diversity was low compared to the diverse plant assemblage at Bayfront Park sites.

During electrofishing habitat surveys and in a DFO macrophyte survey (Leisti et al. 2009), *Vallisneria americana*, a simple, grass-like macrophyte, was dominant at 70% of the surveyed transects. *Myriophyllum spicatum*, a complex but non-native macrophyte, was the dominant species at the rest of the sites. According to Minns et al. (1993), the composition of submerged macrophytes in Hamilton Harbour was similar in 1990 (August to September) at surveyed electrofishing transects. At the time, *V. americana* was the most frequently encountered plant in the Harbour; it comprised 77.3% of the cover followed by *Myriophyllum* sp. at 21.3% (Minns et al. 1993). At the same time, four areas in the other AOCs, Severn Sound and Bay of Quinte, were also surveyed. Of the five areas, Hamilton Harbour had the lowest stem density and percent cover and, therefore, the lowest percentage of quality fish habitat. Mean stem density and percent cover at the five areas also followed a gradient of eutrophication (Minns et al. 1993; Randall et al. 1993). Reduced light availability from turbid conditions, suspended sediment or algal blooms, is likely the main factor limiting macrophyte growth and diversity in Hamilton Harbour (Leisti et al. 2009) and also responsible for differences between macrophyte abundance among AOCs. Since 1990, that status of aquatic macrophytes in the harbour has changed very little.

Simple macrophytes (i.e. grass-like with long narrow leaves) dominate over more complex forms (i.e. branching stems with a variety of leaf forms) in the harbour. Complex macrophytes provide more cover and habitat for a wider variety of invertebrate prey than simpler forms. The two dominant macrophytes in the harbour, *V. americana* and *M. spicatum*, are able to tolerate low light conditions and higher levels of turbidity (Borman et al. 2001). In their studies of the nearshore zone of the Detroit River, Lapointe et al. (2007) found that complex macrophyte assemblages were the most important factor in determining fish distributions in all seasons; fish assemblages dominated by centrarchids and some native cyprinids were associated with patches of complex macrophytes. Complex macrophytes were also found to provide habitat over a longer period; they were abundant in the spring through fall as opposed to simpler forms like *V. americana* that are rare in the spring (Lapointe et al. 2007). Macrophytes are an essential component of fish habitat that provides the structure and cover for both predator (fish) and prey (e.g. zooplankton) alike (Lapointe et al. 2007), and the lack of complex forms in Hamilton Harbour may be contributing to the lack of quality habitat for fish populations and prey. In addition to low-light conditions, the lack of shallow slope shoreline and the presence of the non-native species, *M. spicatum*, are problematic for native macrophyte species. *M. spicatum* begins to grow under the ice as early as February forming a thick canopy that shades native species that are trying to grow and hence, reduces native plant abundance and diversity (Leisti et al. 2009).

Changes in Habitat – Physical Habitat Restoration

Despite restoration of fish habitat at many locations around the harbour, there were no significant differences between IBI scores (IBI, IBI*) at the non-altered and restoration sites at LaSalle Park and the northeast shoreline. At both types of habitat, most metric scores have improved. Initially, trends at the restoration sites looked promising as positive metrics began to improve including changes in native and centrarchid species richness (Fig. 23), percent piscivores (Fig. 25), percent generalists (Fig. 26), native fish biomass, and percent non-native fishes by numbers (Fig. 28) and biomass. Since then, the positive metrics noted above have declined significantly. It is difficult to discern the reasons for the decline in these metrics. Cormorants have been implicated in the decline of Smallmouth Bass in Lake Ontario (Casselman et al. 2002; Lantry et al. 2002; Weseloh et al. 2002; Johnson et al. 2006; Casselman and Weseloh 2007). Poor water quality in the Harbour persists and the displacement of carp from Cootes Paradise may have had a negative effect on nearshore habitats and associated biota. Round Goby have become established in the harbour (1998) after initial improvements at restoration sites were noted, and other data sources (Balshine et al. 2005) indicate that they are locally abundant. Many of the habitat restoration measures in the harbour have involved the placement of riprap and rubble on sandy substrates. Studies have shown that Round Goby and their favoured prey, dreissenid mussels, are significantly more abundant on large, coarse substrates and macrophytes than sand (Jude et al. 1995; Jude and DeBoe 1996). Large coarse substrates provide ideal habitat for gobies and zebra mussels through the creation of large interstitial spaces among rocks that provide ideal spawning and refuge conditions for this species (Jude et al. 1995), and this may provide an advantage to gobies over our native species (Jude et al. 1995).

Improvements in harbour-wide metrics (IBI scores, turbidity intolerant and native cyprinid species richness, percent biomass of specialists and percent native fish biomass) may be related in part to fish habitat restoration efforts. Prior to the creation of the northeast/wildlife islands, there were no macrophytes along the sand-silt shoreline that was frequently disrupted by wind-generated turbulence. The creation of the islands has allowed macrophytes to establish in this area. It is possible that habitat creation is responsible for the increase in specialists at these sites, which may have more food choices and shelter resulting from an increase in habitat diversity. Despite recent declines in centrarchid species richness (2002-2008), centrarchids are now more abundant in the harbour than before habitat restoration. It is important to realize that although extensive restoration efforts have been made in the near shore areas around Bayfront Park, data were not collected at area KB prior to restoration; therefore, no before and after comparisons can be made. However, these restored areas support the most diverse fish assemblages in the harbour and have the best quality habitat.

Improvements to Cootes Paradise, an important spawning, nursery and rearing area for Hamilton Harbour fishes (Holmes and Whillans 1984), should help with the restoration of the warm-water fish community that once supported healthy populations of Northern Pike, Muskellunge (*Esox masquinongy*), Largemouth Bass and Smallmouth Bass (Holmes 1988). At the turn of the century, Cootes Paradise was the most productive coastal wetland in the western end of Lake Ontario; at that time, macrophyte coverage in the marsh was about 90% and aquatic biota were diverse and abundant (Holmes and Whillans 1984; Chow-Fraser et al. 1998). By the mid-1990s, the marsh was severely degraded by many sources including eutrophication, high water levels and Common Carp disturbance and the macrophyte coverage in the marsh was reduced to about 15% (Chow-Fraser et al. 1998). Species diversity at all trophic levels decreased significantly (Chow-Fraser et al. 1998). Since the implementation of the Cootes Paradise barrier and Common Carp exclusion, habitat conditions are slowly improving; macrophyte coverage in the mid-2000s was about 25% (T. Theysmeyer, Royal Botanical Gardens, pers. comm.). Over the long term, improved habitat in Cootes Paradise may benefit harbour fishes.

Water Quality

Water quality in the harbour has improved since the late 1980s. Current levels of phosphorus (P) are significantly lower than levels found in the late 1980s to early 1990s and water transparency has increased since the late 1990s (Charlton and Milne 2007). Researchers from Environment Canada measured P levels during the critical summer period when high P values are most deleterious. Since the late 1990s, there have been more P measurements below the values of the initial goal (34 µg/L) set by the RAP team, but these results have not been consistent (Charlton and Milne 2007). Despite the efforts at municipal waste water treatment facilities (WWTP) to reduce nutrient loadings from point sources (e.g. sewage treatment plants), further reductions are required for progress towards RAP water quality delisting objectives (HHRAP 2003). Charlton and Milne (2007) found that P loadings in the harbour were strongly correlated with combined P loads from two local sewage treatment plants. Randall et al. (1993) found that fish biomass was positively correlated with phosphorus concentration levels supporting the relationship between fish and high levels of nutrients in the harbour. The fish biomass delisting target of 6-7 kg per transect reflects the high end of the reference values from the other AOCs. A recent decline (2008) in total fish biomass slightly below the delisting target (5.4 kg) for the harbour suggests that water quality improvements (i.e. reductions in P loading) are having a positive effect on fish biomass.

Low dissolved oxygen levels in the hypolimnion during the summer period have serious implications for suitable summer habitat for fishes (Charlton and Milne 2007; Doka et al. 2007). Dissolved oxygen levels in the harbour have improved but are still not optimal for fishes. Charlton and Milne (2007) found a decreased number of days with unsuitable dissolved oxygen levels in the summer in recent years (e.g. 2006, 45 days <4 mg/L and 30 days < 1 mg/L) compared to earlier years (e.g. 1998, 87 days <4 mg/L and 80 days < 1 mg/L). Doka et al. (2007) measured dissolved oxygen (mg/L) in the hypolimnion at a station off the north shore of the harbour from June to November 2006 and found that oxygen levels could vary by 4 mg/L in one day (3-10 mg/L).

Index of Biotic Integrity and Fish Species Composition

Mean biomass and numbers per transect varied among years; however, numbers have been at a minimum since 2002. Although this was not a common trend among other areas sampled in recent years, the numbers of fish captured in Hog Bay and Penetanguishene Harbour, Severn Sound were also significantly lower in 2002 than in previous years. Fish catches were variable on an annual basis and could be attributed to crew efficiency, environmental or biological factors. However, following a standardized protocol since the start of the program in 1988 (Valere 1996; Brousseau *et al*. 2005) should minimize the effects of technical variables such as crew efficiency and reduce the effects of seasonality on fish catches. The IBI is an indicator for assessing fish assemblages in littoral areas of the Great Lakes that can be linked to habitat diversity and quality (Randall and Minns 2002). According to Minns et al. (1994), the IBI scores in Hamilton Harbour were poor. Since 1988, both IBI scores have improved significantly, indicating that conditions in the harbour have improved, but average IBI values remain relatively low. IBI values at individual areas within the harbour ranged from poor to fair with the exception of area K, which in 2008 achieved a good score. IBI values in the western end of the harbour at areas K and KB approached or met the delisting targets in 2008. The overall Harbour IBI* scores were significantly higher in the post-restoration period (1996-2008) than earlier.

Examining both the individual metric scores and the integrated IBI score are useful for describing the fish community and for interpreting patterns. In Hamilton Harbour, all the positive richness metrics have increased significantly over time: total, native, centrarchid, cyprinid, turbidity intolerant and native cyprinid species richness. Improvements in the positive richness metrics were reflected in the positive trends in IBI scores. Prior to 1992, centrarchid species were rare in the electrofishing catch. An increase in centrarchids since the mid-1990s may be the result of restoration efforts around Bayfront Park (1992), LaSalle Park (1996) and the northeast shoreline (1996), which has increased underwater physical habitat structure and macrophyte abundance for this type of species. Pumpkinseed was the dominant, non-predatory centrarchid captured over time but the catches of this species have declined significantly since 1998. Both

Bluegill and Rock Bass biomass increased between 2002 and 2008, and were higher average Pumpkinseed biomass.

Pumpkinseed have declined in recent years. Bowlby et al. (2007) documented rare catches of Pumpkinseed and other centrarchids in the Harbour (2006) compared to the Bay of Quinte and other inland lakes. However, both DFO electrofishing surveys (2007) and Ontario Ministry of Natural Resources (OMNR) surveys (2006) in the Bay of Quinte also documented significant declines in Pumpkinseed abundance after dramatic increases in their populations in the 1990s (OMNR 2007). Catches of Pumpkinseed were also significantly lower in Hog Bay, Severn Sound in 2002 than in earlier surveys (Brousseau et al. 2004). The decline of Pumpkinseed in recent years was not restricted to Hamilton Harbour.

Native cyprinids are a small, but important, part of the Hamilton Harbour food web. Although native cyprinid species richness was significantly higher in 2008 than in the previous survey, they were still grossly underrepresented when compared to the catch from other areas (e.g. Bay of Quinte and Severn Sound). Only three common species were found in 2006. Emerald shiner was the dominant native cyprinid but has declined in abundance since a peak in 1990. During a larval fish survey of the harbour in 1985 and 1987, Leslie and Timmins (1992) found 12 species of cyprinids but these fishes comprised less than 5% of the catch indicating that are cyprinids are present in the harbour but uncommon.

An increase in Spottail Shiners in 2006 and 2008, a turbidity intolerant species, suggested that water clarity has improved in some areas of the harbour. However, except for in a few restricted areas, both centrarchids and native cyprinids were not well-represented in fish catches from the harbour. According to Minns et al. (1994), the presence of those species is indicative of a stable ecosystem of high habitat diversity. The under representation of these species suggests that habitat conditions for these species are not ideal in the harbour.

The current trophic composition reflects the imbalance in the harbour fish community. Other studies (Minns et al. 1994; Randall et al. 1993, 1996; Smokorowski et al. 1998; Brousseau and Randall 2003; Bowlby et al. 2007) have shown that fish biomass in the harbour is highly skewed towards generalists with a low percentage of top predators and fewer specialists than in other areas. Generalist biomass in the Harbour is high and strongly correlated with Common Carp biomass. Numbers of carp were lower in recent years after a peak in 1996 but biomass is still high. The peak in carp biomass in the mid-1990s may have been the result of the displacement of carp from Cootes Paradise concurrent with the operation of the carp barrier in the spring of 1996. The exclusion of carp from Cootes Paradise has resulted in a decline in production of carp in the marsh (Lougheed et al. 2004; Spence-Diermair and Theysmeyer 2006) and, concurrently, the catch has declined in the harbour. However, despite significant declines in the Common Carp catch and percent generalist biomass in 2008, Common Carp are still the top contributor to total biomass in the harbour electrofishing catch.

Brown Bullhead was the other key generalist contributing to total biomass in the harbour. The proportion of bullheads in the catch was significantly higher in recent years than what it was in the mid- to late 1990s. Trap net survey conducted at the same time as electrofishing surveys in 2006, found bullheads to be the dominant species in the harbour, comprising 78% of the catch (Bowlby et al. 2007). Large populations of both Brown Bullheads and Common Carp are indicative of a eutrophic and degraded environment. Randall et al. (1993) found that biomass of generalists was highest in most degraded environments affected by eutrophication.

In most years, the average harbour biomass of piscivores was less than 10%. In a balanced system, piscivores should contribute at least 20% of the total biomass (Minns et al. 1994). Bowlby et al. (2007) suggested that, the Channel Catfish (*Ictalurus punctatus*) which is currently classified as a generalist may in fact be the harbour's top predator; if confirmed, this species should be categorized as a piscivore rather than a generalist. Most piscivores were caught in the west end of the harbour where macrophytes were most diverse. Largemouth Bass has been the most abundant piscivore in the electrofishing catch since 1995, and may be correlated with the habitat modifications made around Bayfront Park (1992) related to changes in macrophyte density. Other predators were rare in the catch but some species, like American Eel have completely disappeared from the harbour. The disappearance of the American Eel is a lake-wide occurrence, and is probably not the result of local conditions in the harbour. The Lake Ontario Management Unit reported that the number of eels entering the Moses Saunders

Dam on the St. Lawrence River in 2006 was less than 2% of what it was in the early 1990s despite, recent closures of the commercial and sport fisheries (OMNR 2007). The decline of American Eel in Lake Ontario has been attributed to a combination of variables including habitat loss, over-fishing, mortality in hydroelectric turbines and climatic change (OMNR 2007).

Smallmouth Bass biomass has declined in the harbour since the mid-1990s. Similarly, eastern Lake Ontario stock assessment programs showed a decrease in smallmouth bass populations throughout the 1990s that have remained at low to moderate levels (OMNR 2007). Several researchers have linked the decline in Smallmouth Bass in eastern Lake Ontario, beginning in the 1990s, to double-crested cormorant predation (Casselman et al. 2002; Lantry et al. 2002; Johnson et al. 2006; Casselman and Weseloh 2007). Other researchers have concluded that cormorants are opportunistic feeders that pose no serious threat to commercial or sport fishes (Blackwell et al. 2002; Diana et al. 2006; Neuman et al. 1997; Stapanian 2002) but acknowledged that localized predation on sport fish can occur. Weseloh et al. (2002) documented the expansion and growth of cormorant colonies over an 11-year period between 1989 and 2000; colonies followed the distribution of islands and Hamilton Harbour has one of the three largest populations in Lake Ontario. Because of the size of the cormorant colony in the Harbour and evidence of predation on Yellow Perch and Smallmouth Bass in the literature (above), it is conceivable that the cormorants are having an effect on the density of local fish species.

The decline in the percentage of specialists contributing to total biomass in the harbour since the mid-1990s was concurrent with a significant decline in Alewife. However, significant increases in Alewife and Yellow Perch in 2008 have restored percent specialist biomass in the harbour to former levels. In other coastal areas surveyed by DFO (Brousseau et al. 2004; Brousseau et al. 2005), the majority of specialists were comprised mainly of Yellow Perch, centrarchids, catostomids and cyprinids. In Hamilton Harbour, the specialist group is comprised mainly of offshore species (clupeids and White Perch).

Despite declines in abundance since 1995, Alewife was still the most abundant fish in the 2008 Hamilton Harbour catch. The decline in Alewife abundance is a lake-wide phenomenon (OMNR 2007; O'Gorman et al. 2007). Based on lake-wide assessments of prey fish in American waters of Lake Ontario (Oswego to Rochester), Alewife declined to the lowest level observed in 2006 (O'Gorman et al. 2007). In Lake Ontario, adult Alewife biomass was high in the early 1980s but declined until 1996 where levels have remained low since (O'Gorman et al. 2007). Great Lakes researchers have found links between cormorant predation and declines in Alewife as well as declines in Smallmouth Bass and Yellow Perch mentioned earlier (Burnett et al. 2002; Casselman et al. 2002; Casselman and Weseloh 2007). Locally, Somers et al. (2003) found that Alewife comprised about 90% of the double-crested cormorant diet in the spring.

Another non-native specialist, the White Perch, was a key species in the electrofishing catch. Numerically White Perch was the third most abundant fish in a recent OMNR trap net survey (Bowlby et al. 2007) and also comprised a large proportion of offshore trawl catches in the harbour (Doka et al. 2007). However, numbers of White Perch declined significantly in the Hamilton Harbour catch in 2008. White Perch thrive in a degraded environment (Scott and Crossman 1973). Gizzard Shad, a native clupeid, also made a significant but smaller contribution (< 5%) than alewife and white perch to the nearshore catch in most years. The presence of this species has increased significantly and comprised close to 20% of the total harbour biomass in the 2006 electrofishing catch; however, Gizzard Shad only comprised 9% of the catch in 2008. The increase in Gizzard Shad was largely responsible for the increase in percent specialists and consequently the IBI score in 2006. Leslie and Timmins (1992) found that this species favoured low-gradient, turbid water and predominated in the western end of the harbour off Carrolls Point. Small Gizzard Shad can be an important forage item for large predators, like Northern Pike or Walleye, but once they attain a large size they can not be eaten (Scott and Crossman 1972) and may compete with piscivores and other native species for resources. Aday et al. (2003) found in their study of American reservoirs, that in the reservoirs with Gizzard Shad, centrarchid species (e.g. Bluegill) growth rates and size structure were negatively altered and that invertebrate prey were depleted due to competition and an increase in water turbidity.

Yellow Perch was the dominant percid in the harbour electrofishing catch and is one of the most common species in nearshore areas of Lake Ontario (OMNR 2007). The catch of Yellow Perch (specialist) and Logperch (offshore) peaked in 1998, but declined in subsequent surveys. However, the biomass of Yellow Perch increased significantly in 2008 back to former levels (1998) although a similar increase was not seen in the Logperch population. Recent NSCIN surveys found Yellow Perch to be virtually absent from Hamilton Harbour unlike catches from the Bay of Quinte, Toronto Harbour and inland lakes (Bowlby et al. 2007; OMNR 2007). Currently, the Yellow Perch population in eastern Lake Ontario is low to moderate compared to historic levels but increases were seen in recent years (OMNR 2007). Electrofishing surveys conducted in Severn Sound (2002) also found significant declines in Yellow Perch numbers (Hog Bay) and biomass (Penetanguishene Harbour) compared to previous surveys. Yellow Perch are a species that commonly exhibit annual variability in their populations (Scott and Crossman 1972). Researchers studying the relationship between double-crested cormorant colonies and fish in eastern Lake Ontario found significant declines in Yellow Perch populations between 1976 and 1999 despite the production of moderate- to strong year classes (Burnett et al. 2002; Johnson et al. 2006; Casselman and Weseloh 2007); based on the size of the cormorant population in Hamilton Harbour, declines in the Yellow Perch population could be related to predation. Concurrent with the establishment of Round Goby in Hamilton Harbour (1998-2001), the populations of Johnny Darter (*Etheostoma nigrum*) and Logperch have declined. Reductions in Johnny Darter and Logperch populations have been attributed to competition with the non-native Round Goby based on behavioural studies (Balshine et al. 2005) and research in other areas of the Great Lakes (Dopazo et al. 2008; Reid and Mandrak 2008).

The proportion of native fish biomass in the harbour has improved; an average of 64% in 2006 was the closest this measure has come to the delisting target of 80%. Combined with a significant reduction in Common Carp biomass, native fish biomass has almost doubled since 1998 due to significant increases in the catches of Brown Bullhead, Gizzard Shad, Largemouth Bass and Yellow Perch. The significance of this result needs to be interpreted with caution as two of these species (bullheads and shad) are indicative of eutrophic conditions (Bowlby et al. 2007). Numerically, native catches are almost half of what they were in the late 1990s.

A significant decline in non-native fish biomass since 1998 is positive, and reflects a significant decline in Common Carp biomass. However, this decline may not be totally accurate as boat electrofishing gear in not effective at capturing the newest invader (Round Goby) (pers. observ., Polacik et al. 2008). Despite the inefficiency of boat electrofishing in capturing the Round Goby, it has been detected in higher numbers and at an increased number of locations in Hamilton Harbour. Round Goby became established in the Harbour in 1998 (Balshine et al. 2005). Cormorant diet studies by researchers at McMaster University suggest that the goby population is high (Somers et al. 2003). Cormorants tend to forage on the most readily available prey in Hamilton Harbour. In 2002, alewife made up 90% and round gobies 10% of cormorant chick diets; in 2006, the percentage goby in the cormorants' diet was higher (J. Quinn, McMaster University, pers. comm.). In addition, the percent number and biomass of non-native species have increased recently at the three areas surrounding Bayfront Park in the western end of the harbour.

Finally, a large proportion of the nearshore fish community in the harbour is made up of offshore species. In any given year at least 30% of the nearshore fish community is comprised of these littoral visitors, which are largely non-native species (e.g. Alewife, White Perch). The high proportion of non-native, offshore species is not found in any of the other areas surveyed by DFO (see AOC Comparison below).

Comparison of Hamilton Harbour with Bay of Quinte and Severn Sound

Hamilton Harbour was the most severely degraded of the three Areas of Concern (Hamilton Harbour, Bay of Quinte and Severn Sound) first surveyed back in 1988 and 1990 (Randall et al. 1993; Minns et al. 1994; Smokorowski et al. 1998) and remains so to date. Larger increases in average IBI values have been observed in the Bay of Quinte and Severn Sound than in Hamilton Harbour (Brousseau et al. 2004). Hamilton Harbour IBI values are 1.5-2 times lower than IBI scores for Severn Sound embayments (Penetanguishene Harbour and Hog Bay), the Bay of Quinte (Trenton, Belleville and Big Bay) and West Lake. When the IBI scores from Hamilton Harbour were compared to those from the other areas, four metrics were found to be different.

- Native species richness (lower)
- Centrarchid species richness (lower)
- Trophic composition (piscivores-lower, generalists-higher)

- Proportion of non-indigenous species (higher)

The IBI score is highly correlated with species richness (Randall and Minns 2002). One of the differences between Hamilton Harbour and the other areas was the average number species captured per sample. With the exception of Penetanguishene Harbour, average species richness was notably higher in the other areas. Centrarchid species richness was also significantly lower in Hamilton than in the other areas. On average, each area had two to four times more centrarchid species per transect than Hamilton Harbour. In general, while improvements in water quality in the lower Great Lakes have promoted macrophyte growth and the proliferation of phytophilic species like centrarchids, centrarchid species richness in Hamilton Harbour has remained low. The restriction of centrarchids to certain areas of the harbour suggested that high quality habitat with macrophytes was limiting.

The trophic structure of the harbour fish community was different from that of the other areas. The piscivore species were under-represented and generalist species were over-represented in Hamilton Harbour, respectively, compared to Severn Sound, the Bay of Quinte and West Lake. Also, the proportion of offshore specialists that frequent the nearshore zone of the Harbour was higher than elsewhere. At the other AOC and West Lake, specialist biomass was comprised mainly of centrarchids, percids, native cyprinids, and catostomids. In Hamilton, specialist biomass was comprised mainly of non-native and undesirable species (Alewife, Gizzard Shad and White Perch). Even Penetanguishene Harbour, which historically had similar species richness values to Hamilton Harbour, has achieved a more balanced trophic structure (i.e. more piscivores and fewer generalists) over time that is most likely related to water quality improvements and fish habitat management (Brousseau and Randall 2004).

The percentage of piscivores in Hamilton Harbour was low compared to values from electrofishing surveys in other areas. For example, the average percentage of piscivores contributing to total biomass in Hamilton in 2008 was 8.7% compared to greater than 30% in Severn Sound (2002) and the Bay of Quinte (2007). Based on 2006 Near Shore Community Index netting (NSCIN) trap net surveys, Bowlby et al. (2007) found the catch of Northern Pike in the Hamilton Harbour encouraging but numbers of other piscivores (i.e. Largemouth Bass, Smallmouth Bass and Walleye) were low compared to the Bay of Quinte (OMNR 2007). Walleye were rare in the harbour catch. In eastern Lake Ontario, the Walleye population has been relatively stable since 2001 and recruitment has been successful although the population is still not as large as it was in the late 1980s or early 1990s (OMNR 2007).

Degraded conditions may make the harbour more vulnerable to the invasion and establishment of non-native species. In Hamilton Harbour, non-native species have made up a large proportion of the catch, 32-68% in any given year, compared to less than 10% in other survey areas. While carp continue to be the key contributor to total biomass at Hamilton, they were rarely captured in recent electrofishing catches from other areas (2002-2007). The non-indigenous proportion of the catch in Hamilton Harbour was significantly lower between 2002 and 2008, but these species continue to be more abundant in Hamilton Harbour than elsewhere. Degraded water quality conditions and historical habitat loss are still hindering the recovery of the fish community in the harbour. High quality habitat is required to support a diverse fish community that can support top predators and mitigate the impacts of invasive species (Minns et al. 1999).

Different seasonal trends in species richness were found between Hamilton Harbour and the other areas. While species richness increased significantly by season in both the Bay of Quinte and West Lake, it remained constant and on average, much lower in Hamilton Harbour. This result suggests that the harbour cannot support the same range of species as the other areas on a seasonal basis, possibly due to water quality issues like anoxia in the summer and early fall. The potential impact of seasonal changes in oxygen levels on nearshore fishes in Hamilton Harbour needs to be investigated.

Another distinction between the fish community in Hamilton and the other areas was the seasonal distribution of non-native species. In the other areas, non-native species are a small component of the total catch and therefore, there were no obvious seasonal trends. In Hamilton, the catch of non-natives was significantly lower in the fall than the spring due to the absence of spawning non-native species like Alewife. The decrease in the catch of non-native species in the fall was responsible for the seasonal increase in the IBI score in Hamilton Harbour. Conversely, in the Bay of Quinte and West Lake, seasonal increases in the IBI scores were correlated with species richness. In this case, examining the individual metrics rather than the IBI score was more useful; seasonal trends in species richness would not have been detected if only the IBI score had been examined.

Summary

The Index of Biotic Integrity can be used is an indicator for assessing fish assemblages in littoral areas of the Great Lakes, and can be linked to habitat diversity and quality at different areas (Randall and Minns 2002). In comparison to other AOCs, the state of Hamilton Harbour's fish community continues to be relatively poor. The current structure of the fish assemblage reflects a shortage of high quality habitat in the littoral zone (Minns et al. 2004) containing a diversity of substrates and macrophytes; the percentage of littoral piscivores, native cyprinids, centrarchids and percids was lower than elsewhere. Comparison of IBI metrics to those of other AOCs, examination of trends over time for individual species and the results of the OMNR's NSCIN program also indicated that the state of the fish community was poor. The composition of the offshore component of the IBI score was found to be mainly comprised of non-native species. For this reason, the current IBI score adjusted for offshore species (IBI*) was a more accurate measure of the status of the harbour's fish community.

Fish habitat restoration and water quality initiatives have improved conditions for fish in the harbour but more advances are needed. Increases in macrophyte growth and diversity may create more spawning and nursery habitat for certain native species. For many species, like native cyprinids and centrarchids, there is still relatively little suitable habitat. Poor water quality persists and significant improvements are required before physical and environmental habitat conditions will be suitable to improve conditions for native fishes. The capping of Randle Reef, to commence in the near future, will reduce the leakage of toxic chemicals into the harbour but the effect on the fish community is unknown. None of the other Canadian AOCs studied by this group within DFO have been exposed to the same degree of industrial disturbance and contamination. It is unknown how eutrophication problems associated with waste water treatment facilities will be resolved in the near future but plans for enhanced treatment at local WWTP are encouraging.

In the future, the nearshore fish assemblage in Hamilton Harbour should be monitored periodically (every 2-5 years) using the standardized electrofishing protocol to continue the time series monitoring. Other confounding factors have emerged since the delisting criteria were established in 1992 that are complicating efforts to restore fish populations in the harbour including the addition of non-native species (e.g. Round Goby), the increased abundance of double-crested cormorants, and possibly exploitation. Frequent monitoring will help to better understand the effects of changing biological and environmental conditions on the nearshore fish community in Hamilton Harbour.

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Table 1. Hamilton Harbour electrofishing samples: total number of samples by transect and year. Areas as labelled on Figure 1.

AREA	TRANSECT	1988	1990	1992	1995	1996	1997	1998	2002	2006	2008
A	2	7	3	2	3	4	4	4	4	3	3
A	4	7	3	2	3	4	4	4	4	3	3
B	6	7	3	2	3	4	4	4	6	3	3
B	8	6	3	2	3	4	4	4	6	3	3
C	9	9	1	2	2	3	2	3	4	3	3
C	10	7	3	2	2	3	2	3	4	3	4
C	11	9	1	2	2	3	2	3	4	3	4
C	12	7	3	2	2	3	2	3	4	3	4
D	14	7	3	2	3	4	4	4	4	3	3
D	16	7	3	2	3	4	4	4	4	3	3
E	17	11	1	2	3	4	4	4	4	3	3
E	18	8	3	2	1	4	4	4	4	3	3
E	19	9	1	2	2	4	4	4	4	3	3
E	20	7	3	2	2	4	4	4	4	3	3
F	22	7	3	2	3	4	4	4	4	3	4
F	24	7	3	2	3	4	4	4	4	3	4
G	26	7	3	2	3	4	4	4	4	3	4
G	28	7	3	2	3	4	4	4	4	3	4
H	30	7	3	2	3	4	4	4	4	3	3
H	32	7	3	2	3	4	4	4	4	3	3
J	34	7	3	2	3	4	4	4	4	3	3
J	36	7	3	2	3	4	4	4	4	3	3
K	37	9	1	2		4	3	4	4	3	3
K	38	7	3	2	3	4	3	4	4	3	3
K	39	9	1	1		4	3	4	4	3	3
KB	41B	-	-	-	3	4	3	4	4	3	1
KB	42A	-	-	-	2	4	3	4	4	3	3
KB	42B	-	-	-	3	4	3	4	4	3	3
KB	43B	-	-	-	3	4	3	4	3	3	3
KB	44	-	-	2	3	3	3	4	4	3	3
KB	45	-	-	2	2	4	3	4	4	3	3
Total samples:		189	64	53	55	89	75	89	94	62	98

Table 2. Average water quality values from July and August by year (if available).

Year	Number of Samples	Mean water temperature (°C) (SE)	N	Average dissolved oxygen (mg/L) (SE)	N	Mean conductivity (μmhos) (SE)	N	Mean Secchi depth (m) (SE)
1988	215	24.1 (0.1)		-		-	13	1.4 (0.1)
1990	22	25.8 (0.1)		-		-	20	1.7 (0.1)
1992	44	21.1 (0.2)						
1995	31	23.0 (0.2)		-		-		-
1996	71	22.8 (0.3)		-		-		-
1997	75	20.7 (0.2)		-		-		-
1998	72	22.8 (0.2)	72	12.1 (0.5)	72	477.8 (5.0)		-
2002	69	25.0 (0.2)	69	7.6 (0.1)	69	581.5 (6.1)	69	1.4 (0.0)
2006	31	25.0 (0.2)	31	13.3 (0.6)	31	614.4 (3.3)	31	1.3 (0.1)
2008	67	22.8 (0.3)	67	11.7 (0.3)	67	622.4 (6.2)	67	1.1 (0.0)

Table 3. Median substrate category and macrophyte density by area (A to KB) in Hamilton Harbour. Macrophyte data was collected in September of 1993, 2002, 2006 and 2008.

Shoreline	**Area**	**No. of transects**	**Substrate category[1] Median (range)**			**Macrophyte density[2] Median (range)**			
			2002	**2006**	**2008**	**1993**	**2002**	**2006**	**2008**
East	A	2	6.0 (6-6)	3.0 (3-3)	5.0 (2-6)	0.0 (0-2)	1.5 (1-2)	1.0 (1-1)	1.0 (1-1)
East	B	2	3.0 (3-3)	3.0 (3-3)	3.0 (3-4)	0.0 (0-1)	0.5 (0-1)	1.0 (1-1)	0.5 (0-1)
Northeast	C	4	3.0 (2-6)	3.0 (2-4)	3.0 (3-5)	0.0 (0-0)	1.0 (0-2)	1.0 (1-1)	1.0 (0-1)
Northeast	D	2	3.0 (2-5)	3.0 (3-3)	3.0 (2-5)	0.5 (0-1)	1.5 (1-2)	1.0 (1-1)	0.5 (0-1)
North	E	4	3.0 (3-3)	3.0 (2-3)	3.0 (2-5)	3.0 (3-3)	2.0 (2-2)	1.5 (1-2)	3.0 (2-3)
North	F	2	3.0 (3-3)	3.0 (3-3)	3.0 (1-3)	2.5 (1-3)	1.0 (1-1)	0.5 (0-1)	0.5 (0-1)
North	G	2	3.0 (3-3)	3.0 (3-3)	3.0 (3-3)	3.0 (3-3)	2.0 (2-2)	1.5 (1-2)	1.5 (1-2)
Northwest	H	2	2.0 (2-2)	2.0 (2-2)	2.0 (2-2)	0.0 (0-1)	0.0 (0-0)	0.0 (0-0)	0.0 (0-0)
West	J	2	5.0 (5-5)	5.0 (5-5)	5.0 (3-5)	1.0 (1-2)	1.0 (1-1)	0.5 (0-1)	0.5 (0-1)
West	K	4	5.0 (3-6)	1.0 (1-5)	2.0 (1-5)	2.0 (2-2)	2.0 (2-2)	2.5 (1-3)	2.0 (0-3)
West	KB	5	6.0 (2-6)	5.0 (1-6)	5.0 (1-6)	2.0 (1-3)	2.0 (2-3)	1.0 (0-3)	1.0 (0-2)

[1] Substrate categories are: mud/organic 1, clay/silt 2, sand 3, gravel/zebra mussels 4, cobble/rubble 5 and boulder/armour stone 6.
[2] Macrophyte categories are: 0-none (0 %), 1-sparse (1-19%), 2-moderate (20-70%), and 3-dense (> 70%).

Table 4. Biological indicators of species richness and composition, trophic composition, and fish abundance from electrofishing data used to calculate IBI.

Metric name	Metric variable	Include in IBI	Influence on IBI
Species richness	count of species		
Numbers	number		
Biomass (kg)	biomass		
Native species richness	count of species	Yes	positive
Centrarchid species richness	count of species	Yes	positive
Turbidity intolerant species richness	count of species	Yes	positive
Non-native species richness	count of species	Yes	negative
Native cyprinid species richness	count of species	Yes	positive
Percent piscivore biomass	biomass	Yes	positive
Percent generalist biomass	biomass	Yes	negative
Percent specialist biomass	biomass	Yes	positive
Number of native individuals	number	Yes	positive
Biomass of natives (kg)	biomass	Yes	positive
Percent non-native species by number	number	Yes	negative
Percent non-native species by biomass	biomass	Yes	negative
Percent offshore species by number	number		
Percent offshore species by biomass	biomass		

Table 5. Average biomass, catch in numbers, species richness and metrics of IBI by year of survey.Average biomass, catch in numbers, species richness and metrics of IBI by year of survey.

Metric name	Target	1988	1990	1992	1995	1996	1997	1998	2002	2006	2008
Biomass (kg)	6-7 kg	11.4	9.0	6.4	5.1	10.4	9.5	7.7	6.1	7.5	5.4
Numbers		79.6	55.1	27.5	49.8	46.5	32.8	55.3	28.4	20.5	29.3
Species richness	6-7 species	5.0	4.0	4.8	5.0	5.9	5.4	6.0	4.5	5.6	6.1
Native species richness		2.8	2.1	2.9	3.3	3.8	4.0	4.3	3.0	4.0	4.3
Centrarchid species richness		0.5	0.4	0.8	1.3	1.5	1.2	1.3	1.1	1.0	0.9
Turbidity intolerant species richness		0.2	0.0	0.3	0.2	0.6	0.5	0.4	0.3	0.5	0.7
Non-native species richness		2.2	1.9	1.9	1.7	2.0	1.4	1.7	1.5	1.6	1.8
Native cyprinid species richness		0.6	0.5	0.8	0.5	0.7	1.0	0.7	0.2	0.6	1.2
Percent piscivore biomass	20-25%	2.5	9.0	12.1	12.1	8.9	7.4	4.5	5.9	5.0	8.7
Percent generalist biomass	10-30%	53.5	45.0	42.4	34.3	59.2	56.9	59.7	57.8	55.6	42.3
Percent specialist biomass	50-60%	42.4	44.4	43.7	51.7	31.9	31.8	32.5	32.0	39.4	48.0
Number of native individuals		22.7	21.7	8.8	19.5	19.4	20.5	36.3	12.7	13.9	16.8
Biomass of natives (kg)		3.7	3.1	1.6	1.4	1.9	1.3	1.6	2.7	3.3	2.6
Percent non-native species by number		65.7	58.5	54.1	56.2	49.4	33.4	32.0	41.8	31.8	35.9
Percent non-native species by biomass		64.3	62.1	61.9	61.1	70.3	58.0	57.2	36.0	35.6	39.0
Percent offshore species by number		62.7	49.2	44.4	60.2	43.7	31.4	46.2	36.0	36.8	42.6
Percent offshore species by biomass		35.4	34.7	29.8	43.2	19.6	14.9	23.4	17.9	25.2	28.0
IBI	55-60	29.6	29.7	33.4	36.0	35.6	37.1	37.7	34.1	40.1	44.3
Adjusted IBI*	50-60	15.0	17.4	20.5	18.9	25.2	28.2	24.2	25.2	27.1	29.8
Sample size		189	64	53	55	89	75	89	94	62	98

Table 6. Fish species captured by year in Hamilton Harbour, 1988 to 2008. Index of Biotic Integrity (IBI) groups are indicated in the footnote. Total numbers of samples and species richness in each year are summarized.

Common name	Scientific name	IBI group[1]	1988	1990	1992	1995	1996	1997	1998	2002	2006	2008
Sea Lamprey	*Petromyzon marinus*	N,Y,S,Y									x	
Longnose Gar	*Lepisosteus osseus*	Y,Y,P,N	x	x								x
Bowfin	*Amia calva*	Y,Y,P,N	x			x	x	x	x	x	x	x
Alewife	*Alosa pseudoharengus*	N,Y,S,Y	x	x	x	x	x	x	x	x	x	x
Gizzard Shad	*Dorosoma cepedianum*	Y,Y,S,Y	x	x	x	x	x	x	x	x	x	x
Rainbow Trout	*Oncorhynchus mykiss*	N,Y,P,Y		x	x	x	x		x	x		
Chinook Salmon	*Oncorhynchus tshawytscha*	N,Y,P,Y	x	x	x	x	x	x	x			x
Brown Trout	*Salmo trutta*	N,Y,P,Y		x	x	x	x	x	x	x		
Lake Trout	*Salvelinus namaycush*	Y,Y,P,Y	x	x		x			x			
Rainbow Smelt	*Osmerus mordax*	N,Y,S,Y	x	x	x	x		x				
Northern Pike	*Esox lucius*	Y,Y,P,N	x	x	x	x	x	x	x	x	x	x
White Sucker	*Catostomus commersonii*	Y,Y,S,N	x	x	x	x	x	x	x	x	x	x
Bigmouth Buffalo	*Ictiobus cyprinellus*	N,Y,S,N								x		x
Silver Redhorse	*Moxostoma anisurum*	Y,Y,S,N							x			
Goldfish	*Carassius auratus*	N,Y,G,N	x	x	x	x	x	x	x	x	x	x
Common Carp	*Cyprinus carpio*	N,Y,G,N	x	x	x	x	x	x	x	x	x	x
Golden Shiner	*Notemigonus crysoleucas*	Y,Y,G,N									x	x
Emerald Shiner	*Notropis atherinoides*	Y,Y,S,N	x	x	x	x	x	x	x	x	x	x
Spottail Shiner	*Notropis hudsonius*	Y,N,S,N	x	x	x	x	x	x	x	x	x	x
Bluntnose Minnow	*Pimephales notatus*	Y,Y,G,N							x			
Fathead Minnow	*Pimephales promelas*	Y,N,G,N						x				x
Black Bullhead	*Ameiurus melas*	Y,Y,G,N								x		
Brown Bullhead	*Ameiurus nebulosus*	Y,Y,G,N	x	x	x	x	x	x	x	x	x	x
Channel Catfish	*Ictalurus punctatus*	Y,Y,G,N								x		x
American Eel	*Anguilla rostrata*	Y,Y,P,N	x	x	x	x	x	x	x			
Threespine Stickleback	*Gasterosteus aculeatus*	Y,Y,S,N				x	x	x		x		
Trout-perch	*Percopsis omiscomaycus*	Y,Y,S,Y	x		x			x				

Common name	Scientific name	IBI group[1]	1988	1990	1992	1995	1996	1997	1998	2002	2006	2008
White Perch	*Morone americana*	N,Y,S,Y	x	x	x	x	x	x	x	x	x	x
White Bass	*Morone chrysops*	Y,Y,S,Y	x	x				x				
Rock Bass	*Ambloplites rupestris*	Y,N,S,N	x		x	x	x	x	x	x	x	x
Pumpkinseed	*Lepomis gibbosus*	Y,Y,S,N	x	x	x	x	x	x	x	x	x	x
Bluegill	*Lepomis macrochirus*	Y,Y,S,N			x	x	x	x	x	x	x	x
Smallmouth Bass	*Micropterus dolomieu*	Y,Y,P,N	x	x	x	x	x		x	x		x
Largemouth Bass	*Micropterus salmoides*	Y,Y,P,N	x	x	x	x	x	x	x	x	x	x
Black Crappie	*Pomoxis nigromaculatus*	Y,Y,S,N	x		x	x	x	x	x	x		
Johnny Darter	*Etheostoma nigrum*	Y,Y,S,N	x				x	x	x			
Yellow Perch	*Perca flavescens*	Y,Y,S,N	x	x	x	x	x	x	x	x	x	x
Logperch	*Percina caprodes*	Y,Y,S,Y			x	x	x	x	x	x	x	x
Walleye	*Sander vitreus*	Y,Y,P,Y			x				x			x
Round Goby	*Neogobius melanostomus*	N,Y,G,N								x	x	x
Freshwater Drum	*Aplodinotus grunniens*	Y,Y,S,N	x	x	x	x	x	x	x	x	x	x
	Sample size		189	64	53	55	89	75	89	94	62	98
	Number of species		26	23	26	27	26	27	29	27	21	27

[1]Four IBI groups are identified. Codes are: Native? (Yes, No); Turbidity tolerant? (Yes, No); Trophic group? (Piscivore, Generalist, or Specialist); Offshore? (Yes, No).

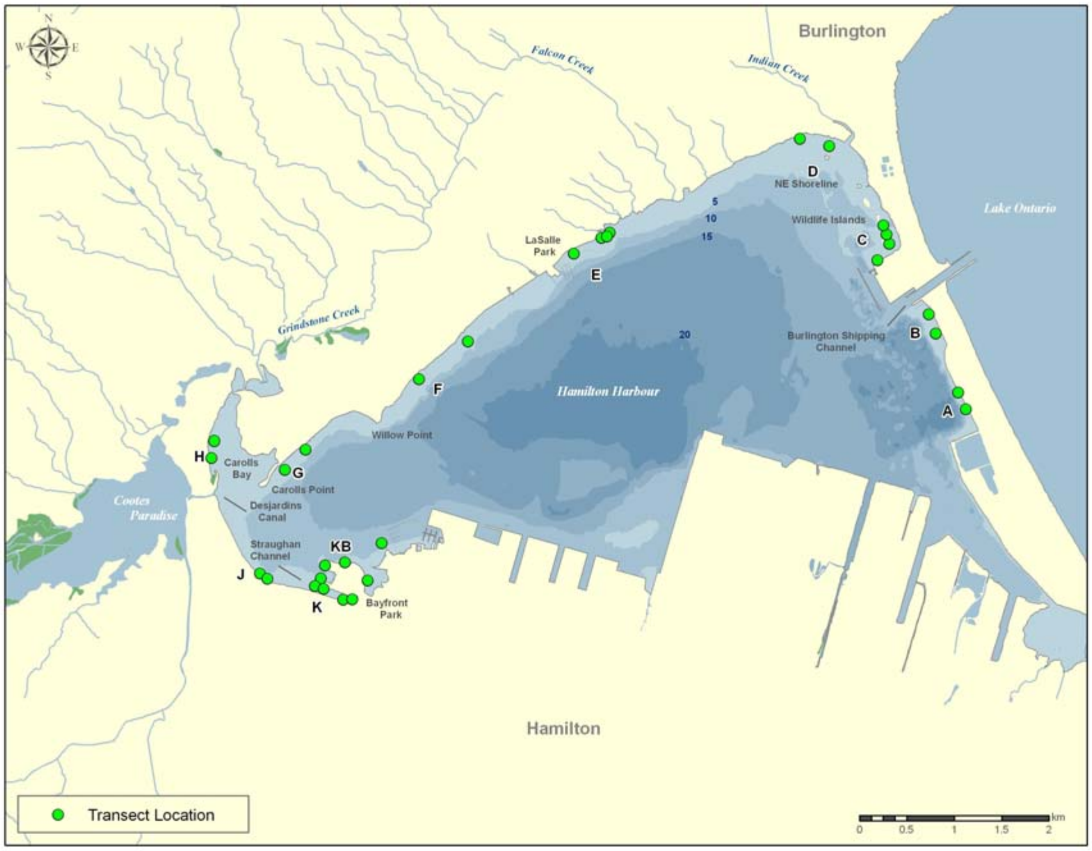


Figure 1. Electrofishing survey areas (A, B, C, D, E, F, G, H, J, K, and KB) in Hamilton Harbour. Restoration sites, in order of chronology, were Bayfront Park (area KB), NE Shoreline (area D), LaSalle Park (area E), and West Harbour Waterfront Trail (area J).

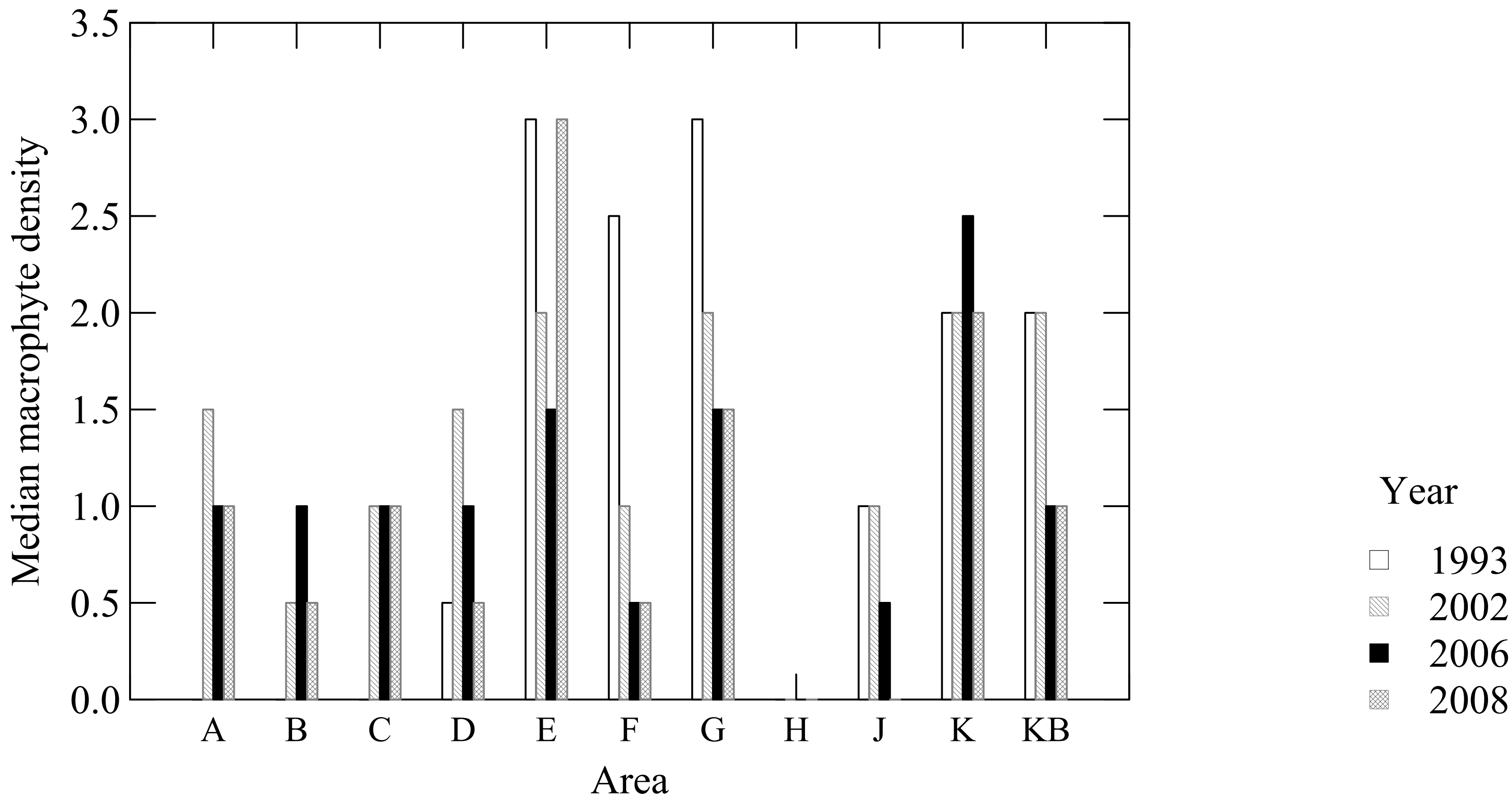


Figure 2. Mean macrophyte density based on visual estimates at transects by area (A to KB) in September 1993, 2002, 2006 and 2008.

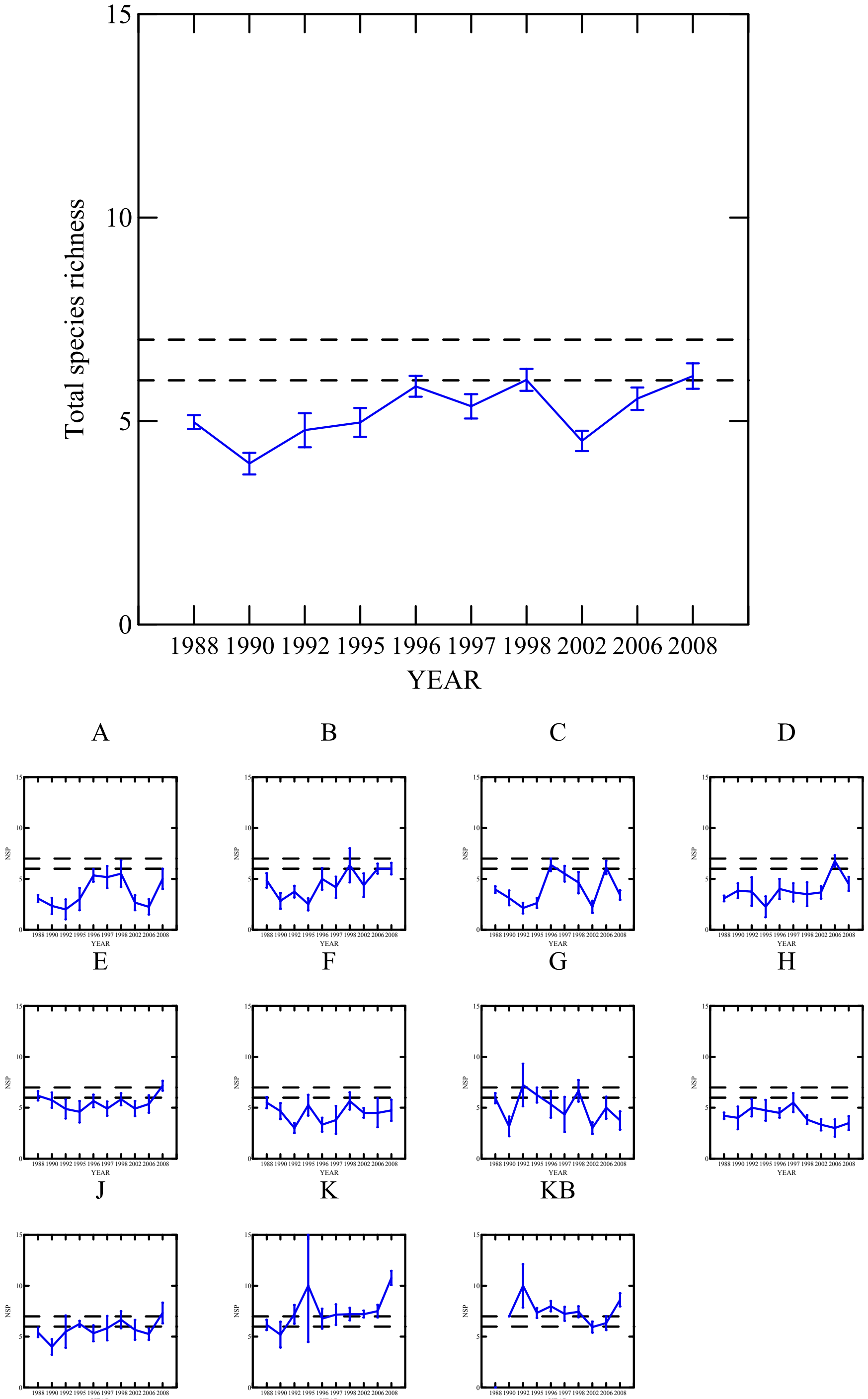


Figure 3. Average species richness in Hamilton Harbour (± SE) for the survey years 1988 to 2006. Upper figure represents an average for all transects, lower smaller figures represent individual sites (Figure 1). Horizontal reference lines (dashed) in this and following figures indicate delisting targets for Hamilton Harbour (see Table 5)

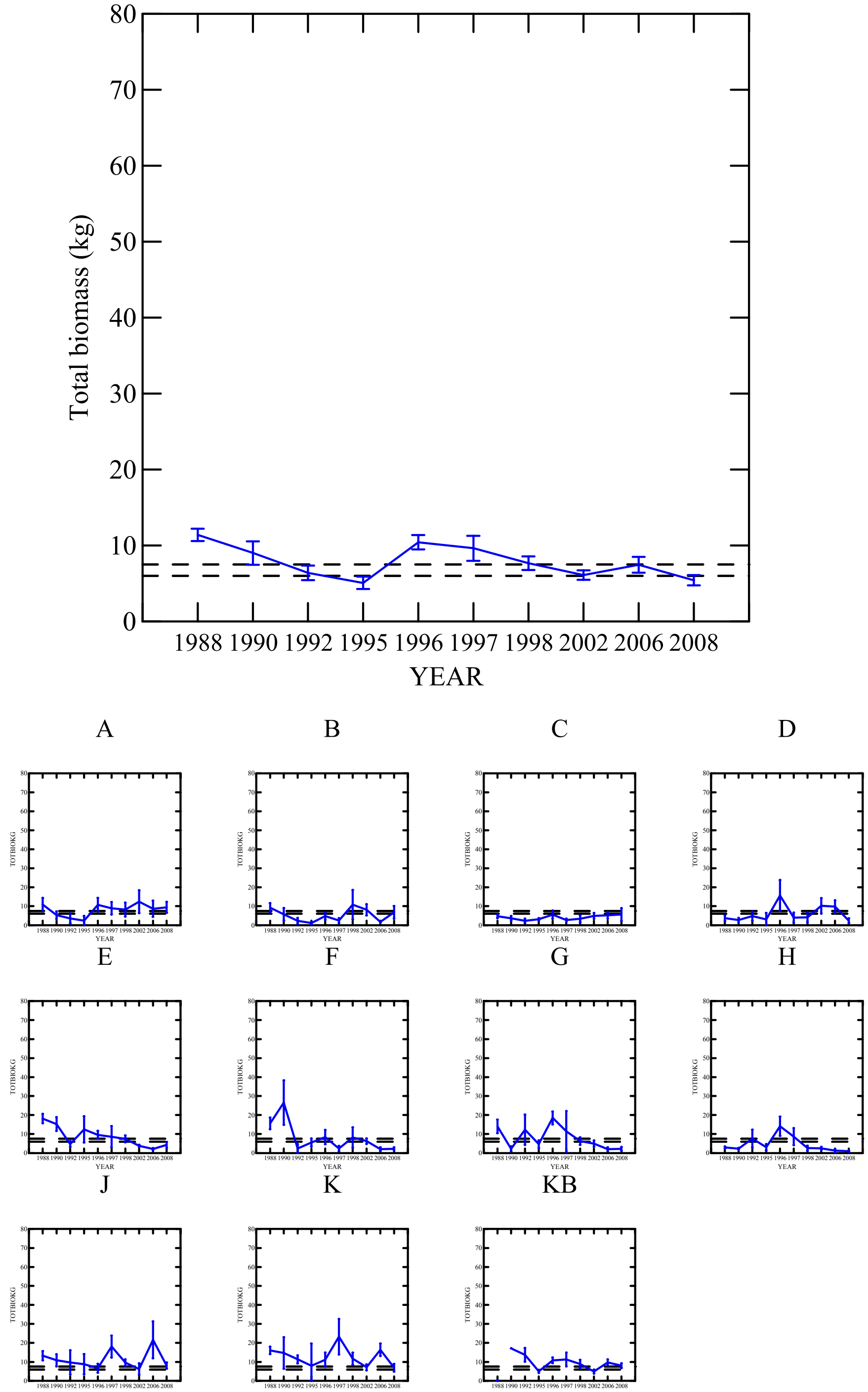


Figure 4. Average total biomass (kg) over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

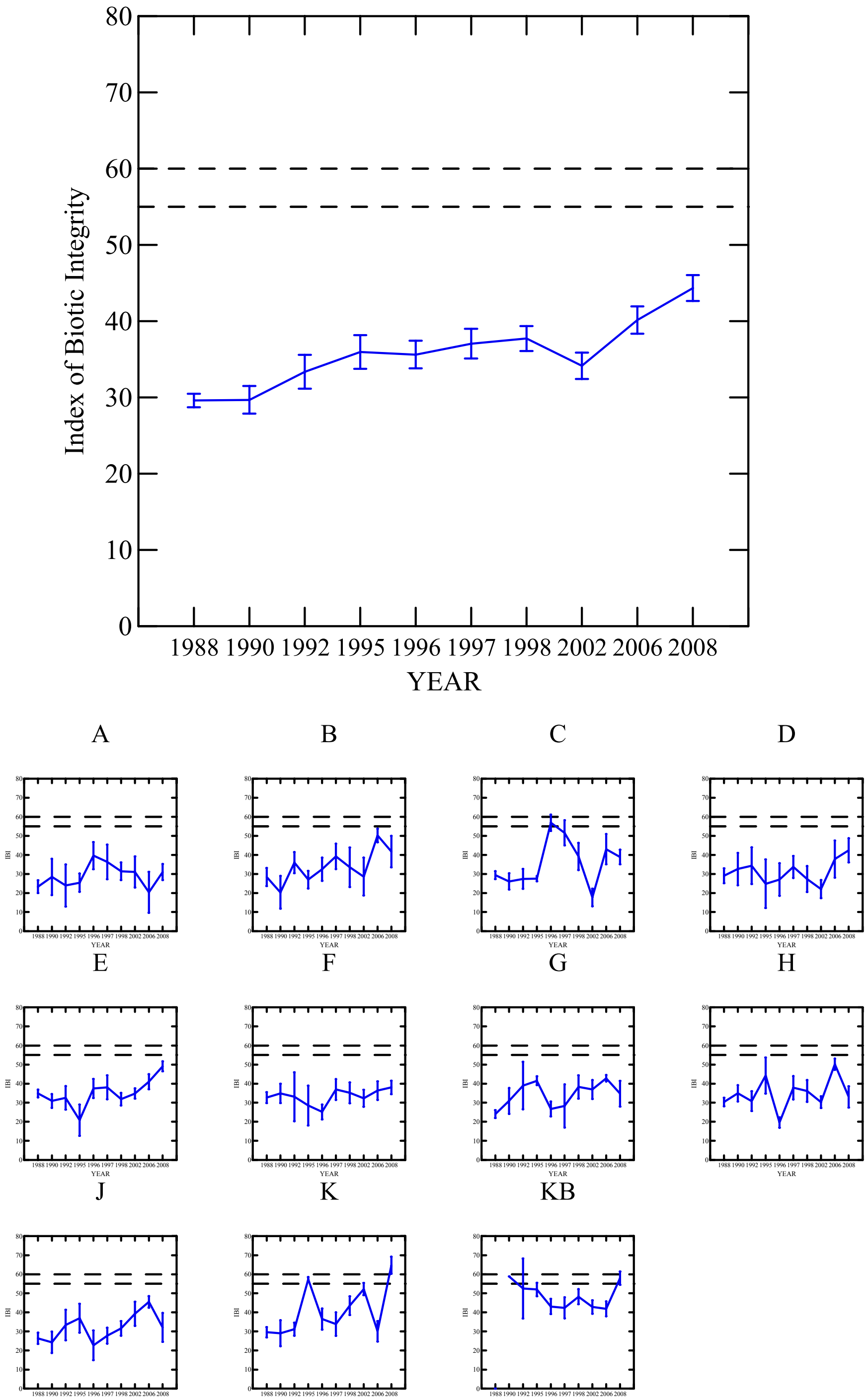


Figure 5. Index of Biotic Integrity scores over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

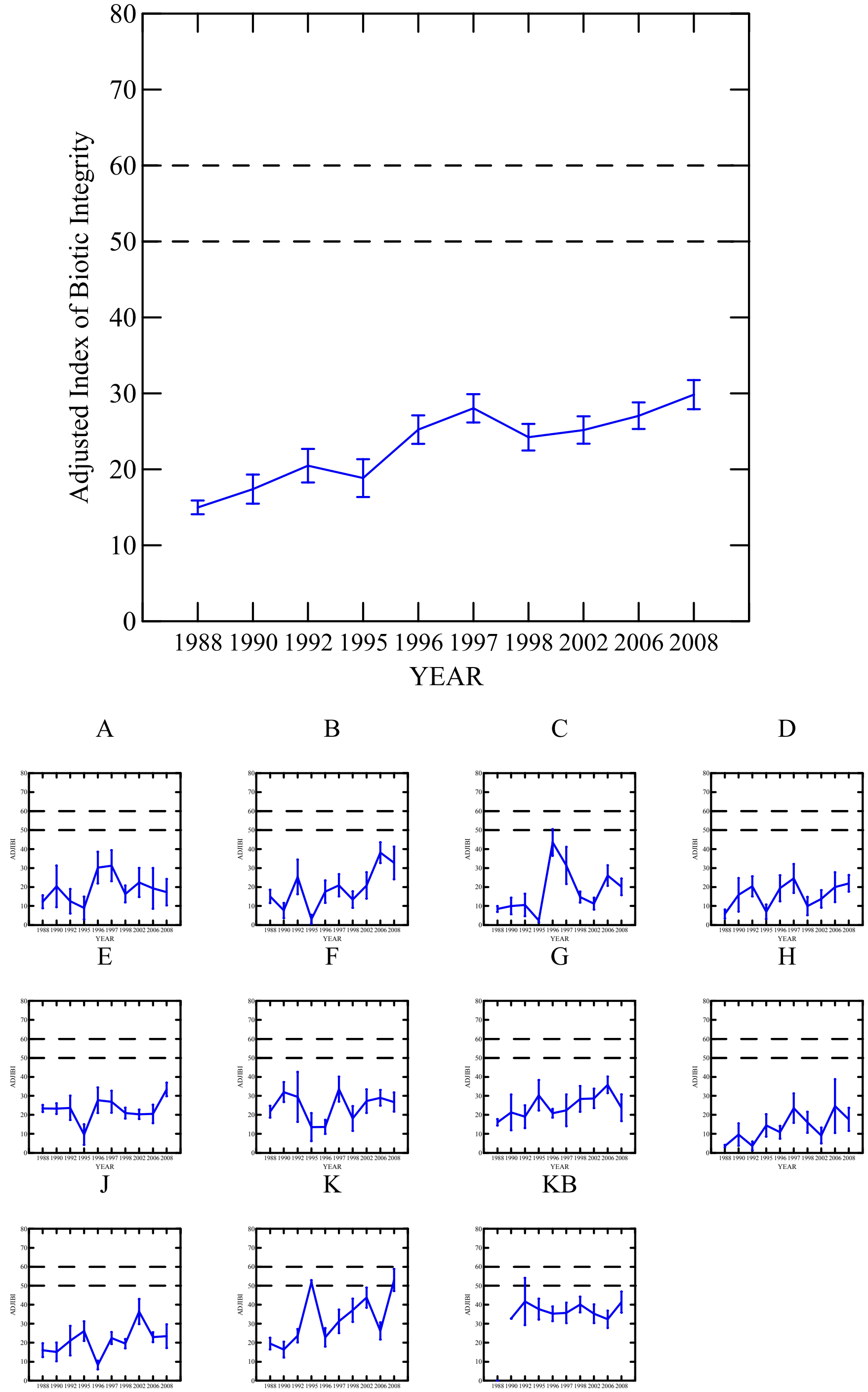


Figure 6. Adjusted Index of Biotic Integrity scores over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

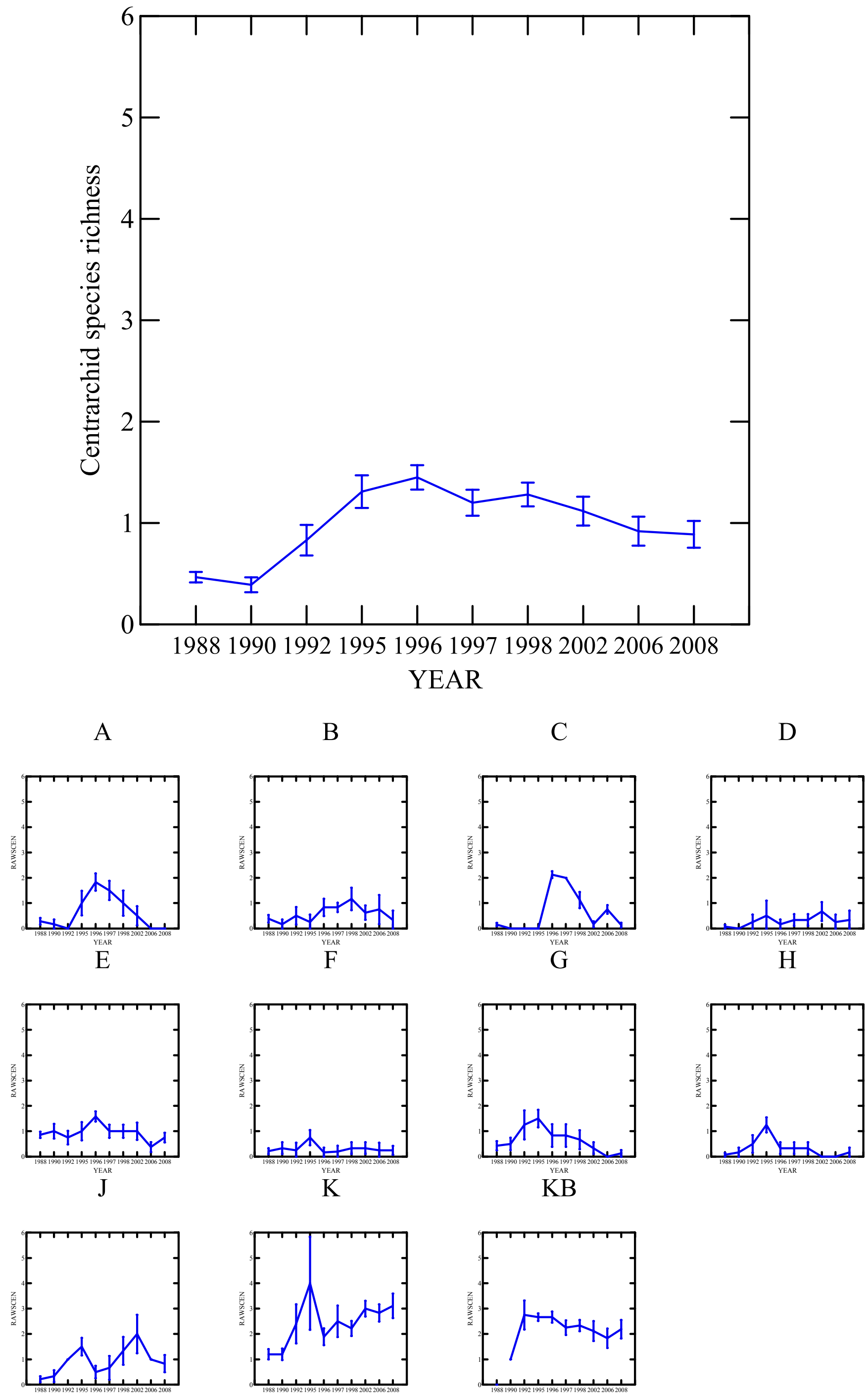


Figure 7. Centrarchid species richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

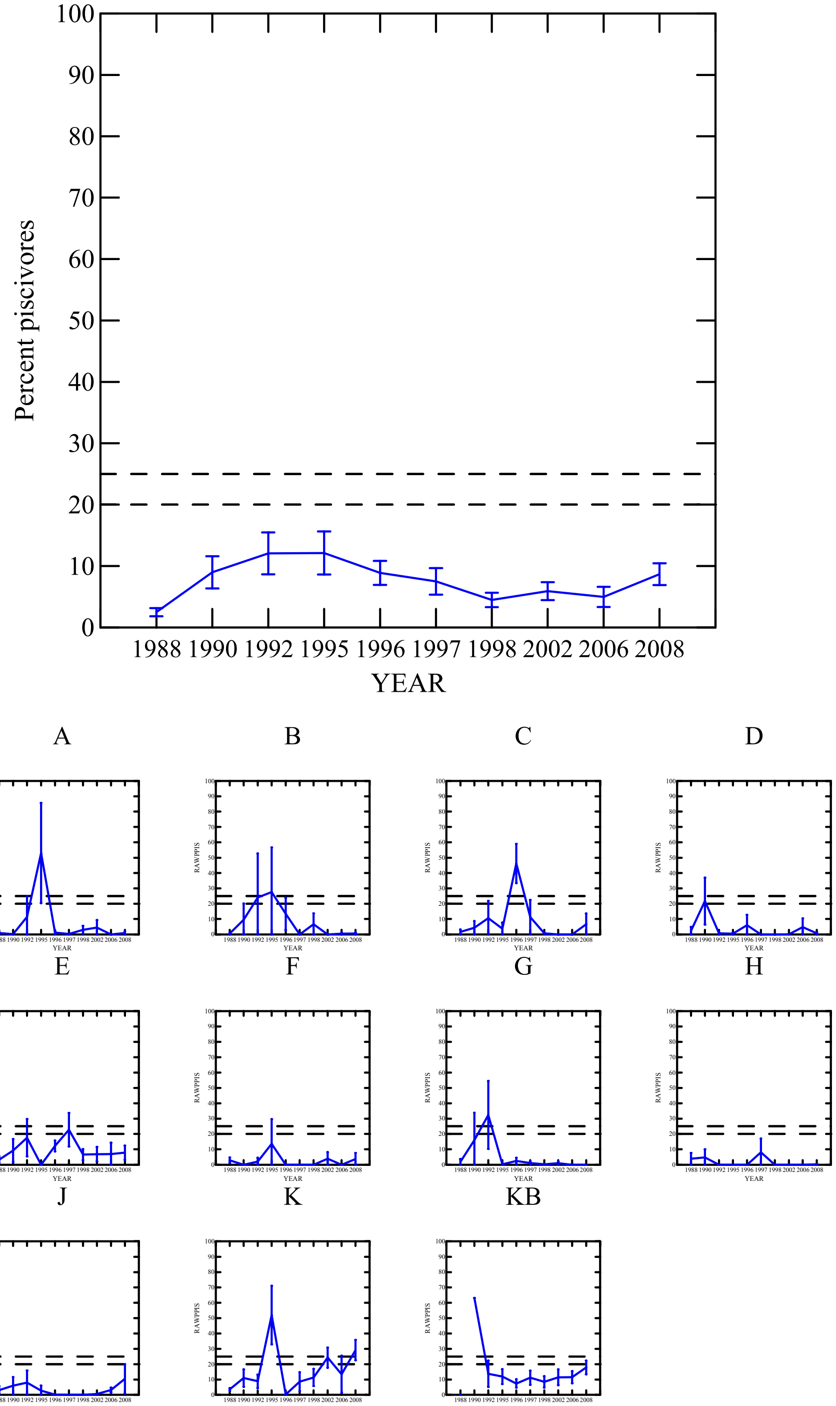


Figure 8. Percent piscivores by biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

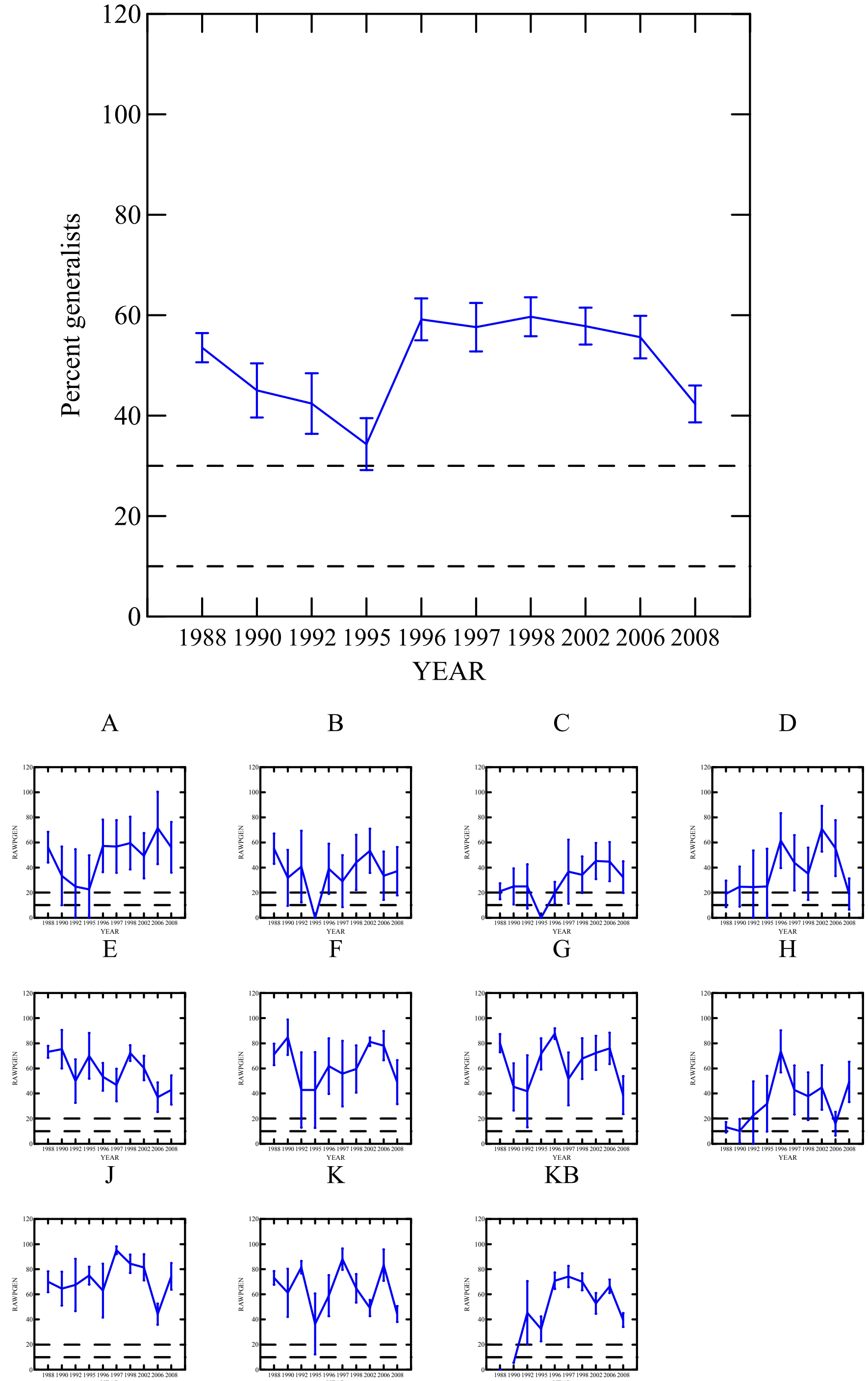


Figure 9. Percent generalists by biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

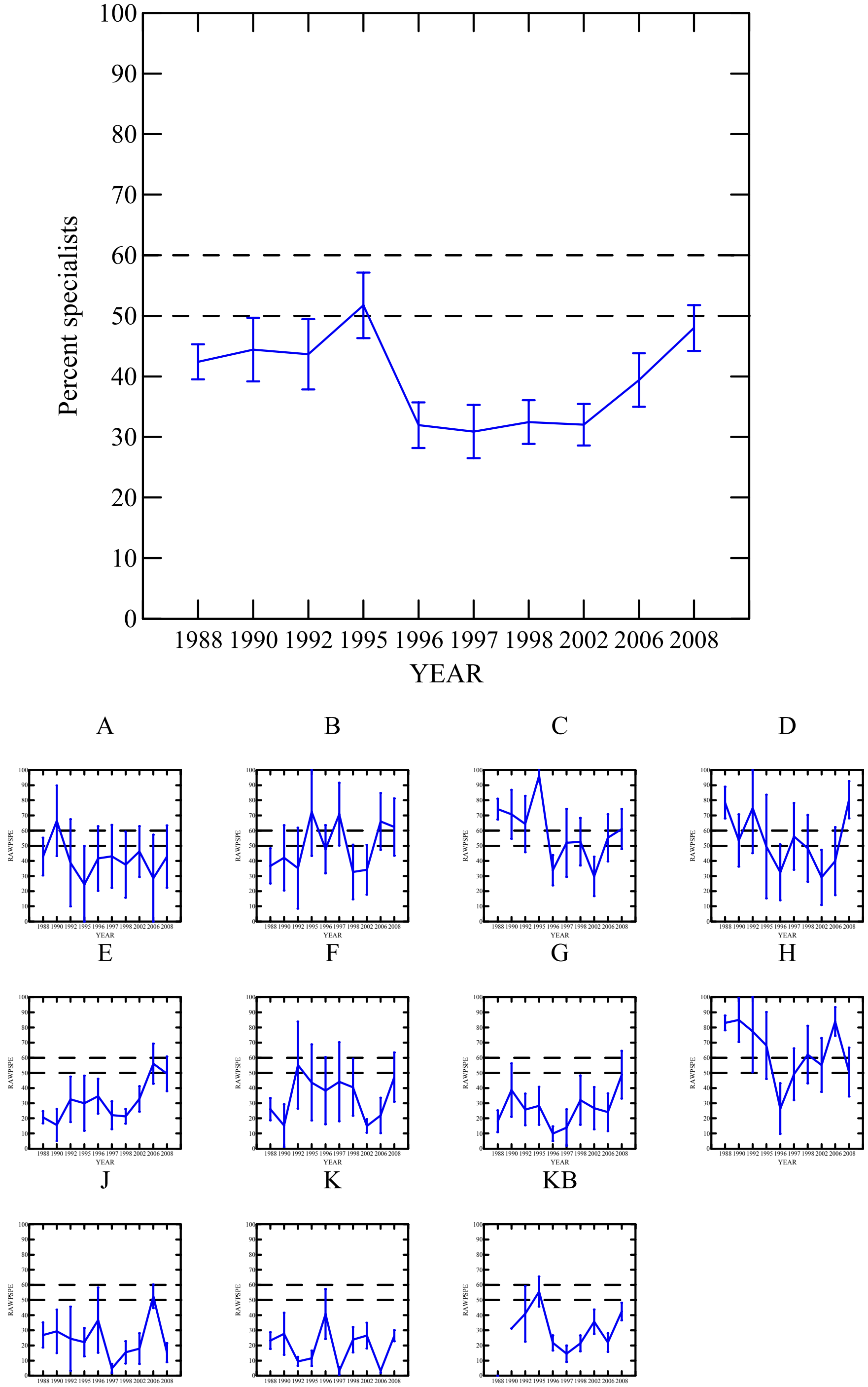


Figure 10. Percent specialists by biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

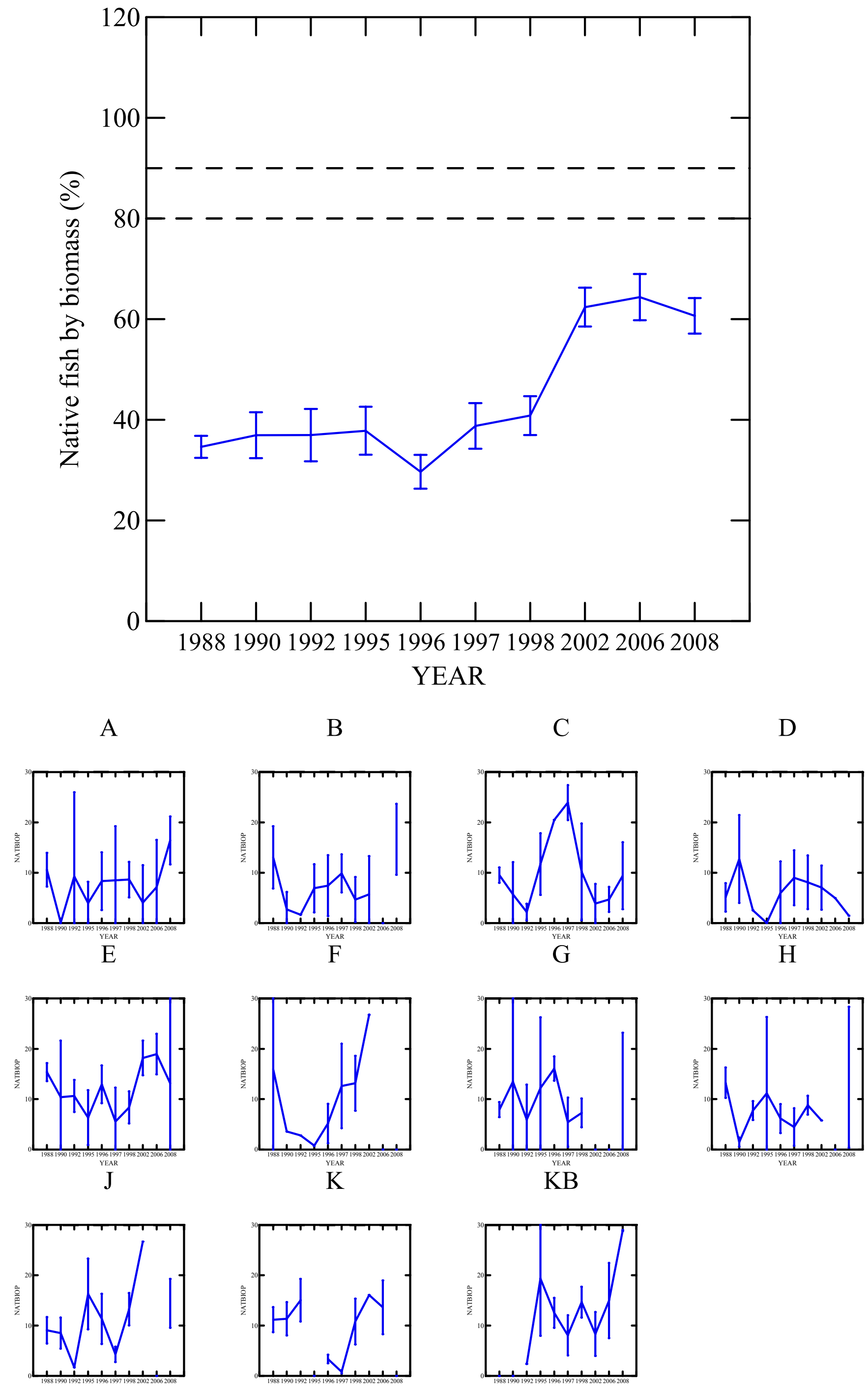


Figure 11. Percent biomass of native fishes over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

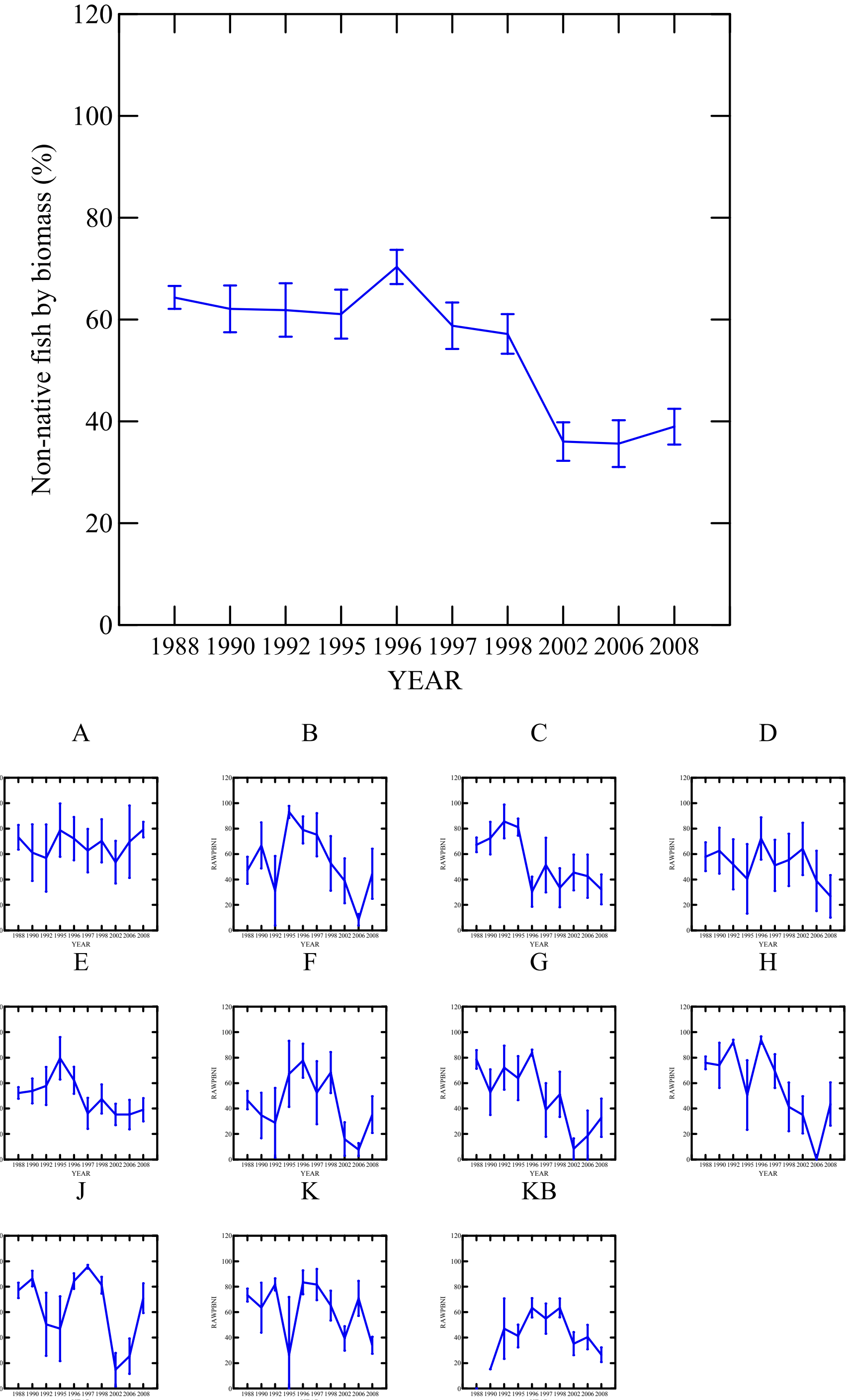


Figure 12. Percent non-native fishes by biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average for all transects, smaller figures represent individual sites.

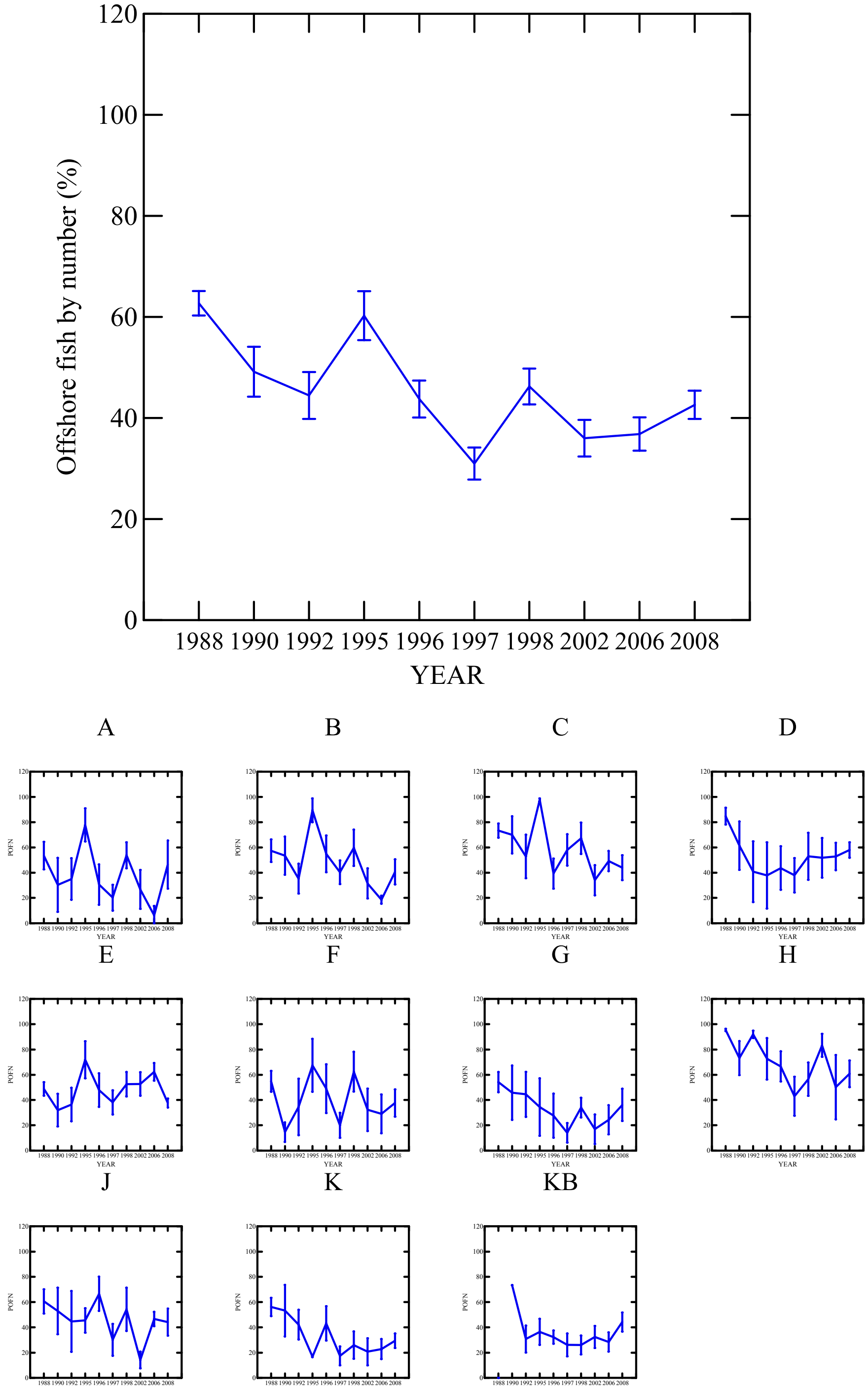


Figure 13. Percent offshore fishes by number over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

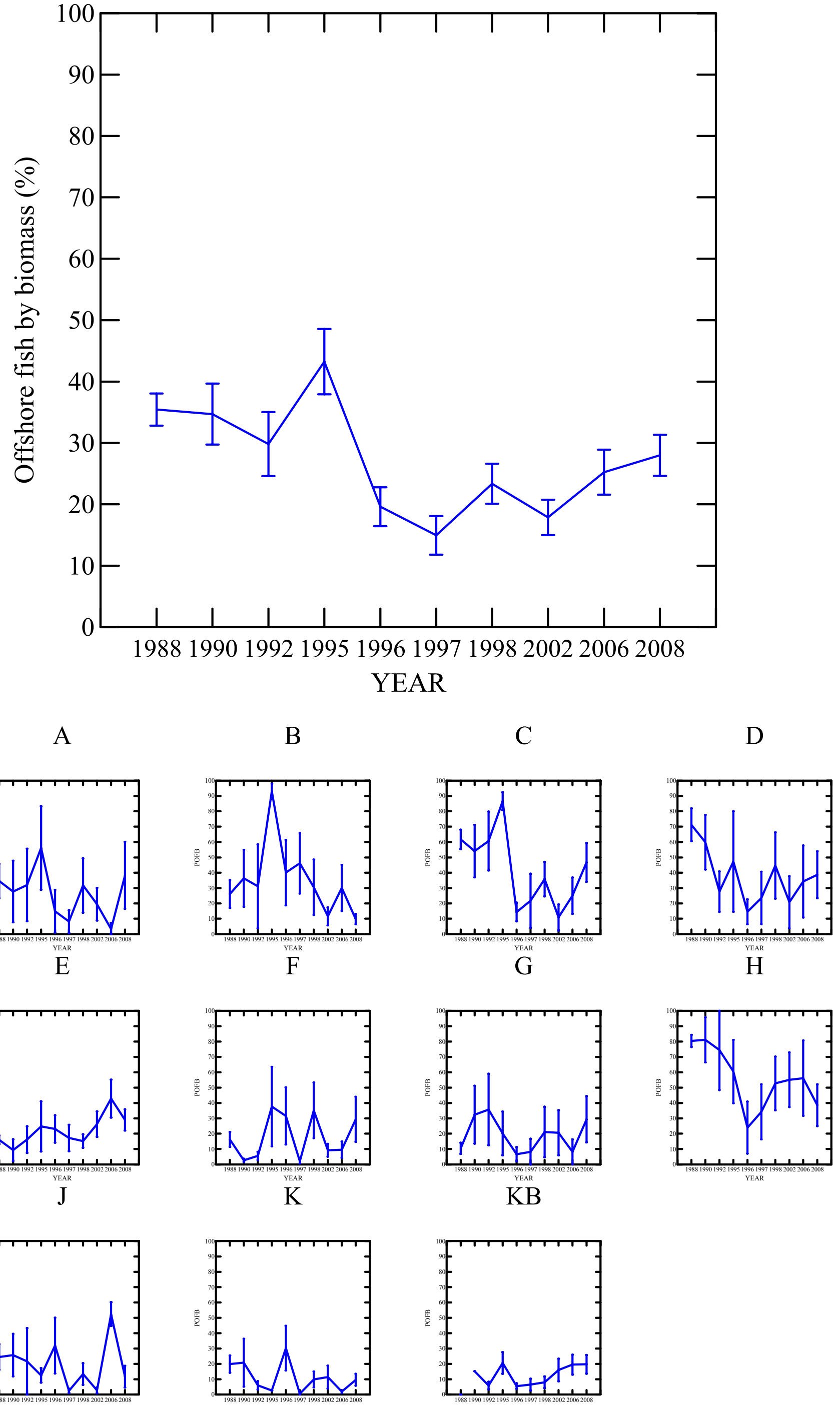
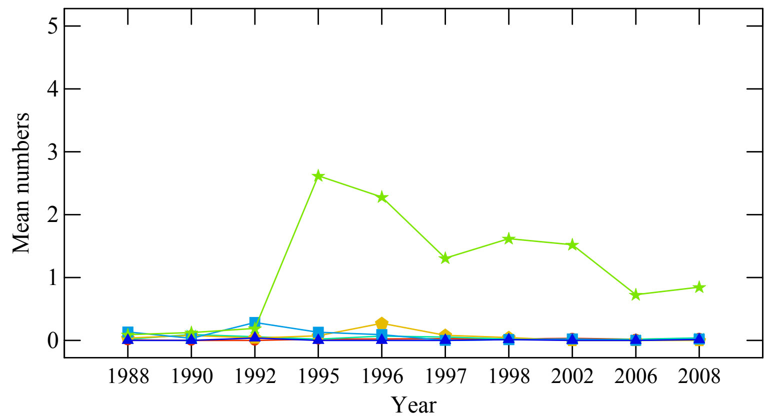


Figure 14. Percent offshore fishes by biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all transects, smaller figures represent individual sites.

Piscivores



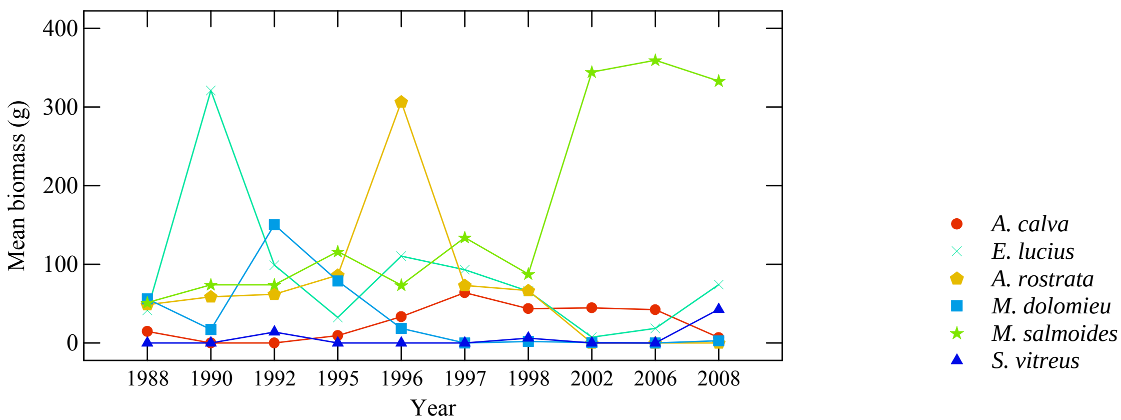


Figure 15. Trends in mean piscivore numbers (top) and biomass, grams (bottom) per transect over time.

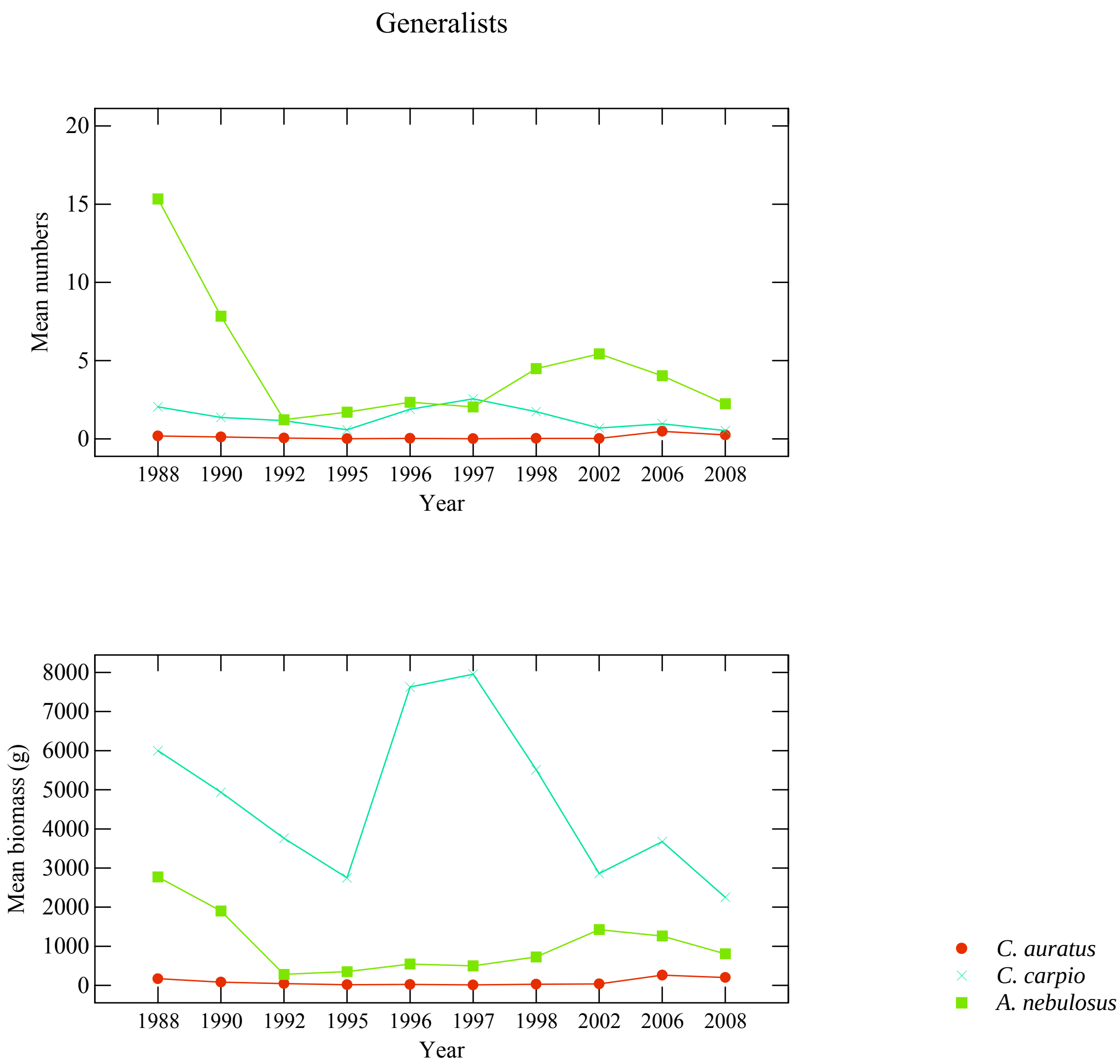


Figure 16. Trends in common generalist numbers (top) and biomass, grams (bottom) per transect over time.

Offshore species

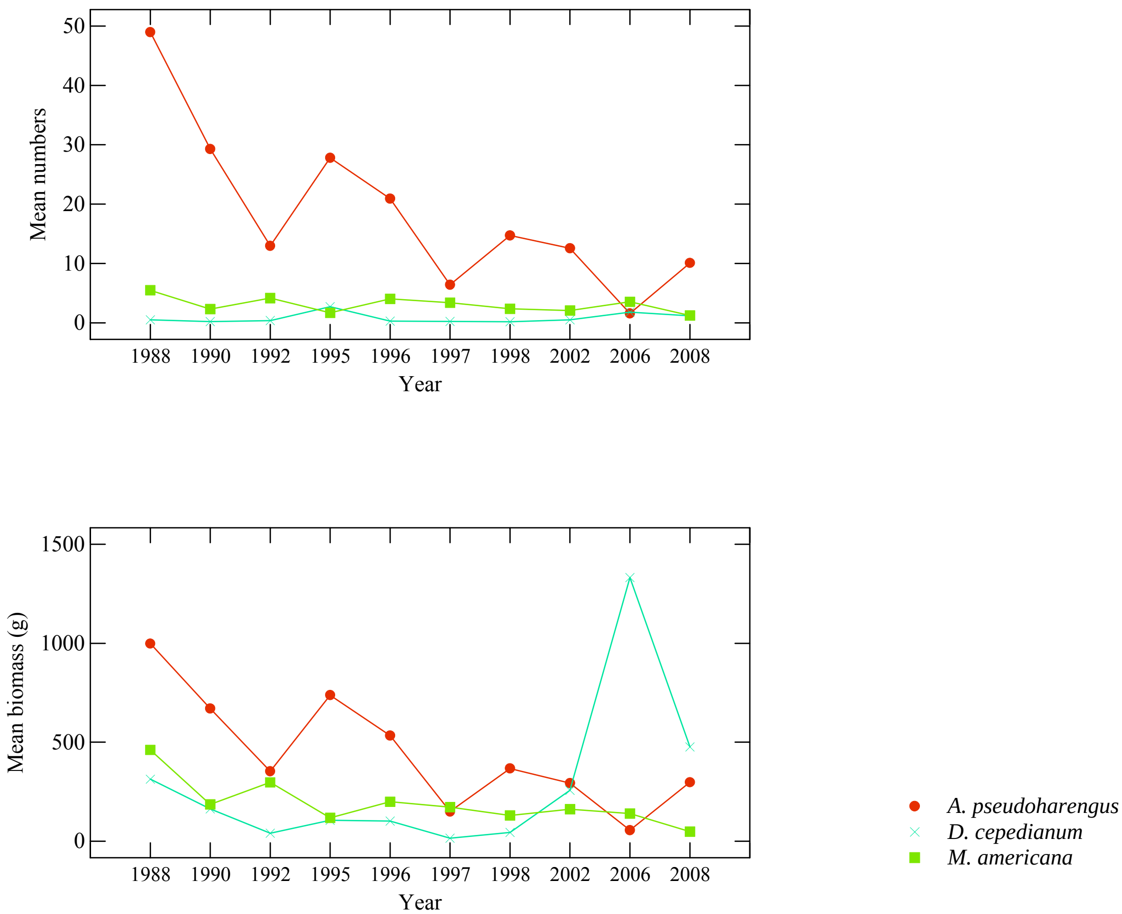


Figure 17. Trends in mean offshore species numbers (top) and biomass, grams (bottom) per transect over time.

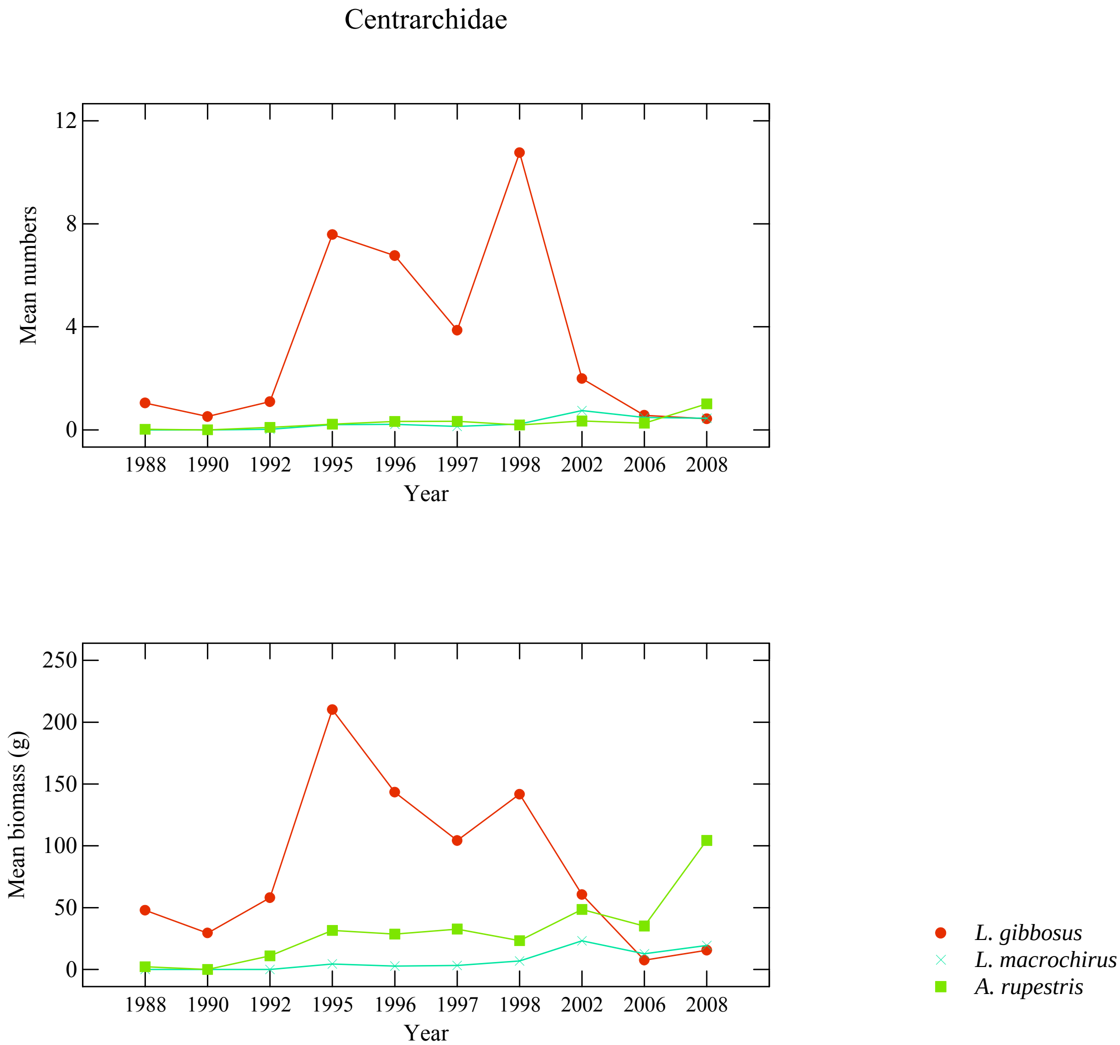
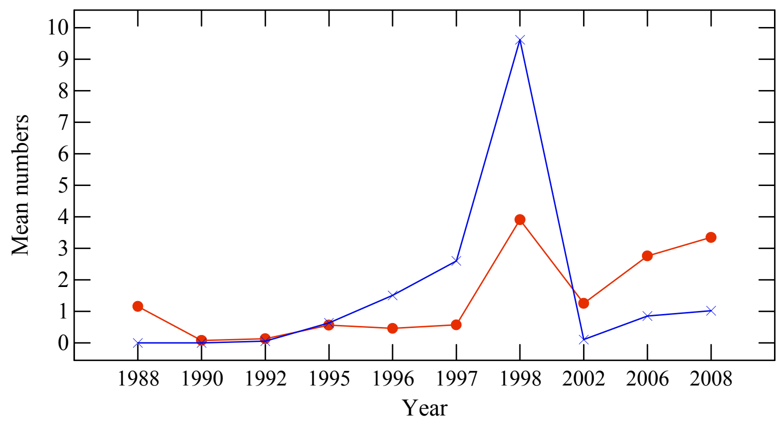


Figure 18. Trends in common centrarchid species numbers (top) and biomass, grams (bottom) per transect over time.

Percidae



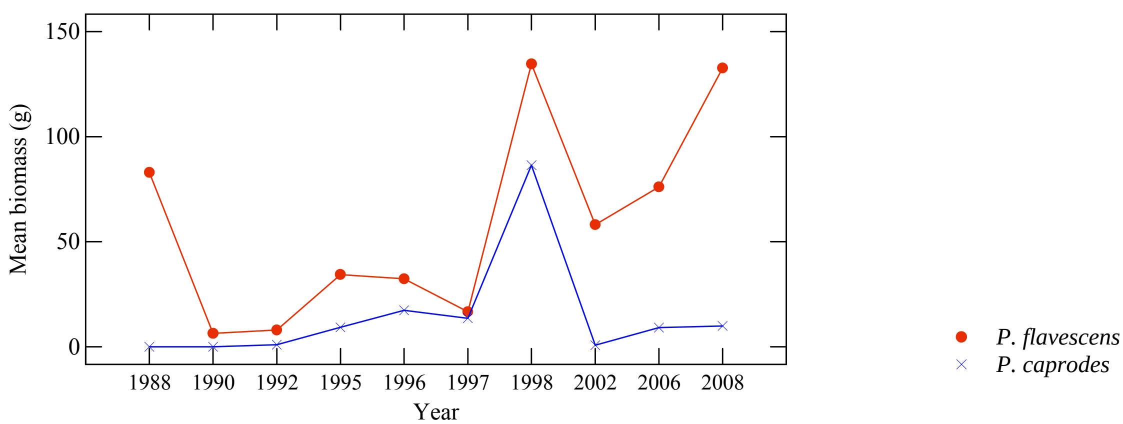


Figure 19. Trends in the two most common percid species, numbers (top) and biomass, grams (bottom) per transect over time.

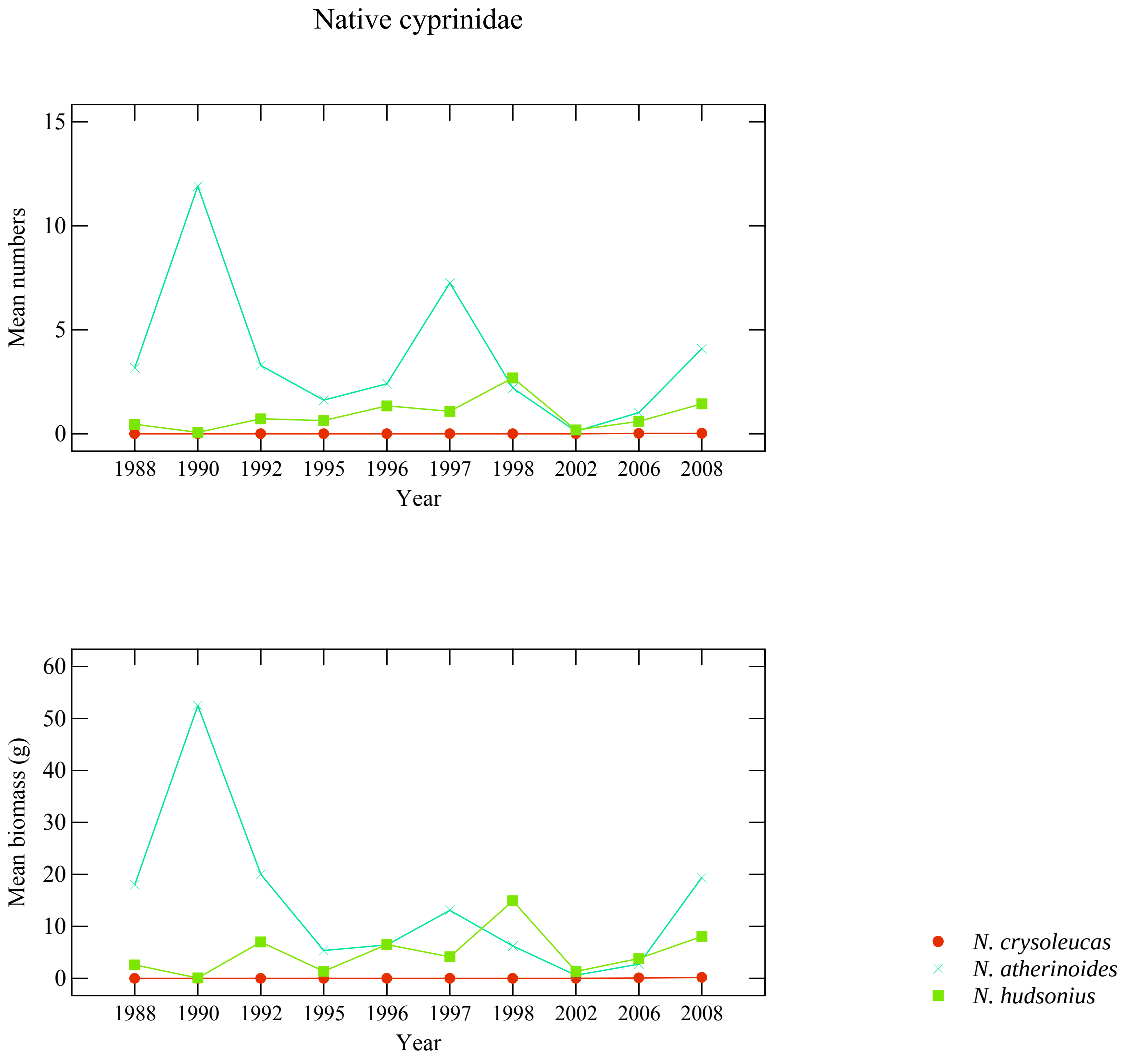


Figure 20. Trends in mean native cyprinid species numbers (top) and biomass, grams (bottom) per transect over time.

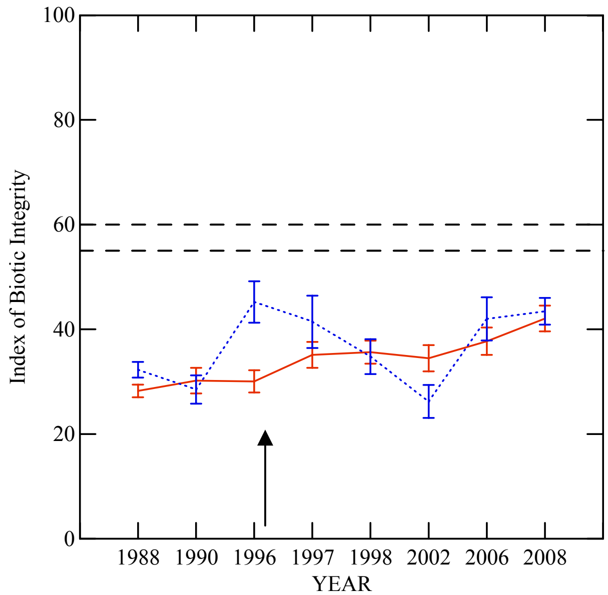


Figure 21. Comparison of Index of Biotic Integrity scores (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

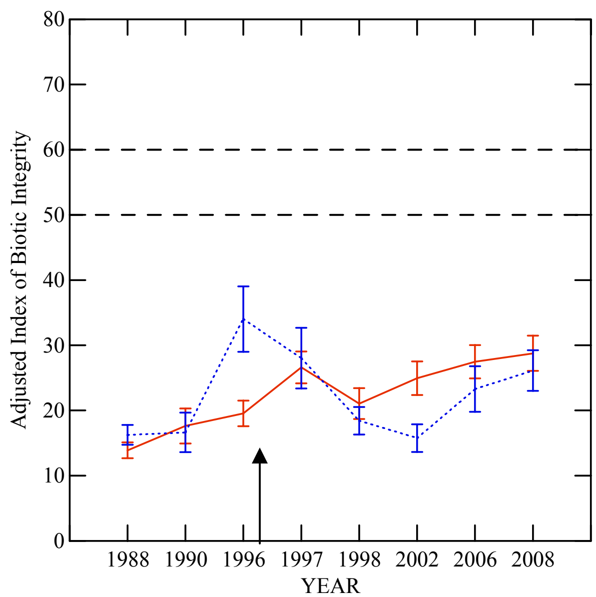


Figure 22. Comparison of Index of Biotic Integrity scores, adjusted for the presence of offshore species (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

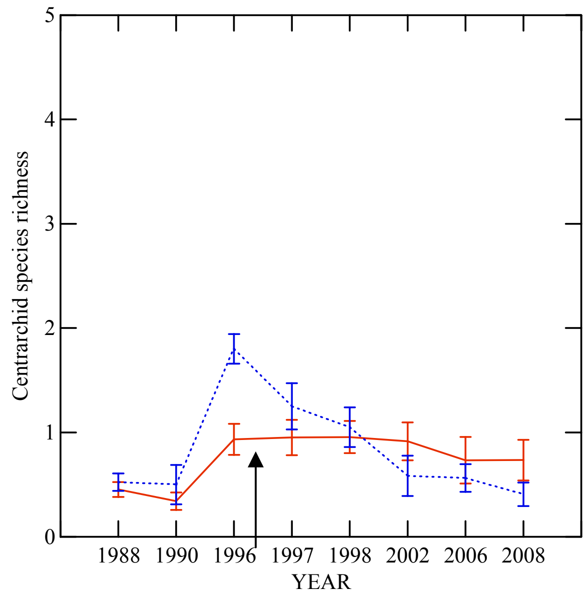


Figure 23. Comparison of centrarchid species richness (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

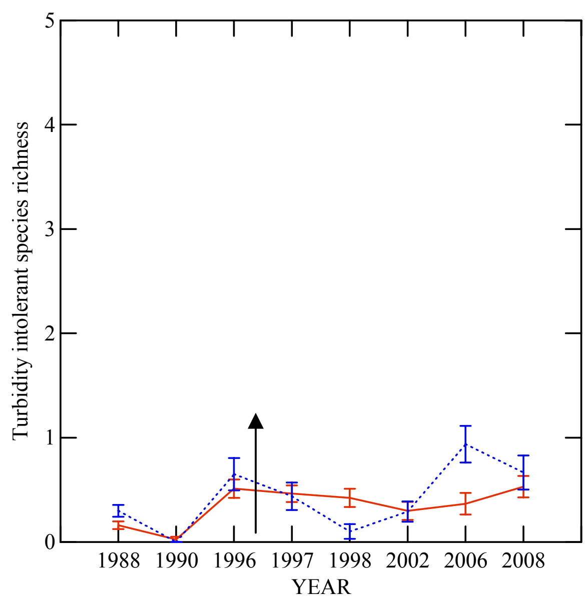


Figure 24. Comparison of turbidity intolerant species richness (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

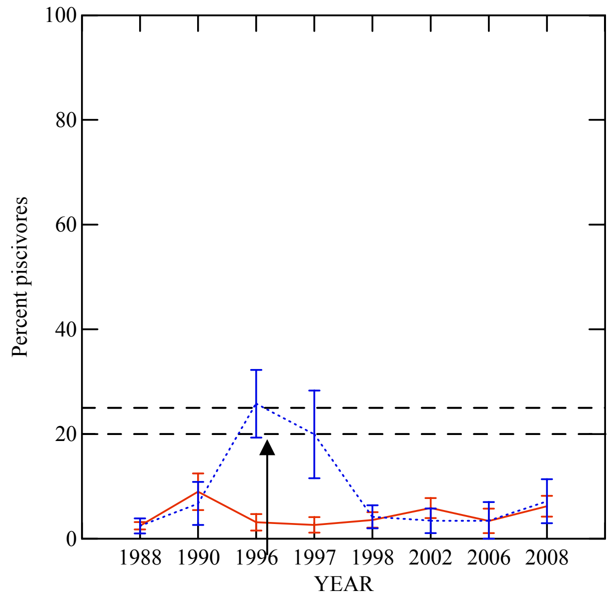


Figure 25. Comparison of percent piscivores by biomass (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

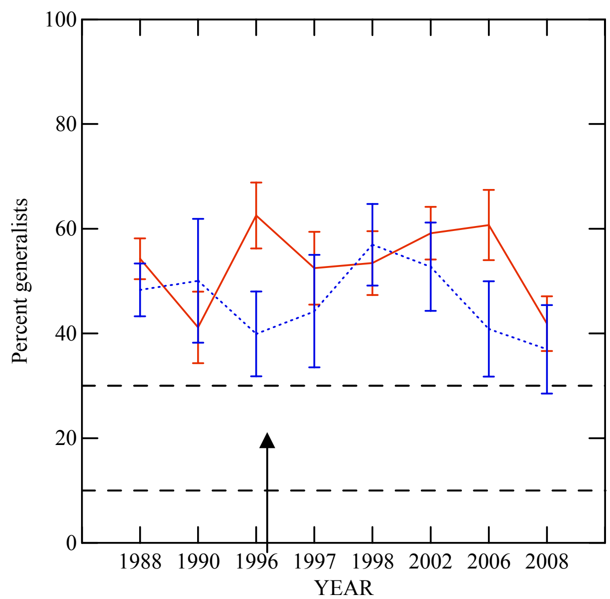


Figure 26. Comparison of percent generalists by biomass (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

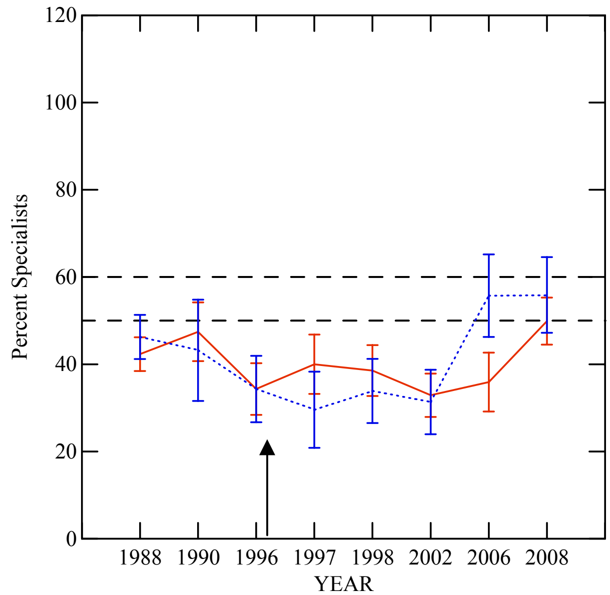


Figure 27. Comparison of percent specialists by biomass (annual mean ± SE) at restoration sites (dashed line, Sites C- northeast shoreline and E- LaSalle Park only), and unaltered sites (solid line) before and after (↑) completion of physical habitat restoration work in Hamilton Harbour.

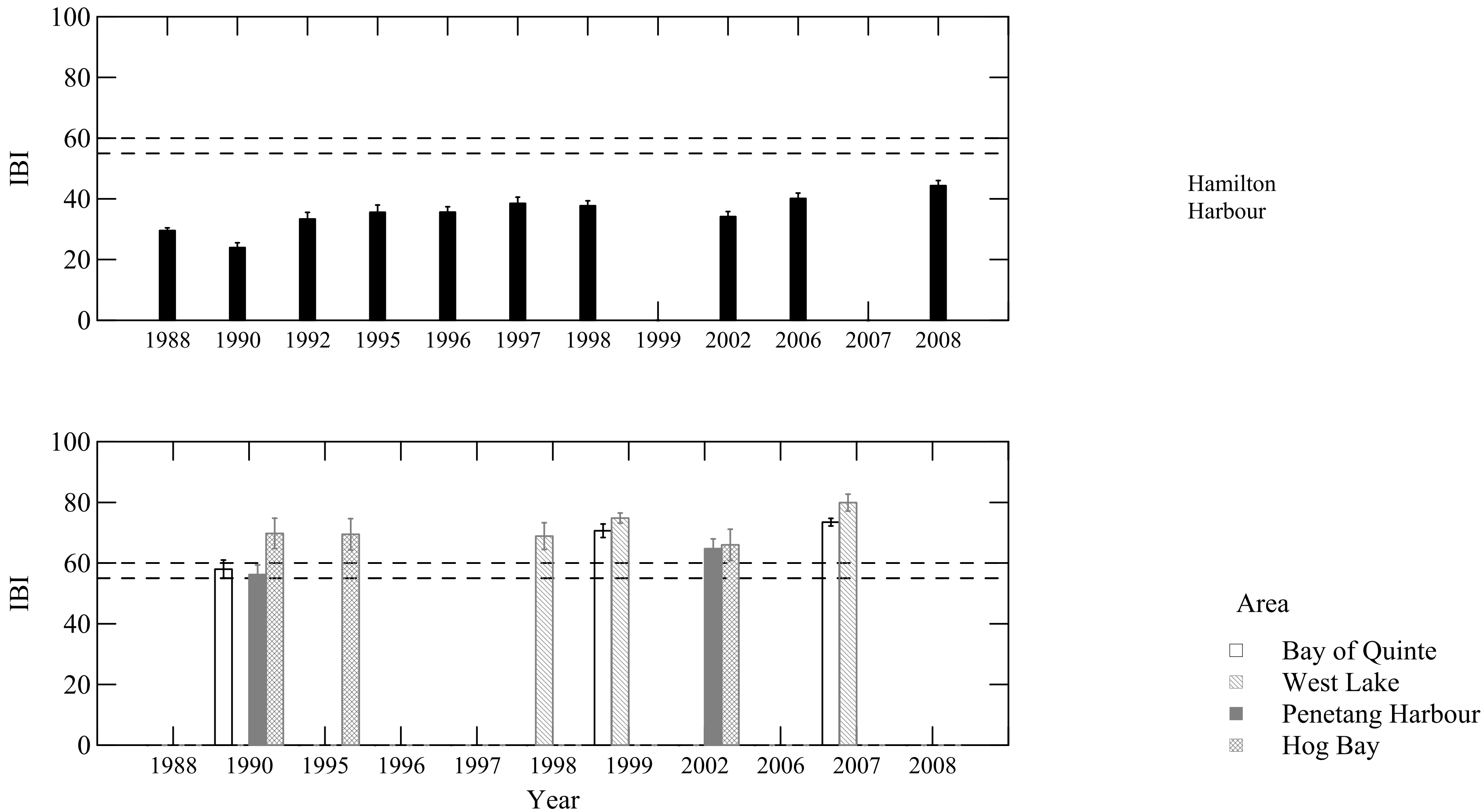


Figure 28. Comparison of average IBI scores per transect by area: Hamilton Harbour (top) and other areas (bottom) among years. The dashed limit lines indicate the Hamilton Harbour delisting target range, 55 to 60, for the IBI score.

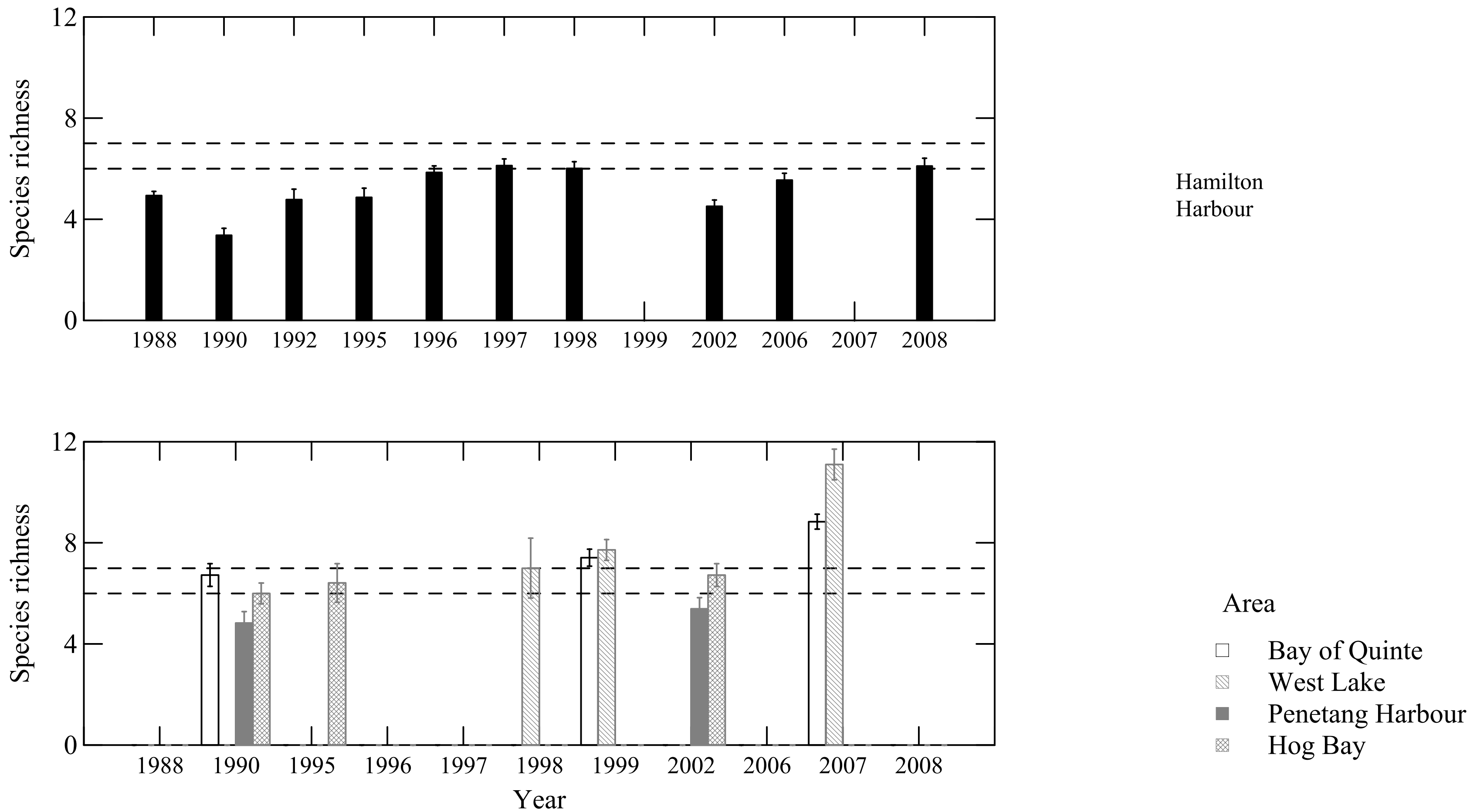


Figure 29. Comparison of average species richness per transect by area; Hamilton Harbour (top) and other areas (bottom) among years. The dashed limit lines indicate the Hamilton Harbour delisting target range, 6 to 7, for species richness.

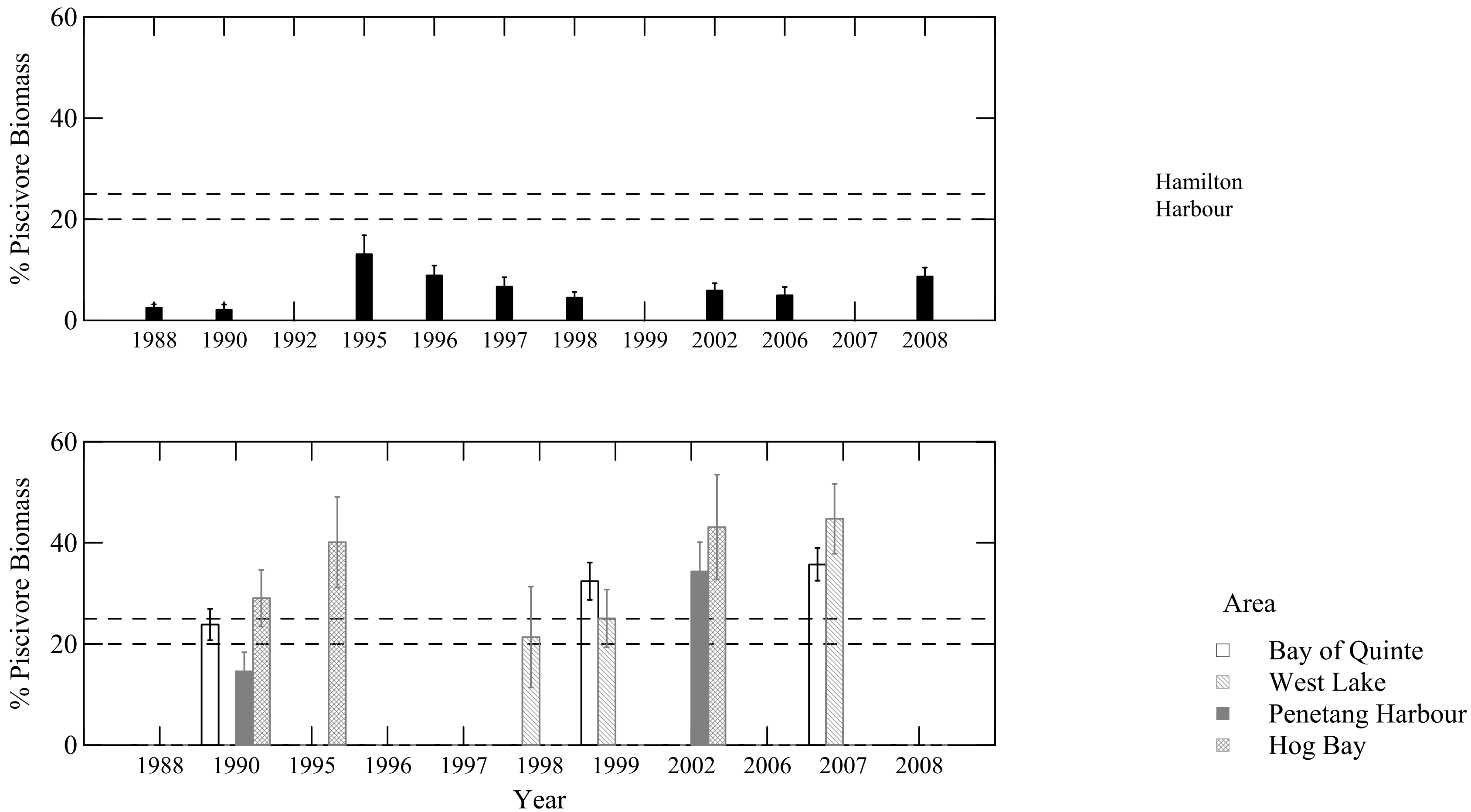


Figure 30. Comparison of the average percent piscivores by biomass per transect by area; Hamilton Harbour (top) and other areas (bottom) among years. The dashed limit lines indicate the Hamilton Harbour delisting target range of 20 to 25, for the percentage of piscivores in the total catch.

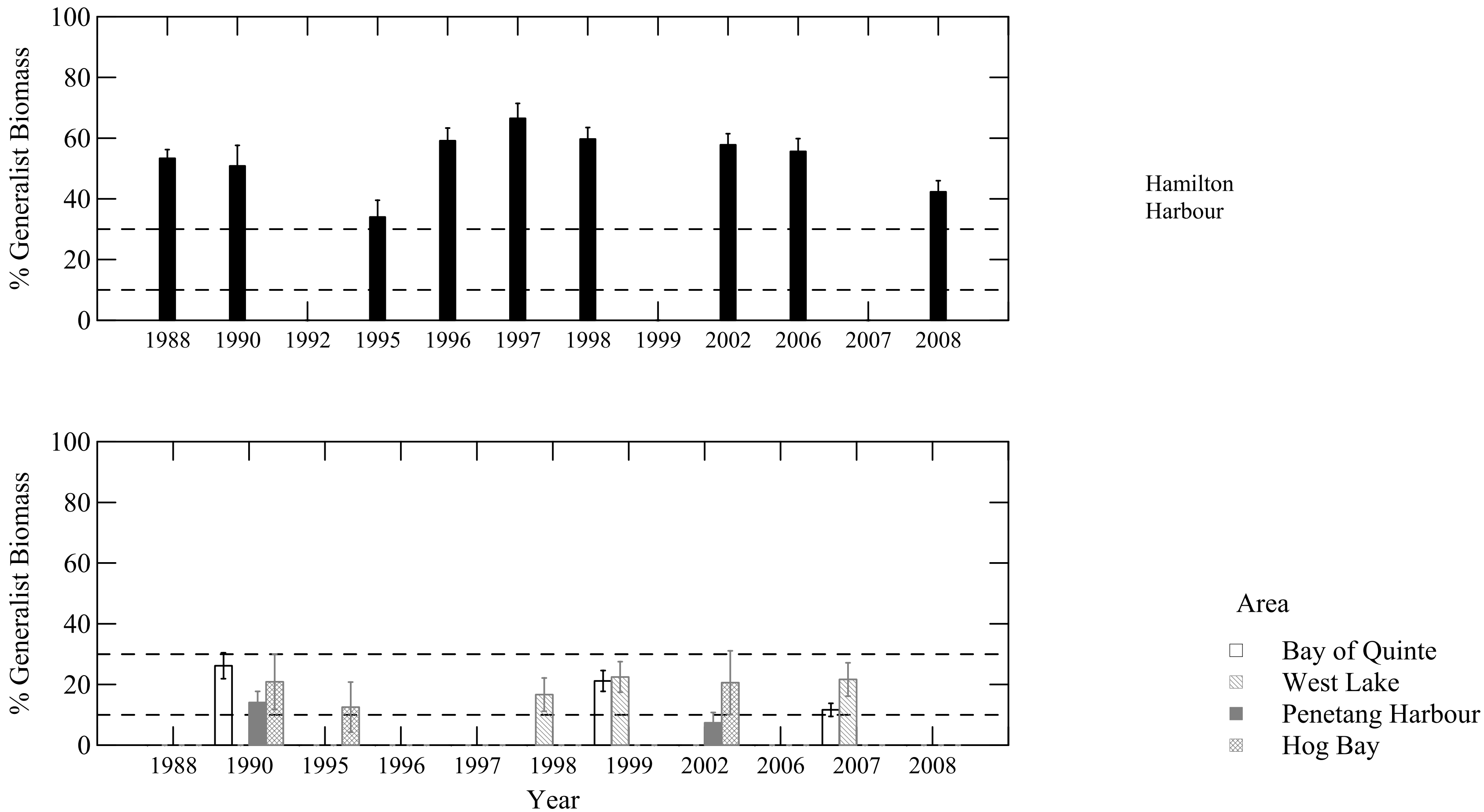


Figure 31. Comparison of the average percent generalists by biomass per transect by area; Hamilton Harbour (top) and other areas (bottom) among years. The dashed limit lines indicate the Hamilton Harbour delisting target range of 10 to 30, for the percentage of generalists in the total catch.

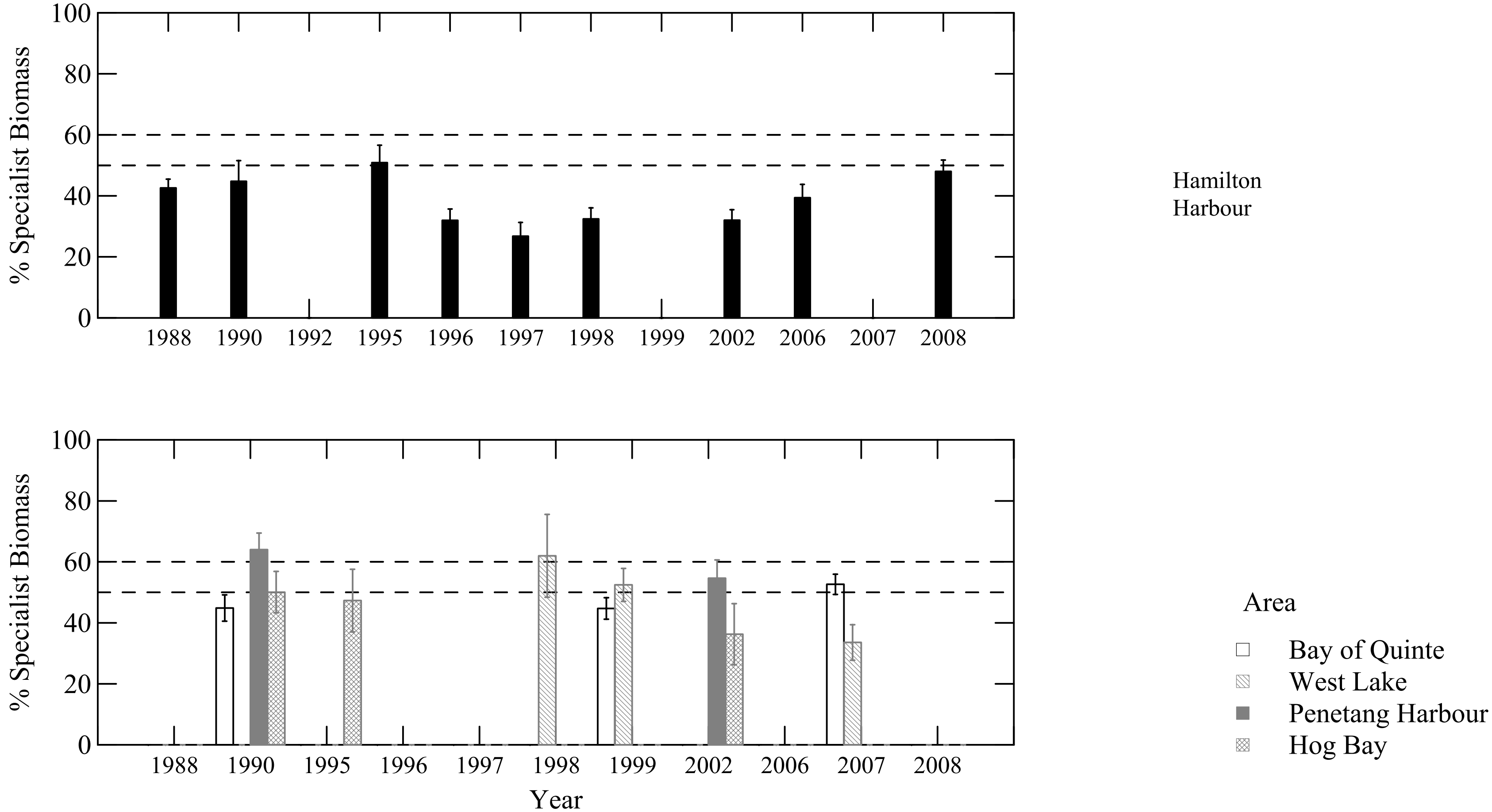


Figure 32. Comparison of the average percent specialists by biomass per transect by area; Hamilton Harbour (top) and other areas (bottom) among years. The dashed limit lines indicate the Hamilton Harbour delisting target range of 50 to 60, for the percentage of specialists in the total catch.

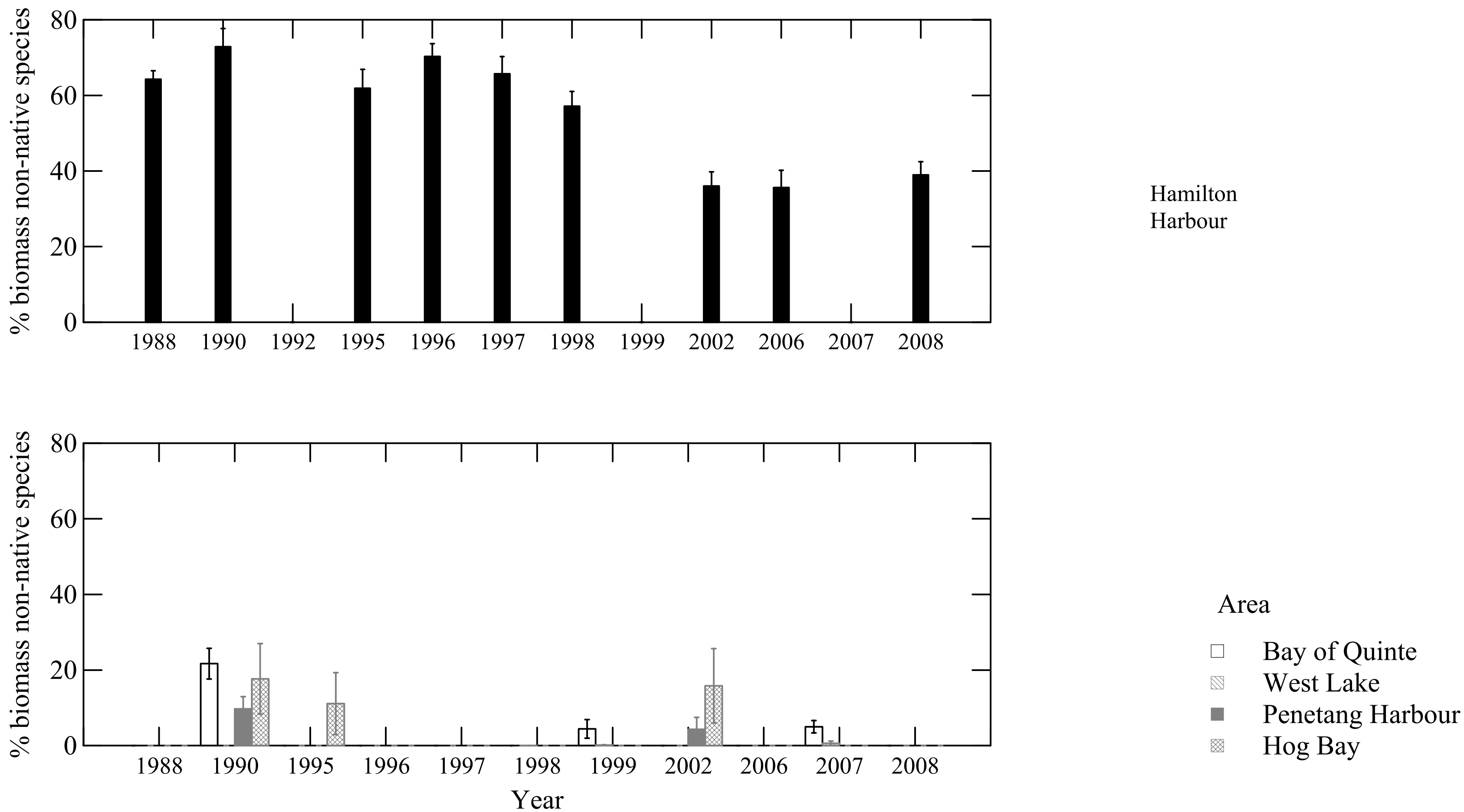


Figure 33. Comparison of the average percentage of the biomass of non-native species per transect contributing to total biomass by area; Hamilton Harbour (top) and other areas (bottom) among years.

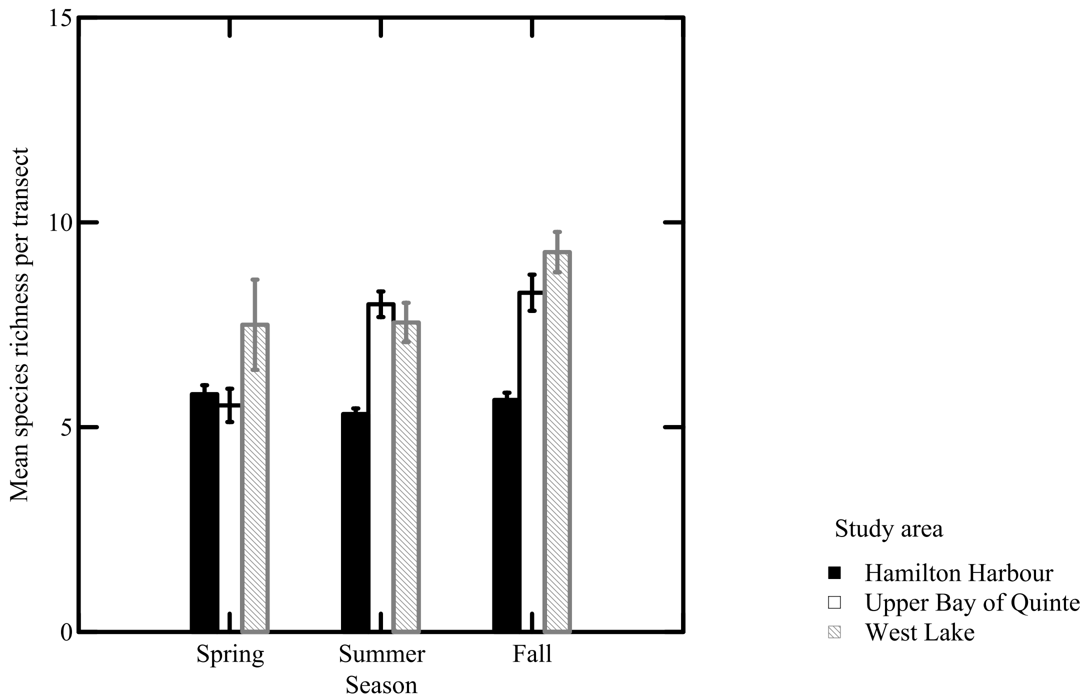


Figure 34. Mean species richness per transect on a seasonal basis by study area: Hamilton Harbour, the lower Bay of Quinte, the upper Bay of Quinte, and West Lake.

Appendix 1. Mean biomass and standard error (SE) of fish (kg) by species and year captured at transects electrofishing in Hamilton Harbour.

Scientific name	1988		1990		1992		1995		1996		1997		1998		2002		2006		2008	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
P. marinus																	0.00	0.0		
L. osseus	0.00	0.0	0.01	0.0															0.01	0.01
A. calva	0.02	0.0					0.01	0.0	0.03	0.0	0.06	0.1	0.04	0.0	0.05	0.0	0.04	0.0	0.06	0.04
A. pseudoharengus	1.00	0.1	0.67	0.1	0.35	0.1	0.74	0.1	0.53	0.1	0.15	0.1	0.37	0.1	0.29	0.1	0.06	0.0	0.30	0.1
D. cepedianum	0.31	0.1	0.16	0.1	0.04	0.0	0.11	0.0	0.10	0.1	0.02	0.0	0.04	0.0	0.26	0.1	1.33	0.4	0.48	0.2
O. mykiss			0.00	0.0	0.00	0.0	0.00	0.0	0.03	0.0			0.01	0.0	0.00	0.0				
O. tshawytscha	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0					0.00	0.0
S. trutta			0.00	0.0	0.24	0.1	0.06	0.1	0.05	0.0	0.00	0.0	0.00	0.0	0.00	0.0				
S. namaycush	0.01	0.0	0.05	0.1			0.04	0.0					0.04	0.0						
O. mordax	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0			0.00	0.0								
E. lucius	0.04	0.0	0.32	0.2	0.10	0.1	0.03	0.0	0.11	0.1	0.09	0.1	0.07	0.1	0.01	0.0	0.02	0.0	0.07	0.0
C. commersonii	0.17	0.0	0.33	0.1	0.58	0.2	0.22	0.1	0.29	0.1	0.14	0.1	0.07	0.0	0.19	0.1	0.10	0.0	0.13	0.0
I. cyprinellus															0.06	0.1			0.04	0.0
M. anisurum													0.01	0.0						
C. auratus	0.17	0.0	0.08	0.0	0.05	0.0	0.02	0.0	0.02	0.0	0.01	0.0	0.03	0.0	0.04	0.0	0.26	0.1	0.20	0.1
C. carpio	6.00	0.6	4.94	1.1	3.76	0.9	2.75	0.8	7.63	0.9	7.96	1.6	5.51	0.9	2.86	0.6	3.68	0.8	2.25	0.6
N. crysoleucas																	0.00	0.0	0.00	0.0
N. atherinoides	0.02	0.0	0.05	0.0	0.02	0.0	0.01	0.0	0.01	0.0	0.01	0.0	0.01	0.0	0.00	0.0	0.00	0.0	0.02	0.0
N. hudsonius	0.00	0.0	0.00	0.0	0.01	0.0	0.00	0.0	0.01	0.0	0.00	0.0	0.02	0.0	0.00	0.0	0.00	0.0	0.01	0.0
P. notatus													0.00	0.0						
P. promelas																			0.00	0.0
A. melas															0.01	0.0				
A. nebulosus	2.77	0.4	1.90	0.6	0.28	0.1	0.35	0.1	0.55	0.1	0.50	0.1	0.73	0.1	1.42	0.2	1.26	0.2	0.81	0.1
I. punctatus															0.01	0.0			0.09	0.1
A. rostrata	0.05	0.0	0.06	0.0	0.06	0.0	0.09	0.1	0.31	0.1	0.07	0.0	0.07	0.0						
G. aculeatus							0.00	0.0	0.00	0.0	0.00	0.0			0.00	0.0				
P. omiscomaycus	0.00	0.0			0.00	0.0					0.00	0.0								
M. americana	0.46	0.1	0.19	0.1	0.30	0.1	0.12	0.0	0.20	0.0	0.17	0.0	0.13	0.0	0.16	0.0	0.14	0.0	0.05	0.0
M. chrysops	0.05	0.0	0.00	0.0							0.01	0.0								
A. rupestris	0.00	0.0			0.01	0.0	0.03	0.0	0.03	0.0	0.03	0.0	0.02	0.0	0.05	0.0	0.04	0.0	0.10	0.0
L. gibbosus	0.05	0.0	0.03	0.0	0.06	0.0	0.21	0.1	0.14	0.0	0.10	0.0	0.14	0.0	0.06	0.0	0.01	0.0	0.02	0.0
L. macrochirus							0.00	0.0	0.00	0.0	0.00	0.0	0.01	0.0	0.02	0.0	0.01	0.0	0.02	0.0
M. dolomieu	0.06	0.0	0.02	0.0	0.15	0.1	0.08	0.1	0.02	0.0			0.00	0.0	0.00	0.0			0.00	0.0
M. salmoides	0.05	0.0	0.07	0.1	0.07	0.0	0.12	0.1	0.07	0.0	0.13	0.0	0.09	0.0	0.34	0.1	0.36	0.1	0.33	0.1

Scientific name	1988		1990		1992		1995		1996		1997		1998		2002		2006		2008	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
P. nigromaculatus	0.00	0.0			0.00	0.0	0.01	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.01	0.0				
E. nigrum	0.00	0.0			0.00	0.0			0.00	0.0	0.00	0.0	0.00	0.0						
P. flavescens	0.08	0.0	0.01	0.0	0.01	0.0	0.03	0.0	0.03	0.0	0.02	0.0	0.14	0.0	0.06	0.0	0.08	0.0	0.13	0.0
P. caprodes					0.00	0.0	0.010	0.0	0.02	0.0	0.01	0.0	0.09	0.02	0.00	0.0	0.01	0.0	0.01	0.0
S. vitreus					0.01	0.0							0.01	0.0					0.04	0.0
N. melanostomus															0.00	0.0	0.00	0.0	0.01	0.0
A. grunniens	0.05	0.0	0.11	0.1	0.15	0.1	0.11	0.1	0.21	0.1	0.11	0.06	0.03	0.0	0.19	0.1	0.07	0.0	0.21	0.1
Sample size	189		64		53		64		89		75		89		94		63		98	
Number of species	26		23		26		23		26		27		29		27		21		27	
Total mean biomass (kg)	11.4	0.8	9.0	1.5	6.4	1.0	9.0	1.5	10.4	0.9	9.6	1.6	7.7	0.9	6.1	0.6	7.5	1.0	5.4	1.5

Appendix 2. Mean number and standard error (SE) of fish by species and year captured at transects electrofishing in Hamilton Harbour.

Scientific name	1988		1990		1992		1995		1996		1997		1998		2002		2006		2008	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
P. marinus																	0.02	0.0		
L. osseus	0.01	0.0	0.02	0.0															0.01	0.0
A. calva	0.01	0.0					0.02	0.0	0.02	0.0	0.03	0.0	0.02	0.0	0.03	0.0	0.02	0.0	0.03	0.0
A. pseudoharengus	49.00	4.3	29.30	5.0	13.00	3.2	27.80	5.1	20.93	4.4	6.41	1.9	14.73	2.5	12.6	2.8	1.58	0.5	10.10	1.5
D. cepedianum	0.50	0.1	0.20	0.1	0.40	0.2	2.72	1.8	0.29	0.2	0.25	0.1	0.18	0.1	0.50	0.1	1.81	0.5	1.17	0.4
O. mykiss			0.14	0.1	0.02	0.0	0.07	0.1	0.06	0.0			0.10	0.0	0.03	0.0				
O. tshawytscha	0.19	0.1	0.09	0.1	0.10	0.1	0.04	0.0	0.07	0.0	0.03	0.0	0.03	0.0					0.14	0.0
S. trutta			0.02	0.0	0.17	0.1	0.09	0.1	0.03	0.0	0.01	0.0	0.06	0.0	0.02	0.0				
S. namaycush	0.01	0.0	0.02	0.0			0.02	0.0					0.01	0.0						
O. mordax	0.02	0.0	0.16	0.1	0.09	0.1	0.07	0.0			0.03	0.0								
E. lucius	0.02	0.0	0.09	0.1	0.06	0.0	0.02	0.0	0.07	0.0	0.05	0.0	0.02	0.0	0.01	0.0	0.02	0.0	0.04	0.0
C. commersonii	0.40	0.1	0.47	0.1	0.91	0.3	0.51	0.1	0.51	0.1	0.28	0.1	0.18	0.1	0.25	0.1	0.66	0.2	0.47	0.1
I. cyprinellus															0.03	0.0			0.01	0.0
M. anisurum													0.01	0.0						
C. auratus	0.19	0.1	0.13	0.1	0.06	0.0	0.02	0.0	0.03	0.0	0.01	0.0	0.03	0.0	0.03	0.0	0.48	0.1	0.26	0.1
C. carpio	2.05	0.2	1.38	0.3	1.17	0.3	0.58	0.1	1.90	0.2	2.56	0.5	1.74	0.3	0.69	0.1	0.97	0.2	0.53	0.1
N. crysoleucas																	0.02	0.0	0.02	0.0
N. atherinoides	3.17	0.7	11.91	3.2	3.28	0.7	1.62	0.4	2.40	0.8	7.25	1.9	2.20	0.6	0.12	0.1	1.02	0.3	4.10	0.6
N. hudsonius	0.46	0.1	0.06	0.1	0.72	0.2	0.64	0.4	1.34	0.4	1.08	0.3	2.69	1.7	0.18	0.1	0.60	0.2	1.40	0.3
P. notatus													0.01	0.0						
P. promelas																			0.01	0.0
A. melas															0.02	0.0				
A. nebulosus	15.33	2.1	7.84	2.6	1.23	0.3	1.71	0.4	2.34	0.4	2.04	0.4	4.49	0.7	5.44	0.7	4.03	0.6	2.30	0.4
I. punctatus															0.01	0.0			0.02	0.0
A. rostrata	0.04	0.0	0.08	0.0	0.04	0.0	0.07	0.0	0.27	0.1	0.08	0.0	0.05	0.0						
G. aculeatus							0.02	0.0	0.27	0.1	0.08	0.0			0.02	0.0				
P. omiscomaycus	0.01	0.0			0.02	0.0					0.04	0.0								
M. americana	5.49	0.9	2.33	0.5	4.17	1.4	1.69	0.4	4.05	0.8	3.40	0.7	2.37	0.4	2.07	0.5	3.55	0.8	1.25	0.2
M. chrysops	0.19	0.1	0.02	0.0							0.01	0.0								
A. rupestris	0.02	0.0			0.09	0.1	0.22	0.1	0.33	0.1	0.33	0.1	0.19	0.1	0.34	0.1	0.26	0.1	1.01	0.2
L. gibbosus	1.04	0.2	0.52	0.2	1.09	0.3	7.58	2.0	6.76	1.2	3.87	0.9	10.76	2.5	1.99	0.5	0.57	0.3	0.43	0.1
L. macrochirus					0.02	0.0	0.20	0.1	0.21	0.1	0.13	0.1	0.23	0.1	0.75	0.2	0.48	0.2	0.45	0.2
M. dolomieu	0.13	0.0	0.03	0.0	0.28	0.1	0.13	0.1	0.09	0.1			0.01	0.0	0.02	0.0			0.02	0.0
M. salmoides	0.09	0.0	0.13	0.1	0.19	0.1	2.62	1.0	2.28	0.5	1.31	0.4	1.62	0.3	1.52	0.3	0.73	0.2	0.85	0.2

Scientific name	1988		1990		1992		1995		1996		1997		1998		2002		2006		2008	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
P. nigromaculatus	0.01	0.0			0.04	0.0	0.07	0.1	0.01	0.0	0.03	0.0	0.01	0.0	0.04	0.0				
E. nigrum	0.01	0.0							0.11	0.1	0.01	0.0	0.02	0.0						
P. flavescens	1.16	0.2	0.08	0.0	0.13	0.1	0.56	0.2	0.46	0.1	0.57	0.2	3.91	0.8	1.23	0.2	2.76	0.5	3.35	0.5
P. caprodes					0.06	0.0	0.64	0.3	1.51	0.4	2.60	0.9	9.62	2.2	0.11	0.1	0.86	0.3	1.02	0.2
S. vitreus					0.04	0.0							0.01	0.0					0.01	0.0
N. melanostomus															0.29	0.1	0.08	0.0	0.47	0.1
A. grunniens	0.07	0.0	0.06	0.0	0.09	0.1	0.04	0.0	0.10	0.0	0.08	0.0	0.02	0.0	0.10	0.0	0.05	0.0	0.09	0.0
Sample size	189		64		53		55		89		75		89		94		62		98	
Number of species	26		23		26		27		26		27		29		27		21		27	
Total mean biomass (kg)	79.6	5.2	55.1	6.4	27.5	4.4	49.8	5.4	46.5	4.9	32.6	3.5	55.4	5.3	28.5	2.9	20.5	1.5	29.6	5.2