TRENDS IN THE NEARSHORE FISH COMMUNITY OF HAMILTON HARBOUR, 1988 TO 1997, AS MEASURED USING AN INDEX OF BIOTIC INTEGRITY

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ABSTRACT

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In 1985 Hamilton Harbour was listed as an Area of Concern by the International Joint Commission, due to the impairment of beneficial uses related to poor water quality and degraded fish and wildlife populations. A Remedial Action Plan (RAP) was developed which included measurable objectives (targets) for habitat restoration in the Harbour and for the fish community structure. In this study an Index of Biotic Integrity (IBI), as developed for Great Lakes littoral habitat, was used to quantitatively measure the impairment or restoration of fish-related intrinsic uses of the Harbour over 9 years (1988-1997). Annual average IBI* scores for the Harbour as measured by fish community monitoring (which included measures of species richness and composition, trophic composition, and fish abundance) have increased since 1990. Some fish community metrics were also higher at the physical habitat restoration sites than at the unaltered sites, but more work is required to evaluate the changes. Further improvements in the fish community are necessary to reach targets: the overall Harbour IBI score of 37 in 1997 was still well below the target range of 55-60 (max IBI = 100), but was closer to the target than the IBI score of 30 in 1990. It is recommended that the quantitative IBI targets replace the original fish community targets in the criteria for delisting the Harbour as an Area of Concern, as the IBI incorporates all of the desirable fish community attributes identified in the Hamilton RAP.

RÉSUMÉ

Smokorowski, K.E., M.G. Stoneman, V.W. Cairns, C.K. Minns, R.G. Randall, and B. Valere. 1998. Trends in the nearshore fish community of Hamilton Harbour, 1988 to 1997, as measured using an Index of Biotic Integrity. Can. Tech. Rept. Fish. and Aquat. Sci. No. 2230

En 1985, le port de Hamilton a été porté sur la liste des secteurs préoccupants par la Commission mixte internationale à cause de restrictions d'utilisations liées à la mauvaise qualité de l'eau et à la dégradation des populations de poissons et d'autres espèces fauniques. On a préparé un plan d'assainissement (PA) comportant des objectifs mesurables (cibles) pour la restauration de l'habitat dans le port et pour la structure des communautés de poissons. Dans le cadre de cette étude, on a utilisé un indice d'intégrité biotique (IIB), développé pour l'habitat du littoral des Grands Lacs, afin de mesurer quantitativement, pour une période de 9 ans (1988-1997), l'altération ou la restauration des utilisations intrinsèques reliées au poisson du port. Les cotes annuelles d'IIB* du port obtenues par la surveillance des communautés de poissons (comportant des mesures de la richesse et de la composition de l'espèce, de la composition trophique et de l'abondance des poissons) présentent des augmentations depuis 1990. On a obtenu des valeurs plus élevées pour certaines communautés de poissons dans les sites physiques de restauration de l'habitat par rapport à celles des sites non altérés, mais des études supplémentaires sont nécessaires pour évaluer ces changements. Pour l'atteinte des valeurs cibles, il faudra d'autres améliorations dans les communautés de poissons : en 1997, la cote IIB de 37 pour l'ensemble du port de Harbour était encore bien inférieure à la plage cible de 55-60 (indice IIB maximal : 100), mais elle était plus près de cette dernière que la cote de 30 obtenue en 1990. Il est recommandé que les cibles quantitatives d'IIB remplacent les valeurs cibles originales pour les communautés de poissons dans les critères de retrait du port de la liste des secteurs préoccupants, étant donné que l'indice IIB tient compte de toutes les caractéristiques souhaitables des communautés de poissons déterminées dans le PA du port de Hamilton.

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1.0 INTRODUCTION

Historically, the waters of Hamilton Harbour, located at the western end of Lake Ontario, provided some of the most productive fish habitat in the Great Lakes, supporting a coldwater fishery dominated by lake trout, whitefish, and lake herring (Holmes and Whillans 1984). The Harbour's extensive marsh lands, Cootes Paradise and along the south and west shores, provided excellent spawning, nursery, and adult habitats for a diverse fishery including pike, bass, yellow perch, sunfish, muskellunge, walleye, drum, burbot, channel catfish, and brown bullhead. In 1900, the Harbour's fishery accounted for 15% of Lake Ontario's total commercial catch.

The conditions in the Harbour have changed dramatically over time as a result of negative changes in water quality and shoreline habitat which was related to population growth and industrial development. By 1988 Hamilton Harbour was considered one of the most severely degraded ecosystems in the Great Lakes (COA 1992a). Infilling of the extensive marsh habitat along the south shore, combined with other less extensive physical habitat modifications around the perimeter of the Harbour, resulted in the loss of 22% of the open water area (relative to 1926) and a reduction of wetland area from approximately 500 hectares (historical maximum), to less than 50 hectares (1992 figures). Inputs of treated and untreated sewage from municipalities (26 stream, WWTP and sewer outfalls), industrial effluent (12 outfalls from the steel industry), and urban runoff resulted in extreme cultural eutrophication (in 1988 total phosphorus exceeded 120 $\mu g \cdot L^{-1}$, and Chl a was approaching 40 $\mu g \cdot L^{-1}$, Charlton and Sage 1996), siltation, highly contaminated sediments, and to a lesser degree, contaminated water (trace metals and organic contaminants). Recreational swimming has been banned in the Harbour since 1940 as a result of excessive bacteria levels, and fish consumption is limited because of high contaminant levels (COA 1992a).

The coldwater fishery has been virtually eliminated as a result of overfishing, competition with introduced species, and the loss of spawning and adult fish habitat. Annual summer anoxia in the hypolimnion of the Harbour results from oxygen consumption by decaying algae and chemically oxygen demanding sediments (COA 1992a). The traditional fishery dominated by desirable native species (including pike, bass, muskellunge, and walleye) has shifted to one dominated by species more tolerant of degraded conditions (exotics such as carp and white perch [Holmes 1988]). The warmwater fishery decline has also been attributed to extensive habitat loss, overfishing, toxic discharges, and the introduction of exotic species (Holmes 1988).

In 1985, the International Joint Commission (IJC) identified 43 Areas of Concern (AOC) in the Great Lakes as part of the Canada-U.S. Great Lakes Water Quality Agreement (GLWQA). An AOC is defined as a location where one or more of 14 identified beneficial uses (both intrinsic and human) are impaired (Hartig et al. 1997). In Hamilton Harbour, all 14 beneficial uses were considered impaired, requiring significant improvement before the Harbour could be delisted as an AOC. In accordance with the

GLWQA, a Remedial Action Plan (RAP) was developed. Background material is provided in the RAP document, which describes the environmental problems, the beneficial uses that are still impaired, the standards that are not yet being met, the cause of the remaining impairment of uses of the Harbour (Stage I RAP, COA 1992a), and the goals and recommendations of the Remedial Action Plan (Stage II RAP, COA 1992b).

Nine of the 14 beneficial uses refer either directly or indirectly to fish (Appendix A), which indicates that fish should be an integral part in selecting targets and criteria for assessing, restoring, and managing aquatic ecosystems (Minns et al. 1994). The criteria for delisting 2 of the beneficial uses which relate directly to fish (degraded fish and wildlife populations and loss of fish and wildlife habitat) include measurable objectives regarding the fish community structure (native vs. exotic species composition, biomass, species richness, spatial variability), and habitat restoration (increase quantity of macrophytes, littoral shore, lagoon habitat, colonial nesting habitat, and water clarity targets). Field monitoring has been extensive, and has involved the sampling of the fish community structure, macrophyte density, and physical parameters at approximately 40 transects in the Harbour both before restoration (1988 and 1990), and after implementation of some of the RAP recommendations (1992-1997, Fig. 1).

As part of the RAP programme, six shoreline sites in Hamilton Harbour were targetted for physical modification and restoration. Of these six sites, three are still in the proposal stage (Northshore, Fisherman's Pier, and Windermere Basin), while three have undergone habitat restoration since the Stage II RAP was published in 1992 (Bayfront Park, LaSalle Park and Northeastern Shorline Islands). Furthermore, habitat restoration has been implemented in Cootes Paradise marsh and at Grindstone Creek. Details of the habitat modifications are provided in the Methods section.

In order to quantitatively measure the level of impairment and degree of restoration of fish-related intrinsic uses of the ecosystem, Minns et al. (1994) developed an Index of Biotic Integrity (IBI) specifically for Great Lakes littoral habitats. The IBI was originally developed for riverine systems by Karr (1981) who argued that using biological criteria (as opposed to chemical and toxicological methods) increases the probability that a monitoring or assessment program will detect measurable anthropogenic influences on aquatic systems. In short, an IBI integrates several biological indicators (metrics representing species richness and composition, trophic composition, and fish abundance and condition) into a single index of ecosystem health which may be more readily understood by a broad, often nontechnical audience (Minns et al. 1994). While not intending to replace physical and chemical monitoring or toxicity testing, IBI provides a relatively inexpensive, simple, and highly sensitive method of monitoring changes in ecosystems, and has been used in a variety of contexts and in a diversity of geographic areas (see Karr et al. 1986, Miller et al. 1988, Steedman 1988, Fausch et al. 1990 *review in* Karr 1991, Wang et al. 1997).

The objectives of this report are as follows: 1) to provide a background description of the fish community in Hamilton Harbour, 1988 to 1990; 2) to describe the spatial variability of the fish assemblages inhabitating the different nearshore areas of the Harbour; 3) to provide quantitative community fish targets including IBI, to be used as a reference against which any future changes in the fish community can be measured and compared; 4) to describe temporal trends in the fish community, 1988 to 1997, both overall and in the vicinity of habitat restoration sites; and 5) to identify monitoring needs (and a survey design) for future years.

2.0 METHODS

2.1 Study Area

Hamilton Harbour (43°14'N, 79°51'W) is an approximately triangular shaped body of water located at the western end of Lake Ontario, with an east-west axis of 8 km and a north-south axis of 5 km (Fig. 1, COA 1992a). The Harbour has a surface area of 2,150 hectares (approx. 22 km^2), a mean depth of 13 m, and a maximum depth of 26 m. The Harbour is connected to Lake Ontario by the Burlington Ship Canal (820 m x 88 m x 9.5 m), which decreased the theoretical hydraulic residence time (i.e. volume/inflow) from about 500 days to 90 days (COA 1992a).

2.2 Fish Surveys

A total of 45 transects, grouped at 10 sites around the littoral zone of the Harbour proper (A-H, J and K), were surveyed with varying intensity in 1988, 1990, 1992, 1993 and from 1995 through 1997 (Fig. 1, Table 1). Fish surveys were conducted using a 6.1 m long Smith-Root SR20E electrofishing boat (Valere 1996). Two anodes (each with a terminal six wire umbrella array) extended from the bow, and the aluminum hull of the boat acted as a cathode. An electric current was produced by a 16 Hp gas motor driving a 7.5 KW generator which had the following output capacity: DC output of 170 - 1000 Volts in four steps; output pulse frequency of 30, 60, or 120 pulses per second (PPS); variable pulse width; maximum continuous output current of 10.4 A at 1000 V DC and 120 PPS. Output ranged from 6.8 A to 10.0 A prior to 1992, and was standardized to 8.0 A after 1992.

An electrofishing crew of 4 conducted the surveys (Valere 1996). One crew member operated the boat and the electrofisher, two crew members worked at the bow of the boat capturing stunned fish with 10 foot long fiberglass dip nets, and the remaining crew member aided the netters in transferring captured fish into the onboard livewell.

A line transect survey design was used with each line parallel to the shore, 100 m in length, and approximately followed the 1.5 m depth-contour. Transect locations on the east, north and west shores of the Harbour represented a range of exposure (fetch), substrate, and macrophyte conditions. Due to shipping depth requirements, a 1.5 m depth-contour does not exist along the south shore and therefore no fish sampling surveys were conducted in this area of the Harbour. Prior to sampling, the beginning and end of each transect was measured and marked on shore. Boat speed was kept as constant as possible and sampling time per transect ranged from approximately 4 - 8 minutes, depending on netting activity, wind speed and direction (Valere 1996).

Field surveys were designed to determine littoral fish community composition, density (number captured per 100 m transect), richness (number of species per transect) and biomass (kg per transect). Fish captured at each transect were held in the onboard live well until processing at the end of each transect. All fish were identified to species on site, however on the rare occasion when species identification was not possible, one or two specimens were sacrificed and preserved in 10% formalin (or frozen) for subsequent identification using Scott and Crossman (1973). All fish were counted; up to 20 of a single species captured per sample were measured for length and weighed (fish < 3 kg ± 1 g;> 3 kg ± 20 g). If the number of a single species exceeded 20, the remaining fish were counted and batch weighed. For most species the length measured was fork length (± 1 mm); however, total length was measured for species with truncated or rounded caudal fins (Valere 1996). Fish were released in an area adjacent to the transect after processing was complete.

After release of the fish, the following information was recorded: date, start and finish time of electrofishing run, wind speed and direction, shock time, voltage, amperage output, surface water temperature, surface conductivity and Secchi disk depth (after 1990). Sub-surface temperature and dissolved oxygen were measured (where applicable) using a YSI model 58 DO meter at both end points of the line transect at a depth of 0.75 m, and at mid-transect out at a depth of 5 m (Valere 1996).

2.3 Habitat Restoration

Restoration work at Bayfront Park (site Kb, Fig. 1) is proceeding in 2 stages. The initial stage (part of the construction of Pier 4 and Bayfront Parks) involved the construction of 65 underwater structures (artificial reefs). The structures were offshore in water > 2 m in depth, and were not surveyed by electrofishing as part of this study. Extensive shoreline work included the addition of armour stones, points and headland structures, as well as the addition of substrates (pea gravel, sand, rock rubble) for spawning, nursery and adult habitat. The shoreline habitat restoration work and reef structures were complete by spring of 1992 (FWRP 1997). The second phase (restoration between Bayfront Park and the Desjardins Canal) has not been completed.

In the 1970’s a bank failure at LaSalle Park on the north shore (site E, Fig. 1) resulted in the use of stabilizing armourstone which effectively separated the Carolinian woodland from the water. A marina, a 130 metre long beach and gravel fill (road construction) have further altered this site over the years. The LaSalle Park habitat restoration project began in January 1995, was complete by spring 1996, and officially opened August 1996 (FWRP 1997). Project activities which impacted on the nearshore habitat included the construction of a promontory and reef at the west end of the site, and the addition of a pebble beach, emergent shoals, reefs, and a variegated shoreline at the eastern end of the site which has doubled the riparian edge through a complex of headlands, wetlands and two small islands.

Restoration of the Northeastern Shoreline (location C, Fig. 1) was designed to replace a small portion of the original wetland and complex system of wetlands, lagoons and sand beach which originally occupied this site before land filling and armourstone edge limited the fish and wildlife habitat. This project was begun in February 1995, was essentially complete by spring 1996, and opened in September 1996 (FWRP 1997). With the primary goal of creating colonial nesting bird habitat, three offshore islands were constructed which had the added effect of sheltering the shoreline and increasing aquatic vegetation coverage from unvegetated to 50% coverage in 1996 (FWRP 1997). Rock reefs and submergent shoals further increased fish habitat, and a trail, viewing platform, and windsurfer launch were designed to draw the public back to the Harbour.

The degradation of Cootes Paradise marsh stems from a combination of fluctuating water levels, nutrient enrichment, high suspended sediment load, and a large carp population (Holmes 1988, Whillans 1996). Restoration efforts include the control of the carp population (operation of a carp barrier fishway), the replanting of marsh vegetation native to the Great Lakes, and the construction of public access facilities (FWRP 1997). Habitat modifications designed to enhance emergent and submergent vegetation and maintain water levels have also been carried out at Grindstone Creek to provide important spawning and nursery habitat (pike, sunfishes etc.) and to maintain viable migration routes to and from the Harbour during critical life stages of species such as pike, trout and Pacific salmon.

2.4 IBI Methodology

Each adaptation of the IBI for a new geographic location requires a careful standardization of procedures, and a knowledge of the expected value for each metric specific to regional biota and stream size (Karr 1991). As mentioned above, Minns et al. (1994) provided the first adaptation of IBI to a non-riverine system, by developing metrics and their expected values specific to the littoral habitats of the Great Lakes. The methods used by Minns et al. (1994) involved five steps: 1) selection of IBI metrics, 2) analysis of raw metrics, 3) metric standardization and IBI formulation, 4) analysis of IBI properties, and 5) analysis of relationships between IBI values and ecosystem habitat conditions. Detailed methodology, rationale, and results of these steps are available in Minns et al. (1994); however, a brief outline of steps relevant to this study follows.

A total of 12 metrics were selected based on a review of IBI metrics in published literature and reports, plus consideration of the features of the littoral fish assemblages (Table 2). The classification of each of the fish species sampled in the Harbour (according to the metric criteria) were as in Minns et al. (1994), and can be found in Appendix B. Two changes to the species classification used by Minns et al.(1994) should be noted: rainbow smelt was changed from non-indigenous to native and bigmouth buffalo was changed from native to non-indigenous (Appendix B). Raw metrics were analyzed using Pearson correlations (to examine redundancy) and principal components analysis (to assess groupings and associations among metrics). In order to obtain an index in the form of a continuous variable, individual metrics were standardized by defining a standardized metric (M_S) as a linear function of a raw metric (M_R), ensuring a minimum value of zero and a maximum of 10 (for positive metrics), using the following equation and conditions:

(1) $$M_S = A + B \cdot M_R$$

If $M_S < M_{MIN}$, then $M_S = M_{MIN}$
If $M_S > M_{MAX}$, then $M_S = M_{MAX}$

A high value for some of the metrics ('negative metrics', 4 of the 12, Table 2) implies low biotic integrity (e.g. a high component of non-indigenous species). Negative metrics therefore have a negative slope (B), and a high intercept (A) which, for sites with a high raw negative metric score, would result in a low standardized metric value, reducing the overall IBI score for that site. Standardized metrics were summed and multiplied by 10/12 to produce an IBI with a minimum value of 0 (possible only if the survey produces no fish) and a maximum value of 100. Qualitative IBI categories were defined to assist interpretation of IBI scores by nontechnical audiences: 0 = No Fish, >0-20 = Very Poor, >20-40 = Poor, >40-60 = Fair, >60-80 = Good, and >80 = Excellent.

Because the IBI developed by Minns et al. (1994) was designed to assess the biotic integrity of littoral zone habitats, the inclusion of "offshore" species (Appendix B) in the IBI calculations may result in a score that is not truly representative of the littoral zone habitat and community (i.e. offshore species are not true 'residents' of that habitat). Therefore, a modified form of IBI (IBI*) was calculated wherein the original IBI was adjusted for the mean of the proportions of fish numbers ($P_{N.OFF}$) and biomass ($P_{B.OFF}$) in samples attributable to incursions of offshore fish species:

(2) $$IBI^* = IBI \cdot \{1 - P_{OFF}\}$$
$$P_{OFF} = \{ P_{N.OFF} + P_{B.OFF}\} / 2$$

2.5 Setting Targets

The objective in 1992 was to identify quantitative fish community targets for littoral habitats in Hamilton Harbour. Randall et al. (1993) observed that some of the characteristics of the fish community in the Harbour (e.g., low species richness and low abundance of predators) were symptomatic of a degraded aquatic ecosystem. Setting fish community targets would provide a reference for monitoring trends in the fish community during the successive years of habitat restoration. The targets were determined by comparing the structure and composition of the fish community in Hamilton Harbour, a degraded system (in terms of eutrophication, water quality and nearshore habitat loss and degradation; Randall et al. 1993), with fish communities in four less degraded environments elsewhere in the lower Great Lakes. Electrofishing data from surveys conducted in 1990, May to August, were used as follows:

Reference Area	Rank	Number of transects	Visits	Number of samples (number with 0 catch)	Months
Hamilton Harbour	5	20	3	60(1)	May - August
Bay of Quinte	4	20	3	59(3)	June - August
Penetang Bay	3	29	3	84(3)	June - August
Hog Bay	2	14	2	28(1)	July - August
Matchedash Bay	1	12	3	36(0)	June - August

The survey areas were ranked from most degraded (Hamilton) to least degraded (Matchedash) (Randall et al. 1993). Electrofishing surveys were conducted using the same standardized protocol at all five areas (1.5 m depth contour, 100 m transects) as described above. Maps showing the location of the survey transects in Bay of Quinte and Severn Sound, and details of the survey procedures are given in Valere (1996).

For each transect, the numbers and biomass of fish by species and total species richness were recorded. Fish species were later assigned to trophic groups (piscivores, generalists, specialists [Minns et al. 1994]), and the percent composition by biomass by trophic group was calculated for each transect. Species were classified as piscivores if their adult diet consisted predominantly of fish (e.g., smallmouth and largemouth bass, walleye), generalists if their diet spectrum was judged to be wide, with multitrophic highly adaptable diets (e.g., carp, brown bullheads). Species were classified as specialists if the did not appear to fit the other two categories - specialists included plantivores, insectivores, and herbivores (e.g., alewife, yellow perch and pumpkinseed). The list of species by trophic group is provided in Minns et al. (1994) and Appendix B1. Transect samples were pooled for each of the five areas, and arithmetic averages were calculated for biomass (kg per transect), species richness (number of species captured per transect), and the percent composition by trophic group. For calculating the trophic group averages, only transects where the fish catch was > 0 were used. Quantitative fish targets for Hamilton Harbour were identified by comparison of the ranges of these fish assemblage measures at the four reference areas to values observed at Hamilton Harbour.

An IBI score was calculated for each of the reference transects, and compared to the IBI scores for Hamilton Harbour in 1990. Using the inter-area spatial comparison, an IBI target range was identified as an additional fish community target. Adjusted IBI scores, which accounted for the presence of offshore species (Minns et al. 1994) were also calculated for comparison with the unadjusted IBI values.

2.6 Statistical Analyses

The overall distribution of each fish assemblage measure (Table 2) was assessed for normality using a Kolmogorov-Smirnov (K-S) D statistic for all data from Hamilton Harbour, and from the four reference areas used to identify quantitative fish community targets. Transformations were used when necessary to produce a normal distribution, or alternatively, non-parametric statistics were used in the data analysis.

2.6.1 Setting Targets

Statistical differences in the fish assemblage measures (biomass, species richness, percent by trophic group, IBI) among the five areas were compared in two steps. First, significant differences among treatments (locations) were tested using parametric Analysis of Variance (ANOVA), or the non-parametric Kruskal-Wallis (KW) 1-way Analysis of Variance if the data violated the assumption of normality. Second, if significant, the ANOVA tests were followed by comparing the average fish measure for Hamilton Harbour with the summed average for the four reference areas, using a Contrast statement in SYSTAT (Wilkinson et al. 1996). A variance ratio test (based on the variance of the logarithms of the data) was used to test for differences in the Coefficient of Variation (C.V.) of biomass between samples (Zar 1974). F and KW statistics were considered significant at $P<0.05$.

2.6.2 Seasonal Analysis

In each year, individual IBI and IBI* measures were plotted by day of year to analyze the distribution of the complete data set and determine whether any seasonal trends were apparent. The detection of seasonal trends was important because the surveys continued later into the autumn beginning in 1995 than in previous years. Results were used to determine an appropriate subset of samples to use to test for inter-annual changes in IBI (see below), and for deciding on a future survey design (objective 5). A LOWESS smoother (which employs a locally weighted robust regression, tension 0.6) was used to look for a functional relationship between Y and X as it works well on non-Gaussian data, is less susceptible to outliers in the series than other smoothing techniques, and does not prejudge the shape of the curve (SPSS 1996).

2.6.3 Annual Analysis

Of the 45 transects located around the Harbour, only 25 were sampled in each year (repeat transects) and were considered representative of both before and after habitat restoration work. In order to achieve a relatively balanced design for the statistical analysis, most non-repeat transects were excluded (Tables 1 and 3). In addition, fall sampling dates were added to the sampling protocol beginning in 1995, therefore all sampling dates greater than 250 (Julian day) were excluded from the analysis. The year 1993 was also excluded from the analysis as, in that year, each site was sampled on only 1 date, and only a subset of the transects was sampled. All statistical analyses were conducted using SYSTAT 7.0 for Windows (SPSS 1997).

Seven transects around the Bayfront Park littoral zone (site Kb) were intensively sampled only after the restoration work was complete (spring of 1992) and did not fit the criteria of a repeat transect (Fig. 1; Table 3). Results from the Kb transects were included as an individual site plot (see below) for visual comparison to the rest of the sites in the Harbour, but they were not included in the statistical analysis of trends through time.

A series of figures were generated showing the annual trends of all 12 metrics, total numbers and biomass of fish, total species richness, mean individual weights, percent off-shore fish by number and biomass (Table 2), and the IBI and IBI* over time for the overall Harbour (all sites combined, excluding Kb), and at each site individually. For analysis of the trends through time in the overall Harbour, a 1-way ANOVA (by year), or the non-parametric Kruskal-Wallis (KW) 1-way Analysis of Variance was used.

A second series of figures was generated illustrating the contrast between restoration (C and E only) and unaltered (A, B, D, F, G, H, J) sites around the Harbour, both before and after restoration work took place. Site K was excluded from this analysis as fish habitat was not directly modified at site K, and would therefore not be directly comparable to sites C and E as a restoration site. For statistical analysis, the years 1988 and 1990 were chosen to represent the period before restoration work; after restoration work was represented by the years 1996 and 1997. A 2-way ANOVA was used to test the significance between years and between type of site (restoration status) for data that did not violate the assumption of normality.

2.7 Future Monitoring Requirements

In a recent paper, Lester et al. (1996) outlined a method for determining the sample size required to detect the response of a fish community to a change in habitat. This method was used to statistically assess the future monitoring requirements of the Hamilton Harbour fish community. The required sample size depends on the anticipated magnitude of change (*d*), the specified significance level (α), the desired power ($1 - \beta$), and the variance of the sampling method (among years and within years). The following formula was used to determine the number of years (n_1) in each phase of the experiment (i.e. before and after habitat alteration) required to detect a change in the IBI:

$$n_2 = \frac{2(t_\alpha + t_\beta)^2}{d^2}\left(V_1 + \frac{V_2}{n_2}\right)$$

where t_α and t_β are Student t values that vary with the significance level (α) and the power ($1 - \beta$) of the test, *d* is the detectable change, V_1 is the among-year variance component,

V_2 is the within-year variance component (i.e. among sites) and n_2 is the number of sites sampled per year.

The use of this formula requires that the data do not violate the assumptions of a t-test (i.e. normal distribution, homogenous variance) and therefore a square root transformation of the IBI was used (see following section for results of transformation). Using this formula the detectable change in the square root of the IBI was calculated for a variable number of years ($n_1 = 1 - 10$), approximating the current level of sampling intensity ($n_2 = 120$ samples per year, including Kb) and at a greatly reduced sampling intensity ($n_2 = 10$ samples per year), with a significance level (α) of 0.05 and 2 power levels ($1 - \beta$): 0.90 and 0.75. The minimum detectable change in the square root of the IBI was plotted as a function of the number of years (n_1).

3.0 RESULTS

3.1 Data Distribution

A normal distribution was obtained for the IBI and IBI* data using the square root transformation (IBI, $D_{624} = 0.05$, $p = 0.09$; IBI* $D_{624} = 0.039$, $P = 0.298$), however no transformation produced a normal distribution for the individual measures (K-S, 1 sample test, all $P < 0.02$). A constant of 0.5 was added to the raw IBI and IBI* data prior to transformation as some of the transects produced zero fish, and this is a preferred method of using the square root transformation when there are very small data and/or when some of the observations are zero (Zar 1984). Thus, all subsequent statistical testing performed on the IBI and IBI* used the transformed data and distribution based statistics, and non-parametric statistics were used on non-transformed individual measures

3.2 Seasonal Analysis

Although there was considerable variability in the data, the plot of the individual IBI and IBI* measures, fitted with the LOWESS smoother, revealed a seasonal pattern, with spring and fall values falling higher than mid-summer values (Figs. 2 and 3). The highest IBI scores were obtained in the fall, and therefore excluding these data from the annual analysis should eliminate bias towards later years when, as noted above, additional sampling was conducted in the fall. The sampling intensity in 1993 was not adequate to justify statistical comparison of these data to other years. Although the adjusted IBI* curves appear somewhat similar in shape to the IBI, the adjusted scores are lower overall, and the fall peak is not as marked (Figs. 2 and 3).

3.3 Fish Community Targets

Several of the fish community measures differed significantly at Hamilton Harbour from the four reference areas (Bay of Quinte, Penetang Bay, Matchedash Bay and Hog Bay). Average species richness was lower at Hamilton than at the reference areas, but the fish community biomass was higher. Both richness (KW 40.7, P<0.001) and biomass (KW 10.6, $P<0.05$) differed significantly among the five areas (Table 4). The biomass values were positively skewed (high frequency of low biomass and low frequency of high biomass); coefficients of variation (C.V.) ranged from 0.71 (Matchedash) to 1.40 (Hamilton). The difference of C.V. in biomass between Hamilton and the reference areas was not significant ($F\ ratio_{59,206} = 1.12$, $P=0.56$).

The trophic composition of the fish communities varied significantly among the survey areas (Table 4). The percent composition of biomass by piscivores and specialists was lower, and the percent generalists was higher in Hamilton Harbour than at the reference areas. The average percent of native species biomass at Hamilton Harbour was less (37.7%) than at the reference areas (> 70%).

Combined, a number of these factors (low species richness and percent piscivores, high percent generalists, and low percent native species biomass) had a negative effect on the Index of Biotic Integrity at Hamilton Harbour. Both the unadjusted and the adjusted IBI* scores were significantly lower at Hamilton than at the reference areas (Table 4, both $P<0.001$).

Fish community targets for Hamilton Harbour were identified from the range of values observed at the reference areas. Two additional criteria were used. To emphasize that the targets were approximate, a target range was identified, rather than a specific single target. Secondly, where appropriate, targets were based on the high end of the range observed at the reference areas; rationalization for using the high end of the range is provided in the discussion. Rounding was also applied when establishing the target range:

Fish Measure	Range at reference areas	Hamilton (1990)	Target for Hamilton
Species richness	5 to 7	4	6 to 7 spp.
Biomass	4 to 7	9	6 to 7 kg
CV of biomass	0.7 to 1.0	1.4	0.7 to 0.8
% piscivores biomass	18 to 25	10%	20 to 25%
% generalists biomass	13 to 28	46%	10 to 30%
% specialists biomass	47 to 67	45%	50 to 60%
% native biomass	77 to 91	38%	80 to 90%
IBI	58 to 66	30	55 to 60
IBI*	48 to 62	18	50 to 60

Some of the fish assemblage values (Table 4, and text table above) are slightly different than the values originally used to set targets for Hamilton Harbour (values reported in Anon. 1993). The reason for these differences was that subsequent to the initial analysis, all electrofishing data were entered into a computerized data base (Moore et al. 1998). Minor errors in the original data set were identified and corrected as part of the data verification and data entry procedure. The trophic categories assigned to the fish species as given by Stoneman (Appendix B) are under review which may affect the values for % composition by trophic group. Targets for IBI and adjusted IBI were added to the original targets.

3.4 Annual Analysis -- Overall Harbour and Individual Sites

3.4.1 Individual Parameters and Metrics

Total species richness in the Harbour was lowest between 1990 and 1995, and was greatest, on average, in 1996. Species richness differed significantly among years ($KW_5 = 19.2$, $P = 0.002$). Total species richness in 1997 was slightly lower than 1996 and was similar to species richness found in 1988, remaining below the target species richness of 6-7 species in all years (Fig. 4). Trends at individual sites were variable. Sites A and C initially had quite a low species richness, however both appeared to show an increase in 1996. Around Bayfront Park at sites K and Kb, species richness was usually within or higher than the target range.

Total biomass and total numbers of fish in the Harbour follow a similar pattern with decreases through the initial years, followed by increases to 1996 (both measures showing significant differences between years -- biomass KW = 28.2, numbers KW = 57.97, both $P < 0.001$, Figs. 5 and 6). High numbers and biomass in the early years appear to be partially attributable to the contribution of sites E and F, at which brown bullhead, alewife, white perch and carp predominated (Appendix C). Site K appears to have had a consistently high total biomass over the years, however the species composition appears to have shifted from a dominance of alewife, brown bullhead and a few large carp, to an increased contribution of emerald shiner, pumpkinseed and logperch, as well as carp and alewife. The total biomass of fish in the Harbour remains, on average, slightly greater than the target of 6-7 $kg \cdot transect^{-1}$. Total numbers at site C increased, yet biomass remained low, resulting in very low mean individual weights (Figs. 5 to 7). There was no significant difference in the mean individual weights of fish in the Harbour between years (KW = 4.65, P = 0.46, Fig. 7), however larger individual fish generally appear more common at sites A, B, and D, and in 1996 at sites F and G.

Total species richness was broken down by type of species (with correlation between metrics - Minns et al. 1994) for use as richness metrics in the IBI (Table 2). All of the richness metrics showed significant change in the desired direction since 1988 in the overall Harbour (KW all $P < 0.001$, Figs. 8-12). Richness was greatest in 1996 or 1997 for total native species, centrarchid species, turbidity intolerant species and native cyprinid species, and was lowest in 1997 for non-indigenous species. Since 1992 the greatest richness of native and centrarchid species was found at sites K and Kb; since 1995-6, increases in native, centrarchid and turbidity intolerant species richness were observed at sites A and C (Figs. 8-10). The increase in native cyprinid species richness in 1997 appears to be driven by increases at sites B and F, otherwise this metric is quite variable among years (Fig. 12). In general it appears that non-indigenous species richness has decreased at most sites throughout the Harbour to 1997 (Fig. 11).

The trophic structure of the fish community was presented by classifying all fish species into one of three groups (piscivores, generalists and specialists) and expressing the composition in terms of percentage of total biomass. The maximum contribution of these metrics to the IBI would be achieved if the biomass was equally divided among the three trophic groups since an overrepresentation of generalists would tend to destabilize assemblages (Minns et al. 1994). Percent piscivores was approaching the target to 1995, however 1996 and 1997 saw a decrease in the proportion of this trophic group; differences in the average percent differed significantly among years (KW = 16.2, P = 0.006, Fig 13). Percent specialists was increasing to the target range until 1996 when this metric dropped below the target, although there was no significant difference among years (KW = 7.8, P = 0.165, Fig. 15). The Harbour had an overrepresentation of generalists by biomass in all years, and although initially this metric was decreasing towards the target, in 1996 and 1997 the trend was reversed in an undesirable direction. Differences among years were significant (KW = 11.5, P = 0.043, Fig. 14). Generalists appear to be most consistently predominant at sites J and K, and this group appears to have increased at Kb from less than 40% in 1995 to over 70% in 1997. Percentage generalists appears to be driven by the level of carp biomass relative to other species in a sample (Appendix C).

The final two positive metrics included in the IBI calculation are the number and biomass of native fish over time. The number of native fish in the Harbour reached a low in 1992 and increased steadily to 1997, but on average did not exceed 1988 levels (KW = 11.7, P = 0.039, Fig. 16). The biomass of native fish decreased from 1988 to 1992, leveling off through to 1997 (KW = 31.8, P < 0.001, Fig. 17).

The final two negative metrics included in the IBI calculation are the percent non-indigenous fish by number and biomass over time. The percent non-indigenous fish by number steadily decreased from greater than 60% in 1988 to less than 40% in 1997 (KW = 43.5, P < 0.001, Fig. 18). Percent of non-indigenous fish by number declined at many sites in the Harbour. At site Kb, numbers of non-indigenous fish declined, but the percent biomass increased through to 1996. In the overall Harbour, the percent non-indigenous fish by biomass remained constant over the years with a slight drop in 1997 (KW = 5.3, P = 0.378, Fig. 19).

The percent offshore fish by number and biomass was calculated in order to correct for the inclusion of these species in the littoral zone IBI (to result in the adjusted IBI or IBI*). The greater the proportion of offshore fish in each sample, the greater the difference between the original and adjusted IBI. Offshore fish represent a greater proportion by number than by biomass, however both have decreased since 1995 (by numbers KW = 50.0, biomass KW = 37.3, both signficant among years, P < 0.001, Figs. 20 - 21). Most individual sites have shown decreases in the percent offshore fish since 1995-1996. The increase in percent offshore fish at site C in 1995 was due to the presence of an average of 92 alewife (offshore non-indigenous species) at the site at the time of sampling (Appendix C).

3.4.2 IBI and IBI*

The Index of Biotic Integrity for the fish community in the littoral zone in the Harbour has increased slightly but not significantly since 1992 (ANOVA, $F_{5,472} = 1.60$, $P = 0.157$, Fig. 22). Overall the IBI remains well below the target of 55-60. Variability in IBI among individual sites was high, showing increases in recent years at some sites (e.g. site C), but declines at others (site Kb; Fig. 22).

The adjusted IBI* showed a slightly different trend over the years with a decrease in 1995 followed by an increase to 1997; differences among years were significant (ANOVA, $F_{5,472} = 8.05$, $P < 0.001$, Fig. 23). In each year the IBI* score was lower than the unadjusted IBI score because of the exclusion of the offshore fish. The IBI* for the Harbour was significantly greater in 1996 and 1997 than in 1988, 1990 or 1995 (Bonferonni adjusted post hoc).

3.4.3 Habitat Restoration

The results of the assessment of the effects of restoration work on the Harbour's fish community indicates that, for some of the metrics, the IBI and IBI*, the restoration sites saw greater improvements relative to the unaltered sites after work was completed in 1996 (Figs 24-38, Table 5). For many of the metrics however, the score at the restoration sites were initially superior in 1988 prior to habitat alteration, dropped below unaltered sites mid-study (possibly due to construction activities) and then increased post-restoration work in 1996 (Figs. 24, 25, 29, 30, 34-36). Furthermore it generally appears that the fish community at the unaltered sites also changed in the desired direction, which was previously reflected in the results of the overall Harbour analysis.

Metrics which showed the greatest increase at restoration sites, since habitat improvements in 1996, include the following: native and centrarchid species richness, percent piscivores, generalists, non-indigenous fish by numbers and biomass, and percent native fish by biomass (Figs. 24, 25, 29, 30, 34-36). Metrics which show similar patterns through time regardless of whether restoration work was carried out at the site include turbidity intolerant, non-indigenous and native cyprinid species richness, percent specialists by biomass, and the number and biomass of native fish over time (Figs. 26-28, 32-33).

The comparison of the IBI scores between restored and unaltered sites before and after habitat manipulation indicated that there were significant differences between the type of site, but the direction of the difference depended on the year of comparison (2-way ANOVA, Year*Rehab, $F_{3,\ 333} = 2.62$, $P = 0.05$, Fig. 37 and Table 6). In the 2 years after habitat restoration the IBI scores at the altered sites (C and E) were greater than at the unaltered sites (Fig. 37). The same analysis on the IBI* did not result in a significant interaction term ($F_{3,\ 333} = 2.04$, $P = 0.11$), but did indicate that there were significant differences in the IBI* score both between years and between type of site, with the 1997

IBI* score significantly greater than 1988 and 1990 (Year $F_{3, 333} = 11.2$, $P < 0.001$, Bonferroni post hoc, equivalent to the overall Harbour comparison) and the IBI* score at the restoration sites significantly greater than at the unaltered sites, all years combined (Rehab $F_{1, 333} = 6.5$, $P = 0.01$, Fig. 38; Table 6).

3.5 Future Monitoring Requirements

The transformed (square root) IBI data were used to determine the minimum detectable change based on the current and a reduced sampling intensity (Fig. 39, a and b). The average of the square root IBI in 1997 was 6.15 (corresponding to an IBI score of approximately 38) and the square root of the IBI target minimum is 7.42 (corresponding to a score of 55). The difference between the current level and the target is 1.23; this difference exceeds the minimum detectable change after only 1 year of monitoring at an intensity of 120 samples per year, or 2 years of sampling at a reduced intensity of 10 samples per year (Fig. 39, a and b). For example, if the IBI score in the Harbour did reach the target in 1998, this change would be measured as significant (power = 0.90) at the current level of sampling intensity (120 samples per year).

However, smaller differences in the square root IBI would take considerably longer to detect statistically. If current monitoring levels were maintained (120 samples annually), at least 3 years of data would be required (Fig. 39 a). to have a 75% chance (power = 0.75) of detecting a difference of 0.5 in the square root IBI (an increase in the IBI from 38 to 44). If sampling intensity was reduced to 10 samples per year, a minimum of 8 years of data would be required to detect the same difference in the IBI scores (Fig. 39 b). Additional sampling years would be required to detect small incremental increases in the IBI if the power of the test was increased to 0.90 (Fig. 39 a and b).

4.0 DISCUSSION

Any local fish community is reflective of the environment in which it inhabits. Measures of that community such as fish species richness, abundance, biomass and community composition can therefore be used as biotic measures to monitor and evaluate the condition of the habitat. Hamilton Harbour remains an Area of Concern under the Great Lakes Water Quality Agreement as many of the criteria for delisting the Harbour have not yet been met (App. A). However, over recent years, considerable efforts have been made to restore Hamilton Harbour to an area where intrinsic and beneficial uses are no longer impaired. Through the analysis of data from an extensive field monitoring program of the fish community in Hamilton Harbour, we were able to provide a background description of the fish community, and describe how fish assemblages vary spatially within the Harbour. By comparing fish community analyses with similar data from 4 less degraded Areas of Concern in the Great Lakes, we were able to provide quantitative community fish targets in terms of fish species richness, biomass, trophic composition and an Index of Biotic Integrity. With these same Hamilton Harbour fish community data, we were able to describe temporal trends in the fish community in the

Harbour overall and near habitat restoration areas. Finally, future monitoring needs and a survey design were determined.

4.1 Fish Community of Hamilton Harbour Before Restoration and Improvements in Fish Habitat

Hamilton Harbour has been extensively degraded. Historically it provided some of the most productive fish habitat in the Great Lakes. Now it provides habitat suitable mainly for warm-water, species more tolerant of degraded habitat. Numerous physical (infilling and other habitat loss), chemical (excessive nutrient and chemical inputs) and biological (introduced species and overfishing) factors contributed to the decline of the fish community (Holmes 1988) and a shift to a community dominated by species indicative of a eutrophic environment such as white perch (*Morone americana*), brown bullheads (*Ameiurus nebulosus*) and carp (*Cyprinus carpio*) (Hartig et al. 1997).

Details of the fish community structure in 1990, in comparison to communities in less degraded habitats, are summarized in Table 4. Several important features of the community structure in Hamilton Harbour differed from the reference areas. In the Harbour, species richness was on average lower and biomass was higher than at the reference areas. Piscivore biomass was lower in the Harbour, the proportion of generalists (like common carp) was higher, and the proportion of the total biomass which was comprised of native species was lower in the Harbour than at any of the reference areas. Collectively, these differences affected the Index of Biotic Integrity in Hamilton Harbour; both IBI and adjusted IBI* values were significantly lower in Hamilton Harbour than at the four reference areas.

Remediation of the Harbour (implying a reduction of the intensity of some specific human abuses), has occurred since the 1970s through a reduction in pollutant loadings from industrial or municipal waste streams (Holmes 1988). As a result, major improvement in water and sediment quality were observed to 1987 (Charlton and LeSage 1996). Since 1987, water quality in the Harbour has seen marginal improvement. The range in total phosphorus concentrations measured in a given year has been greatly reduced, and in 1996 and 1997 total phosphorus concentrations fluctuated around the initial goal of 38 $\mu g \cdot L^{-1}$ (Charlton, unpublished data) However, further nutrient load reductions are required to reduce phosphorus and Chl a concentrations from 1995 levels (approx. 40 $\mu g \cdot L^{-1}$ and 20 $\mu g \cdot L^{-1}$ respectively) to the final RAP goal concentrations (17 $\mu g \cdot L^{-1}$ and 5-10 $\mu g \cdot L^{-1}$ respectively, Charlton and LeSage 1996). Perhaps the most significant improvement in water quality in the Harbour since 1987 is the increase in secchi depth from fluctuating around 1.5 m in 1987, to fluctuating around 3 m in 1997, with a maximum secchi depth greater than 5 m (Charlton, unpublished data). Increased water clarity should facilitate the recovery of submerged macrophytes in the Harbour.

Habitat restoration, which includes remediation plus active efforts to foster recovery of the natural system (Holmes 1988), has occurred in Hamilton Harbour with the addition of physical habitat structures in 3 sites in the littoral zone (1 completed in 1992, and 2 in 1996), as part of the Remedial Action Plan for the Harbour (AOC 1992a, b). Restoration of preferred littoral fish habitat may have a positive influence on the fish community, at least in the areas adjacent to the modified shorelines. To detect changes in the fish community over time, quantitative fish targets were set using survey data from less degraded littoral areas in the lower Great Lakes.

4.2 Quantitative Fish Community Targets

The fish community targets which were developed (Table 4) were provisional and probably reflect conservative goals for the Harbour. All of the reference areas were designated 'Areas of Concern' because of water quality and habitat concerns. Randall et al. (1993) noted that the five areas could be ranked according to degree of habitat degradation from the most degraded (Hamilton) to the least degraded (Matchedash Bay, Severn Sound). Although the reference areas provide a gradient in environmental conditions for comparison, none of these areas are pristine. Indices from relatively unaltered areas (non-AOC) may be higher. Unaltered areas, particularly protected embayments like Hamilton Harbour, are rare in the lower Great Lakes and it may be difficult to find better reference areas in future. Because the reference areas are located within AOCs, the fish goals must be considered to be conservative.

The percent composition by trophic group from the reference sites may represent a balanced littoral fish community, but some qualification is needed. The fish surveys were constrained both spatially (1.5 metre depth contour) and temporally (summer of one year). A more precise description of a balanced community structure (in an ecological bioenergetic sense) may result if the sampling was a) more spatially and seasonally robust, b) included all life history stages, and c) was conducted for many years. The quantitative targets are nevertheless useful, as they were established by referencing the 100 m survey transects. Progress towards achieving the targets can be monitored using the standardized survey protocol. The fish targets provided a baseline or point of reference for detecting changes over time in attributes of the fish community.

Interpretation and comments on the individual fish targets are useful for identifying their limitations. The target for overall fish biomass is slightly less than the biomass observed in 1990. Randall et al. (1993; 1996) showed that the biomass of fish in littoral areas of the lower Great Lakes was positively correlated with the concentration of phosphorus, a nutrient element. A causal relationship has not been established for localized areas in the Great Lakes, but linkages between fish production and phosphorus have been demonstrated at other locations (Downing et al. 1990; Lee and Jones 1991). The target of a lower fish biomass is thus consistent with the RAP water quality goal of reducing nutrient loadings in the Harbour (COA 1992b). The quantitative target for fish biomass, as for all fish targets, was set using the range of values from the reference areas as a guideline. The total biomass target of 6-7 kg per transect is at the high end of the reference range, which reflects the high productivity of the Harbour, where phosphorus concentrations are higher than the reference areas (Randall et al. 1993). However a desirable community biomass, with reduced phosphorus loadings, may be lower. A target for a lower CV of biomass was also identified in the original list of targets (COA 1992b, Appendix A). However, the results presented here indicated that the coefficient of variation of biomass was not significantly higher at Hamilton than at the reference areas ($P>0.10$). The biomass targets are most appropriate as general indicators of the expected trend (lower biomass and variance) with harbour remediation.

As noted in the previous section, all of the fish community composition measures were significantly different at Hamilton Harbour than at the reference areas, possibly reflecting the degraded conditions in the Harbour (Randall et al. 1993). All of the established fish community goals were within the range of values observed at the four reference areas. Two of the goals (species richness and % piscivore biomass) were set at the higher end of the range, to be consistent with the general RAP goals of increasing the abundance of top predators in the Harbour, and to increase fish species richness so that the biomass would not be dominated by a few, usually undesirable, species (COA 1992a).

All of the targets are based on average values for 100 m survey transects. Biomass is expressed as average kg per transect. Approximate absolute biomass densities ($kg{\cdot}ha^{-1}$) can be calculated by assuming a catch efficiency of 0.3, and a survey area of 100 m by 10 m (Randall et al. 1993). This catch efficiency is very approximate, and it can only be applied to the combined fish assemblage, not to individual species. The biomass target of 6-7 kg per transect relates to an absolute biomass of 200 - 233 $kg{\cdot}ha^{-1}$ (for a narrow zone centered at 1.5 m depth), which rounded to the nearest 50 kg, gives a rough target of 200 to 250 $kg{\cdot}ha^{-1}$. The latter absolute biomass densities were used in the RAP document as a target range for total biomass (Appendix A). For monitoring and interpreting the fish community goals, the raw data (catch per transect in kg) are a more direct measure to use. Catch per transect data were used in the calculation of the IBI.

The Index of Biotic Integrity (IBI) provided a useful multivariate measure of ecosystem health (Minns et al. 1994). Many of the individual metrics which were used to calculate the IBI were consistent with the fish measures used for the community targets (species richness, % piscivores, % native species). The IBI target range (55-60) which was added to the original list of fish community targets was reasonable, as it was within the range of IBI scores observed at the AOC reference areas, and it is also similar (although somewhat less) to the range of values observed in natural coastal wetland areas at non-AOC locations in the lower Great Lakes (Randall, unpublished data). The IBI provides a composite index of the fish community structure, incorporating all of the desirable fish community attributes identified in the Hamilton Remedial Action Plan (COA 1992b).

4.3 Variability in Fish Catches

Figures 2 and 3, as well as the individual site averages presented in Figures 5 through 23, illustrate the considerable variability in fish community as captured between samples, between sites, and between years. Details of spatial variability in the fish community data around the perimeter of the Harbour are provided in the plots from individual sites.

Although much of the variability may be due to behaviour or habitat preferences, some of the variability may be attributable to changing efficiency of the electrofishing gear. The efficiency of electric fishing can be affected by a variety of factors including 1) environmental factors such as conductivity, water clarity, habitat structure and season, 2) biological factors such as species composition, fish density and size, and species specific behaviour and morphology, and 3) technical factors including crew experience, motivation, equipment design and maintenance, and standardization of effort (Zalewski and Cowx 1990). The standardized field protocol used in the collection of the data would have minimized the influence of technical factors on sampling efficiency. Variation in sampling efficiency due to environmental and biological factors would introduce random error, and were likely factors influencing the variability of the catch data.

4.4 Temporal Trends in the Fish Community

Since 1988 the fish community Index of Biotic Integrity (IBI) in Hamilton Harbour has increased marginally, but not significantly. However, the adjusted IBI* also increased, and the increase was significant. The IBI* scores are important, since the adjusted index focuses on the inshore species, which inhabitat the nearshore areas, and disregards the offshore species. In later years, particularly in the vicinity of habitat restoration areas, a number of fish community measures were within, or approaching, the target range (Figs. 4-23). However, a comparison of RAP targets in Hamilton Harbour in 1990 vs. 1997 indicates that for some targets, the fish community in the Harbour has deteriorated further from the goals set for this AOC since 1990 (text table below). The most significant change is seen in the percentage by biomass of the three trophic groups, particularly the proportion of generalists, which has increased. However, the percentage by biomass can be misleading due to the potential of a few large fish (like carp) to influence this metric. For example, percent generalists by biomass at site K was greatest in 1997 (Fig. 14) as the result of an average of 8 carp (non-indigenous generalist) being sampled, contributing an average of 20.7 kg biomass to the total sample. In contrast, an average of 21 pumpkinseed (native centrarchid specialist) were sampled at site K in 1997, however their contribution to total biomass was an average only 0.34 kg per sample due to their smaller size than carp.

Fish Measure	Hamilton (1990)	Hamilton (1997)	Target for Hamilton
Species richness	4	5.3	6 to 7 spp.
Biomass	9	9.5	6 to 7 kg
CV of biomass	1.4	1.5	0.7 to 0.8
% piscivores biomass	10%	8%	20 to 25%
% generalists biomass	46%	60%	10 to 30%
% specialists biomass	45%	32%	50 to 60%
% native biomass	38%	39%	80 to 90%
IBI	30	37	55 to 60
IBI*	18	28	50 to 60

Metrics contributing to the increase in the IBI include: increases in centrarchid, cyprinid, native and turbidity-intolerant species richness, and decreases in non-indigenous species richness, and percent non-indigenous fish by number (Figs. 8 - 12, 18). Overall therefore, the fish community in the Harbour has changed in a direction consistent with RAP goals. Further improvements are required for the IBI in the Harbour to reach the target range. Although the individual metrics are instructive for identifying specific fish community changes, the Index of Biotic Integrity, a composite of all the metrics, provides a more reliable tool for monitoring, assessing and evaluating biological systems (Karr 1987). It is therefore recommended that the quantitative IBI and IBI* targets replace the original fish community targets in the criteria for delisting the Harbour as an Area of Concern (Appendix A).

Overall, it appears that the fish community as measured by IBI* (all sites combined) has changed in the desired direction. Data from the habitat restoration sites were also encouraging. Some of the metrics and the IBI scores were higher at the restoration areas after work was completed in 1996 (e.g., centrarchid species richness, piscivore biomass; Figs 24-38, Table 5) than at the unaltered sites. These results are consistent with the hypothesis that the changes to the physical habitat would benefit the fish communities.

The difference in the ANOVA results for the unadjusted and adjusted IBI* scores at the restored and unaltered habitats (Table 6), however, complicated the interpretation of these data. The interaction term in the ANOVA model is important, as it is a test for differences in the fish measures between the impacted (restored) and unimpacted (unaltered) sites after restoration (Green 1979; Underwood 1993). A significant interaction term, as was found for the unadjusted IBI, suggests that there were differences in the IBI between the restored and the non-restored sites, and the difference was seen in the years after restoration (1996 and 1997). However, the fact that the interaction term was not significant for IBI* suggests that offshore species may have contributed to the significant interaction term for the unadjusted IBI. The observation that IBI* increased at both the restoration and the unaltered sites confounded attempts to interpret the impact of the restoration work on the littoral fish community. For both IBI and IBI*, differences between the restored and non-restored sites were greatest in 1996 and less in 1997; that is, the IBI indices for both habitat areas converged in the most recent year. A longer time series of data after restoration is required to better evaluate the impact of the habitat restoration, and to sort out the other confounding factors which may have impacted on the IBI scores in both the restored and unaltered nearshore areas (e.g., changes in water clarity, macrophyte density and the abundance of offshore species).

A critical question is whether the alterations to littoral habitat resulted in changes in fish biomass, community structure and production, or whether the results are simply reflecting a redistribution of fish already present in the Harbour (i.e. a concentration of fish in a more localized area of preferred habitat)? It is not possible to answer this question without *a priori* knowledge of total fish production in Hamilton Harbour; however, our survey was not designed to measure production. IBI scores at the restoration sites may be reflective of fish concentrating at these sites of high habitat diversity. A literature review on whether artificial reefs increased fish production, or simply attracted fishes due to behavioural preferences, found that in most cases, the evidence for increased production was circumstantial and inadequate (Bohnsack 1989). However, the attraction versus production hypotheses are not mutually exclusive. Artificial habitat would be most likely to increase fish production in areas isolated from natural reefs and for habitat-limited species (Bohnsack 1989). Considering the severe degradation of fish habitat in the Harbour, it is possible that observed improvements in the overall Harbour IBI are related at least in part to the improvements in physical habitat at the localized restoration sites.

If physical habitat (spawning, nursery or adult habitat) was limiting fish production in Hamilton Harbour, then the improvements in fish habitat could result in an increase in the productive capacity of the system, providing the three critical types of habitat (spawning, nursery and adult) are available. However, to date, this study in Hamilton Harbour only includes 2 years post physical habitat manipulations, which is a limited time frame. Knowledge of the life history characteristics and habitat preferences of fishes which utilize Great Lake littoral habitats during at least a portion of their life is a necessary prerequisite to understanding the impact of habitat alterations on the fish community, and the time frame involved.

Lane et al. (1996a, b, c) conducted an extensive literature review of nursery, adult and spawning habitat characteristics of Great Lakes fishes. The majority of the 120 lake-spawning species utilize shallow water habitat, and the majority of those (105) spawn in the spring, 12 spawn in the fall and 3 spawn in the winter (Lane et al. 1996c). Although gravel and sand are the most commonly used substrates, cobble and silt substrates were also frequently used for spawning. However, the amount of vegetation cover (emergent and submergent) largely determined the use of silt substrates, which support vegetation growth, as numerous species spawn on or in the vicinity of vegetation. Strong association with fixed cover, such as rocks and logs, was also found. Spawning habitat selection by many species reflects the need for available food and protective cover for the newlyhatched fish to enhance growth and survival (Lane et al. 1996c). Few fishes use bedrock or hard-pan clay as either spawning or nursery habitat.

Larval fish of most species which spend at least a portion of their first year of life in the Great Lakes (127) occur in water depths of 2 metres or less, and most were associated with areas of vegetated sand and silt substrates (Lane et al. 1996a). Macrophytes provide both structure and cover for protection from predators, and provide food for young fish by harbouring abundant invertebrate prey (Randall et al. 1996). Gravel substrate, boulder, cobble and rubble also provide suitable cover for young-of-the-year fish (Lane et al. 1996a). A study of larval fish found in Hamilton Harbour in 1985 and 1987 found that a shortage of habitat containing high substrate and plant diversity limited larval fish distribution mainly to the western sector and Cootes Paradise, and limited larval fish abundance of many species (Leslie and Timmins 1992). Gizzard shad (*Dorosoma cepedianum*, collected mainly in nearshore turbid areas) and alewife (*Alosa pseudoharengus*, collected mainly in relatively clear open water) larvae comprised 85% of the total catch. Juvenile fish made up < 1% of the total catch in both years studied.

Water temperature preferences often dictate the depths at which adult fish reside, with cold water species being restricted to the hypolimnion during the stratified period (Lane et al. 1996b). Most cyprinids remain at depths < 2 m throughout their life and most centrarchids and percids remain at depths < 5 m year round. Adults of many fishes are associated with cover (logs and rocks), and utilize a variety of substrates including sand, silt and vegetation. For species which become pelagic as adults (alewife, lake whitefish, rainbow smelt, spottail shiner and salmonids, Appendix B), substrate becomes of little importance (Lane et al. 1996b). The presence of such offshore species in littoral habitats was accounted for in the calculation of the adjusted IBI, although no age or size distinction was made in this study.

In summary, habitat with high substrate and plant diversity is of prime importance to the success of nearly all species found in the Harbour during the larval and spawning phase, and remains important for most species during the adult phase. The rock reefs, islands, emergent shoals and ‘log’ cover used as restoration structures have added to the habitat diversity in the littoral zone of the Harbour, and have had the added indirect effect of increasing vegetation coverage through decreased wave action. Randall et al. (1996) found that littoral habitats with abundant submerged macrophytes had a significantly higher index of fish production than adjacent sites with low macrophyte abundance. Furthermore, the fishway (carp barrier) constructed at the opening to Cootes Paradise has had the effect of allowing the revegetation of the marsh, improving spawning and nursery habitat for many Harbour fishes. Since a shortage of diverse habitat appeared to be limiting the distribution and abundance of many species in the Harbour (Leslie and Timmins 1992), any increase in habitat diversity should benefit the fish community.

The results from the seasonal analysis of the IBI and IBI* indicates that the fish community at the sites improved in the spring and fall (Figs. 2 and 3), which may be the result of adults moving into shallower water to spawn. Since the transects were at a depth of 1.5 m, as the summer progresses some fish may move to slightly deeper waters and would not be included in the catch, thus lowering the IBI. The increase in the IBI in the fall is likely partially due to the presence of spawning offshore species (salmonids), as this fall increase is not as pronounced in the IBI adjusted for the presence of offshore species (Figs. 2 and 3). The fall increase in the IBI and IBI* may also be due to the movement of young fish from Cootes Paradise into the Harbour (B. Valere pers. obs), and/or to their increased catchability by the electrofishing gear because of their larger size (Zalewski and Cowx 1990) after growth during the summer.

Although the fishway in Desjardin Canal has improved conditions in Cootes Paradise, carp which are excluded from spawning in the marsh may seek vegetated spawning habitat elsewhere in the Harbour. With the exclusion of carp from Cootes came the potential of increased turbidity and lower biomass of rooted plants in the Harbour proper (a result of the activities of carp, Leslie and Timmins 1992). However an analysis of carp biomass at all sites in the Harbour indicates that there was no significant change in carp biomass between 1988 and 1997 (ANOVA, $F_{5, 58} = 1.30$, $P = 0.28$). Localized changes in carp biomass on a site by site basis have not yet been investigated.

The improved water quality and macrophyte cover in Cootes Paradise may increase the recruitment success of the remaining carp in the marsh. Annual August electrofishing surveys of Cootes Paradise found 471 young-of-the-year carp in 1995 and over four times the number (1996) young-of-the-year carp in August 1997 (Theijsmeijer unpublished data). With the improvements in aquatic vegetation and water clarity in the marsh, it would be expected that recruitment of all species would increase, including carp. The same annual August electrofishing survey of Cootes Paradise found that numbers of young-of-the-year pumpkinseed and yellow perch increased significantly between 1996 (806 and 19, respectively) and 1997 (4716 and 575, respectively, Theijsmeijer unpublished data). It is expected that the restoration of the marsh will eventually result in the movement of a large number fish species into Cootes, resulting in a natural balanced fish community such as we see in the marshes at the Bay of Quinte or Matchedash Bay reference areas (Table 4). Changes to the fish community in Cootes Paradise could impact the fish community in the Harbour, as these two habitat areas are contiguous.

Water quality, particularly in the hypolimnion, remains to be a concern in Hamilton Harbour. Further improvements in the water quality of effluent streams into the Harbour are necessary in order to achieve final RAP goals (Charlton and Le Sage 1996), although a number of measures (total phosphous, chlorophyl a, secchi depth) are currently fluctuating around the initial RAP targets (M. Charlton, unpublished data). The anoxic hypolimnion prevents the re-establishment of a coldwater fishery and it may also be negatively impacting the warmwater fish community through wind-generated upwelling of anoxic bottom water (J. Fitzsimons, unpublished data). Three years (1994-1996) of measurements by an *in situ* logger placed at a depth of 5 m on an artificial reef at the Bayfront Park site (Kb) measured oxygen at or below the critical level of 3 ppm over 40%

of the time during the stratified period. No fish were captured at the artificial reefs when dissolved oxygen levels fell below this critical level (J. Fitzsimons, unpublished data). The frequency of upwelling events which could affect fish at a depth of 1.5 m, what happens to the oxygenated water, and where the fish go during and after periods of upwelling, are all questions warranting further study.

4.5 Future Monitoring Requirements

The assessment of the level of monitoring of the Hamilton Harbour fish community indicates that the 1997 sampling intensity should be adequate to maximize the chances of detecting statistically significant changes in the fish community (as measured by IBI scores) over time. The probability of determining a change in the fish community is highly dependent on the level of change observed, i.e. if the observed change is large, then it will be statistically detectable within 1 year. Considering the small incremental increases in the IBI since 1988, it is highly unlikely that the IBI in Hamilton Harbour will reach the target in 1 year, and additional years of monitoring are required. Between 1990 and 1997, the IBI in the Harbour increased from 30 to 37, and in order to reach the target range of 55, an additional increase of 18 is required. If the increase in the IBI continues at a constant rate, it would take an additional 18 years for the IBI to reach the target, however with continued remediation efforts it is possible that this rate of change will increase.

Due to the seasonal changes in the IBI, it is also recommended that the Harbour be sampled a minimum of 3 times per season (spring, summer and fall). Reducing the number of transects and the period of sampling within a year would result in data that are not comparable to existing data. A reduction in the sampling intensity within a year would also necessitate the collection of nearly three times the number of years of data to statistically detect small changes in the IBI (Fig. 39 a and b). If financial constraints are an issue, we recommend that the current level of sampling be conducted on a biennial basis.

4.6 Summary and Conclusions

Despite the water quality issues still to be addressed in the Harbour, the results at this stage of the restoration of the Harbour are encouraging. The first steps taken in the recovery process included habitat restoration, combined sewer overflows, sewage treatment plant upgrades and watershed plans (COA 1992b). These steps were designed to encourage warm water littoral species, and the improvements in the IBI* scores for Hamilton Harbour's littoral habitats were consistent with this goal. Preliminary survey data from the localized habitat restoration sites were also encouraging and consistent with RAP goals; more work needs to be done to evaluate and substantiate these changes (see below). Plans to continue habitat restoration activities at Cootes Paradise, Grindstone Creek, and the West and Southeast shorelines could result in a continued positive response from the fish community. Efforts to reduce the impact of contaminated sediments and foster the recovery of the benthic community will begin this year. The remaining water quality issue of low dissolved oxygen in the hypolimnion is considered as part of future Harbour restoration efforts.

Results and the interpretation of data from this study are tentative. Future data analysis and monitoring are needed. Specifically, the following is needed: 1. a long term study to better understand and interpret 'overall Harbour' changes versus changes to the fish community at the localized restoration sites; 2. a detailed description of changes to habitat, and a clear understanding of the relative influence of individual habitat factors on the fish community (water clarity, macrophyte density, zebra mussel density, nearshore habitat alteration, involving changes to depth, structure, substrate and exposure); 3. the influence of anoxia in the hypoliminion on nearshore habitat and fishes; 4. the impact of the carp barrier on carp abundance in the Harbour.

Monitoring of the fish community in Hamilton Harbour should continue in future, in tandem with RAP activites, to provide long-term data on fish-habitat linkages in an area undergoing restoration.

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Table 1: Hamilton Harbour Electrofishing Samples: Total Number of Samples by Transect and Year

Repeat	**Area**	**Transect**	**1988**	**1990**	**1992**	**1993**	**1995**	**1996**	**1997**
	A	HH1	10	1	2			4	4
X	A	HH2	7	3	2	1	3	4	4
	A	HH3	8	1	2				
X	A	HH4	7	3	2	1	3	4	4
	B	HH5	9	1	1				
X	B	HH6	7	3	2	1	3	4	4
	B	HH7	9	1	2			4	4
X	B	HH8	6	3	2	1	3	4	4
X	C	HH9	9	1	2		2	3	2
	C	HH9a						1	2
X	C	HH10	7	3	2	1	2	3	2
	C	HH10a						1	2
X	C	HH11	9	1	2		2	3	2
	C	HH11a						1	2
X	C	HH12	7	3	2	1	2	3	2
	C	HH12a						1	2
	D	HH13	9	1	2				
X	D	HH14	7	3	2	1	3	4	4
	D	HH15	9	1	2			4	4
X	D	HH16	7	3	2	1	3	4	4
X	E	HH17	11	1	2		3	4	4
X	E	HH18	8	3	2	1	1	4	4
X	E	HH19	9	1	2		2	4	4
X	E	HH20	7	3	2	1	2	4	4
	F	HH21	10	1	2				
X	F	HH22	7	3	2	1	3	4	4
	F	HH23	10	1	2			4	4
X	F	HH24	7	3	2	1	3	4	4
	G	HH25	11	1	2			4	4
X	G	HH26	7	3	2	1	3	4	4
	G	HH27	9	1	2				
X	G	HH28	7	3	2	1	3	4	4
	H	HH29	9	1	2			4	4
X	H	HH30	7	3	2	1	3	4	4
	H	HH31	9	1	2				
X	H	HH32	7	3	2	1	3	4	4
	J	HH33	9	1	2		2	4	4
X	J	HH34	7	3	2	1		4	4
	J	HH35	9	1	2				
X	J	HH36	7	3	2	1	3	4	4
X	K	HH37	9	1	2			4	3
X	K	HH38	7	3	2	1	3	4	3
X	K	HH39	9	1	1			4	3
	K	HH40	7	3	1				
x	Kb	HH41		1	3	2	3	4	3
x	Kb	HH41b				2	3	4	3
	Kb	HH42		1	2	2	3		
x	Kb	HH42a				2	2	4	3
x	Kb	HH42b				2	3	5	3
	Kb	HH43			2	2	2		
x	Kb	HH43b				2	3	4	3
x	Kb	HH44		1	2	2	3	3	3
x	Kb	HH45			2		2	4	3

Table 2: Biological indicators representing species richness and composition, trophic composition, and fish abundance, calculated from electrofishing data, to be examined individually and used in the calculation of the IBI.

ID	Metric Code	Metric Name	Metric Variable	Include in IBI	Influence on IBI
1	NSP	Total Species Richness	CountOfSpecies	No	
2	NUMBERS	Total Numbers	Number	No	
3	TOTBIOKG	Total Biomass	Biomass	No	
4	MEANWT	Mean Individual Weights	Biomass	No	
5	SNAT	Native Species Richness	CountOfSpecies	**Yes**	**Positive**
6	SCEN	Centrarchid Species Richness	CountOfSpecies	**Yes**	**Positive**
7	SINT	Intolerant Species Richness	CountOfSpecies	**Yes**	**Positive**
8	SNIN	Non-indigenous Species Richness	CountOfSpecies	**Yes**	**Negative**
9	SCYP	Native Cyprinid Species Richness	CountOfSpecies	**Yes**	**Positive**
10	PPIS	Percent Piscivore Biomass	Biomass	**Yes**	**Positive**
11	PGEN	Percent Generalist Biomass	Biomass	**Yes**	**Negative**
12	PSPE	Percent Specialist Biomass	Biomass	**Yes**	**Positive**
13	NNAT	Number of Native Individuals	Number	**Yes**	**Positive**
14	BNAT	Biomass of Natives (kg)	Biomass	**Yes**	**Positive**
15	PNNE	Percent Non-indigenous by Number	Number	**Yes**	**Negative**
16	PBNI	Percent Non-indigenous by Biomass	Biomass	**Yes**	**Negative**
17	POFN	Percent Off-Shore by Number	Number	No	
18	POFB	Percent Off-Shore by Biomass	Biomass	No	

Table 3: Hamilton Harbour Electrofishing Samples: Number of repeat transects used in analysis by area and year.

Area	1988	1990	1992	1995	1996	1997
A	14	6	4	6	8	8
B	13	6	4	6	8	8
C	32	8	8	8	12	8
D	14	6	4	6	8	8
E	35	8	8	8	16	16
F	14	6	4	6	8	8
G	14	6	4	6	8	8
H	14	6	4	6	8	8
J	14	6	4	6	8	8
K	25	5	5	3	12	9
Kb		2	7	19	28	21

Table 4:Fish community targets for Hamilton Harbour. Fish assemblage measures for Hamilton are compared to four other reference locations (see text). Values are arithmetic means (with ranges in parenthesis). The compositional measures (percent trophic groups and percent native) were calculated for transects where the biomass was greater than 0.

Location	Hamilton	Quinte	Penetang	Hog	Matchedash	KW	CONTRAST	Targets for Hamilton[1]
Number of samples	60	59	84	28	36	(prop.)	F (prop.)	(average for 100 m transects)
Number of samples with 0 catch	1	3	3	1	0			
Fish assemblage measures								
Species richness	4.1 (13)	6.7 (14)	5.1 (12)	4.8 (9)	6.9 (8)	40.7 (P<0.001)		6 to 7 species
Biomass	9.1(71.9)	7.0(30.1)	4.8(21.2)	3.8(12.8)	3.7(9.4)	10.6 (P<0.05)		6 to 7 kg
CV of biomass	1.40	0.89	0.96	0.86	0.71	1.12 (P=0.56)		0.70 to 0.80
% Piscivore biomass	9.5(96.2)	25.1(82.2)	17.8(100.0)	22.9(82.7)	23.8(68.7)	36.4 (P<0.001)		20 to 25%
% Generalist biomass	45.5(100.0)	27.6(97.6)	15.6(100.0)	13.3(83.0)	26.4(80.3)	21.9 (P<0.001)		10 to 30%
% Specialist biomass	44.9(100.0)	47.3(100.0)	66.6(100.0)	63.8(94.0)	49.8(91.2)	16.08 (P<0.003)		50 to 60%
Percent native biomass	37.7(100.0)	77.2(97.6)	91.0(87.9)	88.1(83.5)	90.7(77.6)	100.7 (P<0.001)		80 to 90%
Index of Biotic Integrity (IBI)	30.2	58.0	58.6	58.6	65.8		86.4 (P<0.001)	55 to 60[2]
Adjusted IBI	17.8	48.5	56.4	56.4	61.9		167.3 (P<0.001)	50 to 60[2]

[1] targets from RAP (1992)
[2] proposed IBI targets

Table 5: Summary of results of the restoration site vs. non-restoration site, before and after rehab work comparison. Biological indicators representing species richness and composition, trophic composition, and fish abundance. Positive sign indicates the restoration site score was greater than the unaltered site score.

Metric Name	Influence on IBI	1988	1990	1996	1997
Native Species Richness	Positive	+	+	+	+
Centrarchid Species Richness	Positive	+	+	+	+
Intolerant Species Richness	Positive	+	-	+	-
Non-indigenous Species Richness	Negative	+	+	-	-
Native Cyprinid Species Richness	Positive	+	-	-	-
Percent Piscivore Biomass	Positive	≅	-	+	+
Percent Generalist Biomass	Negative	-	+	-	-
Percent Specialist Biomass	Positive	+	-	≅	-
Number of Native Individuals	Positive	+	-	+	+
Biomass of Natives (kg)	Positive	+	+	+	+
Percent Non-indigenous by Number	Negative	-	+	-	-
Percent Non-indigenous by Biomass	Negative	-	≅	-	-
IBI		+	-	+	+
Adjusted IBI*		+	-	+	+

Table 6. Results of Analysis of Variance testing for the effects of Year (1988,1990,1996,1997) and Habitat (restored or non-restored) on the Index of Biotic Integrity (IBI) scores.

	Sum-of-squares	df	Mean-square	F-ratio	P
IBI					
Year	8.56	3	2.85	3.57	0.014
Habitat	9.18	1	9.18	11.48	0.001
Year*Hab	6.29	3	2.10	2.62	0.051
error	266.24	333	0.80		
IBI*					
Year	25.77	3	8.59	11.21	0.000
Habitat	4.95	1	4.95	6.46	0.011
Year*Hab	4.69	3	1.56	2.04	0.108
error	255.12	333	0.77		

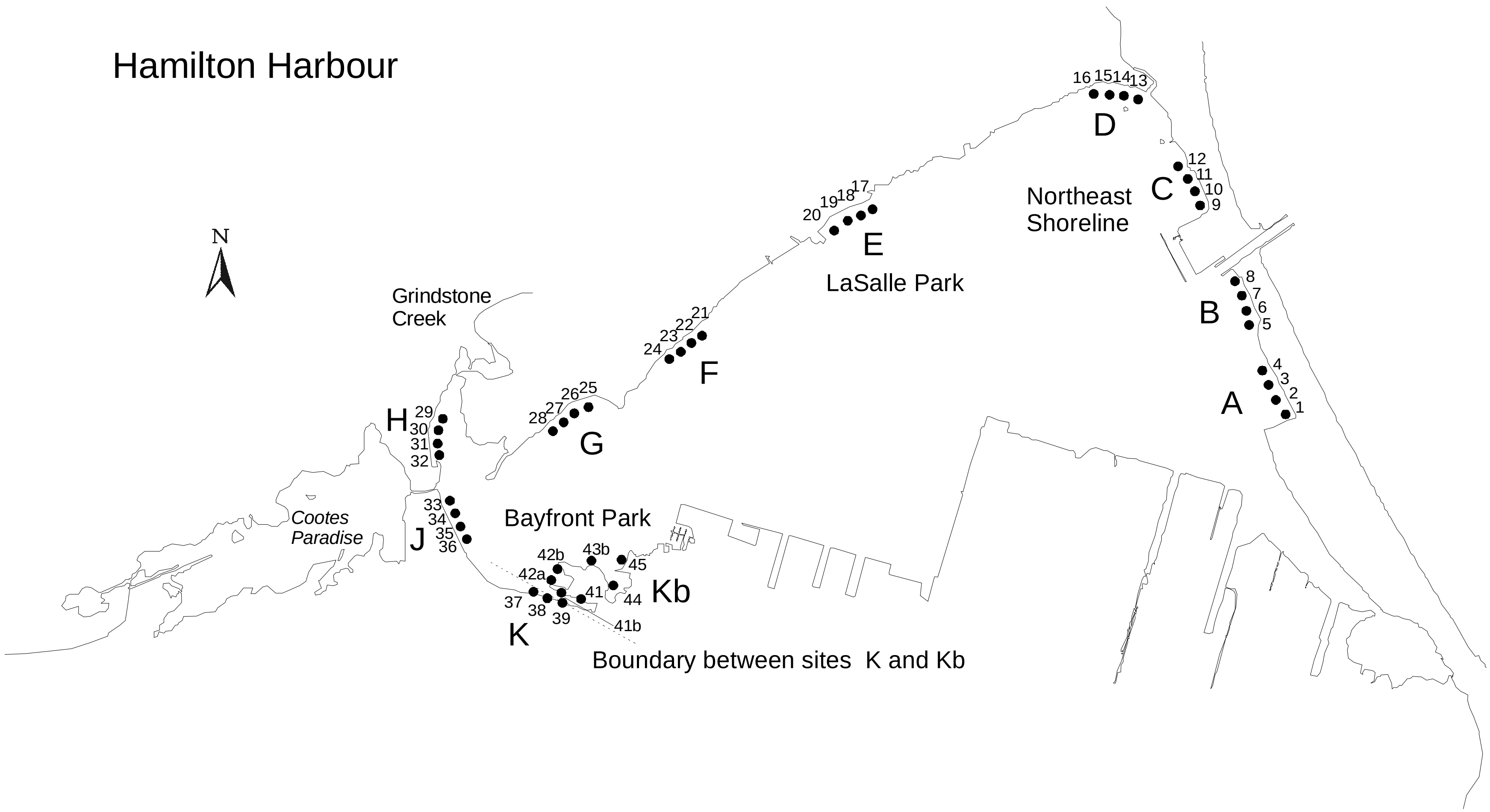


Figure 1: Map showing the location of 100m transect surveyed by electrofishing in Hamilton Harbour.

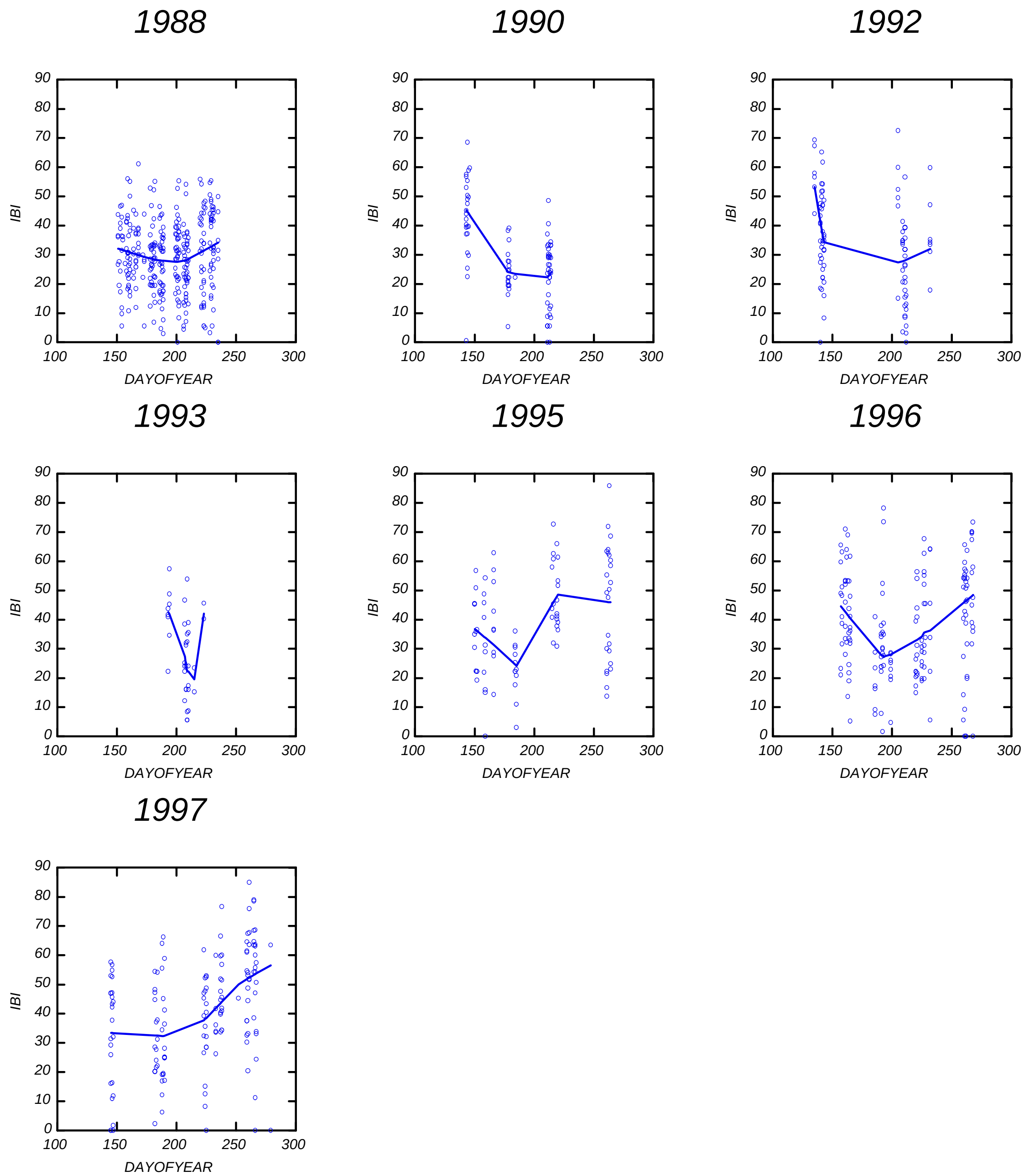


Figure 2: Individual Index of Biotic Integrity scores by day of year in Hamilton Harbour in each year sampled (all data). Curve fitted to the data using LOWESS smoother (tension 0.6).

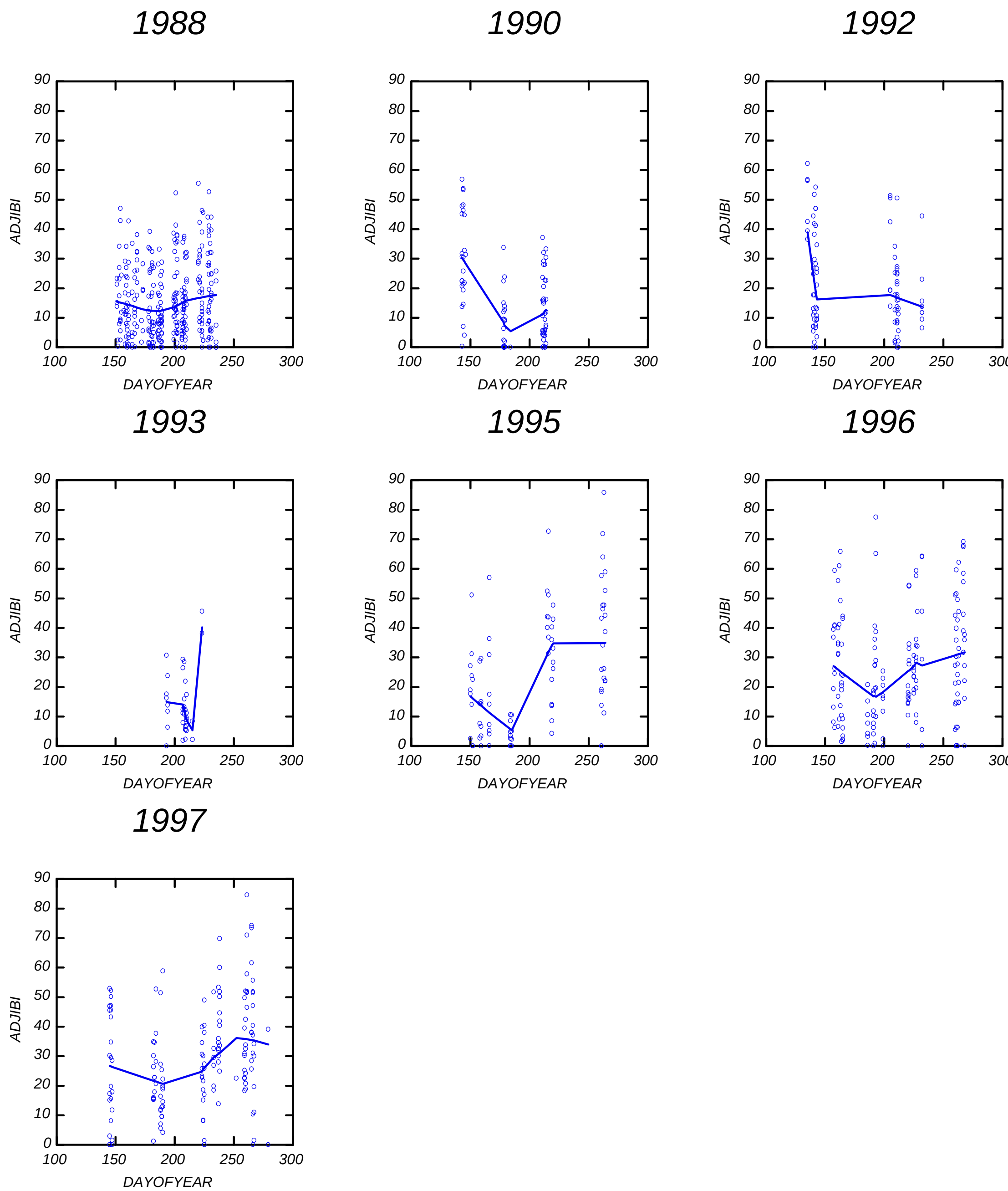


Figure 3: Individual Index of Biotic Integrity scores, adjusted for the presence of offshore species, by day of year in Hamilton Harbour in each year sampled (all data). Curve fitted to the data using a LOWESS smoother (tension 0.6).

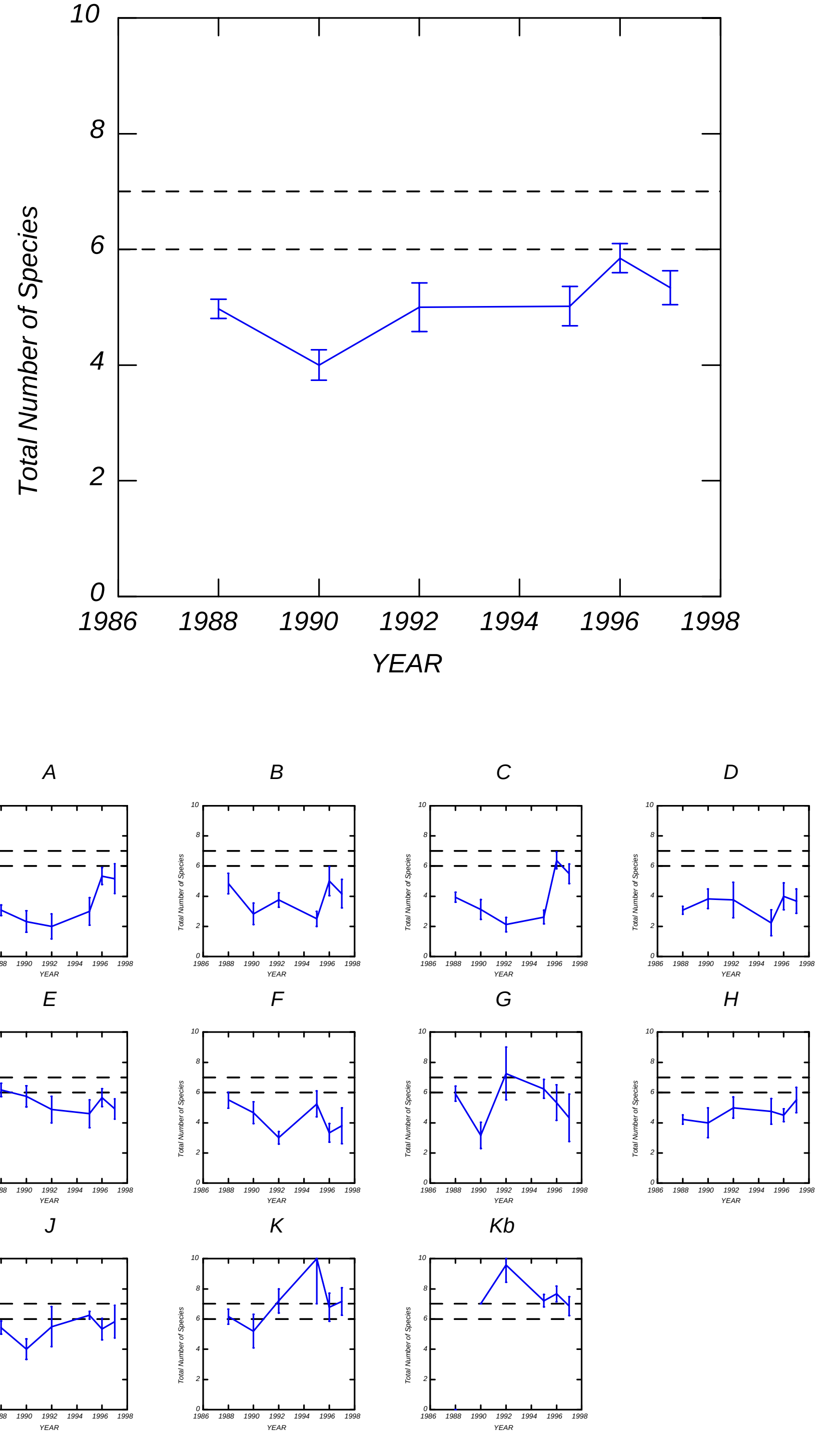


Figure 4: Total Species Richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat 100 m transects (excluding Kb); for this and all subsequent figures, the horizonal dashed lines indicate the target range (see text). Smaller figures represent individual sites.

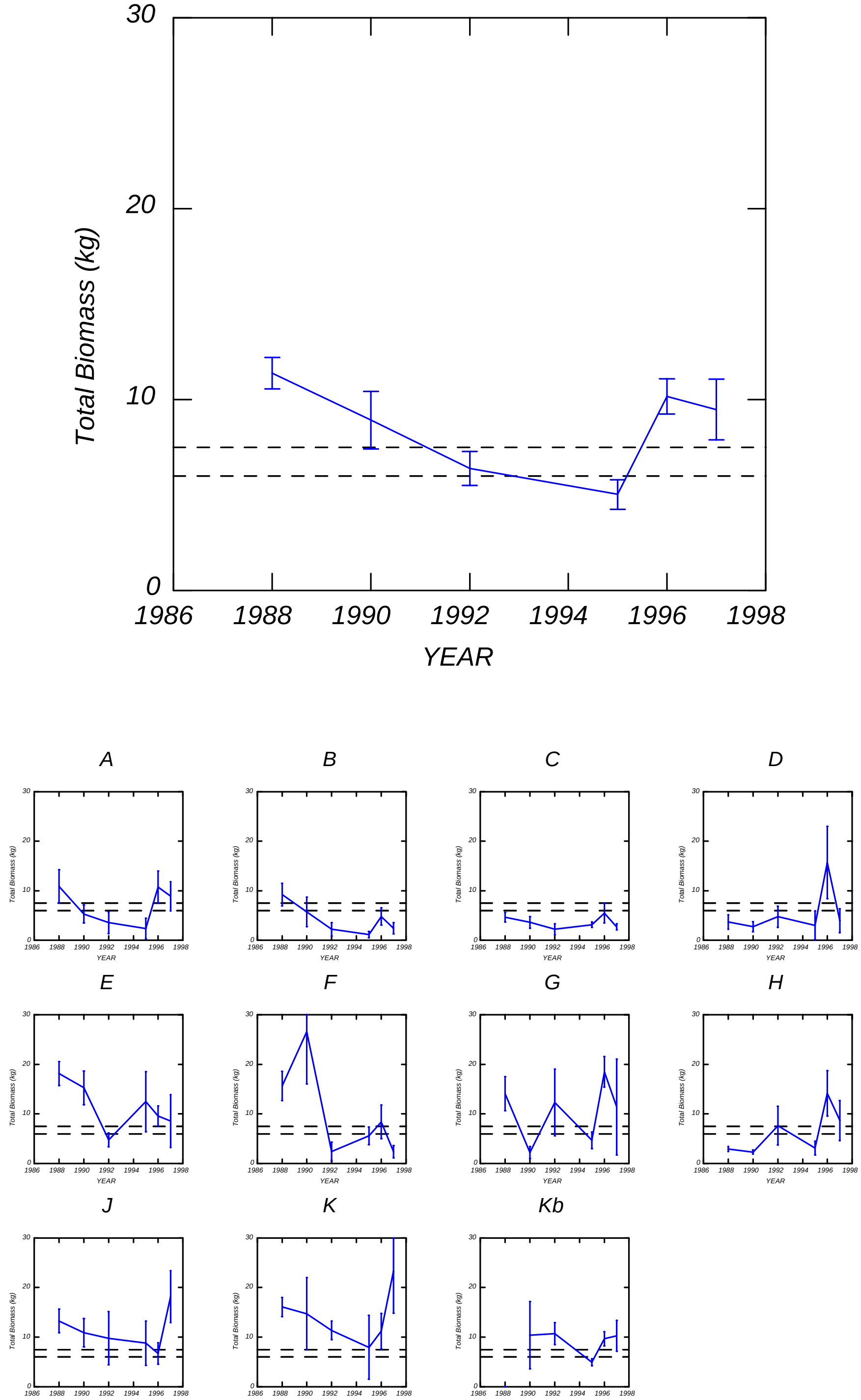


Figure 5: Total Biomass (kg) over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

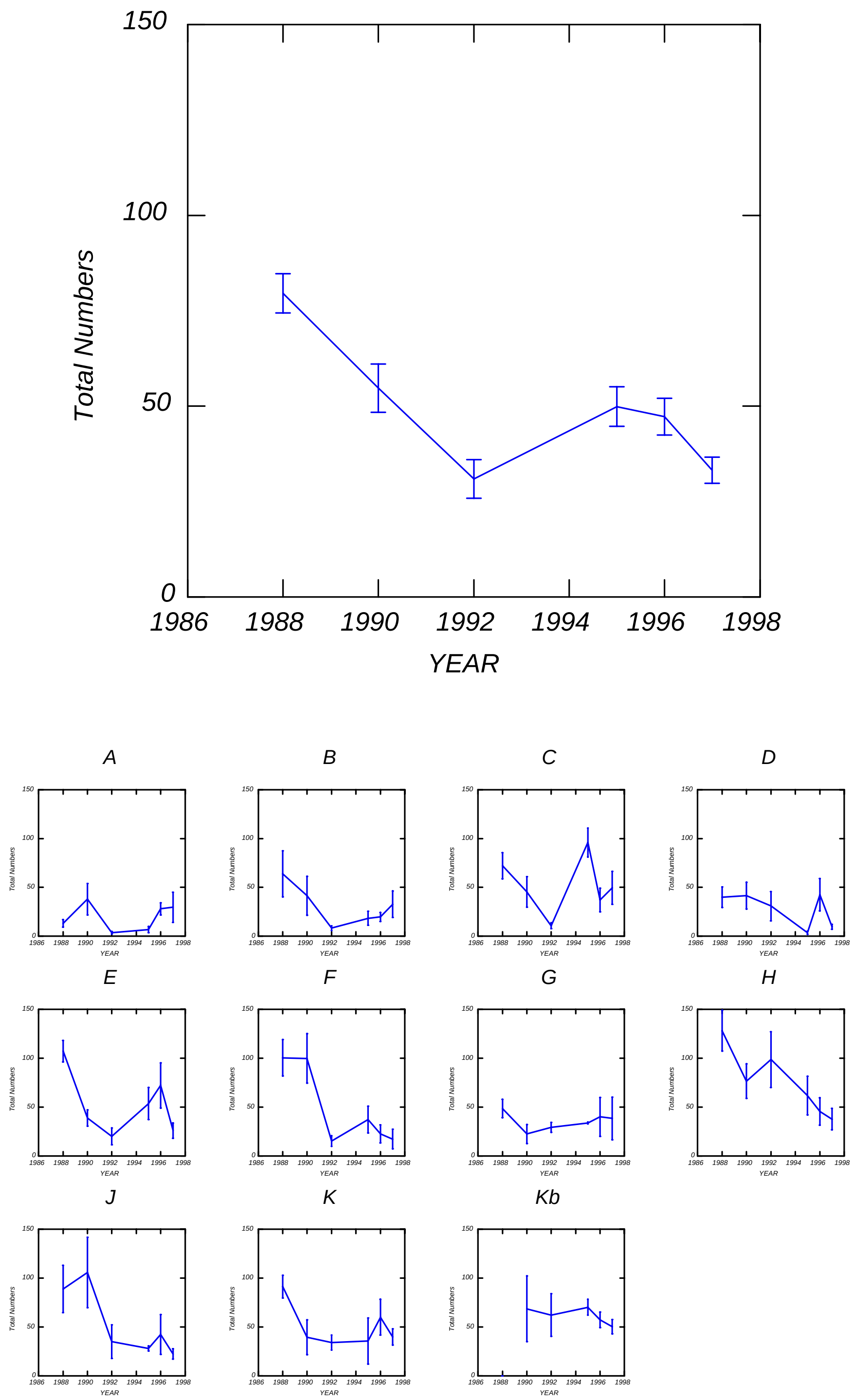


Figure 6: Total Numbers over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

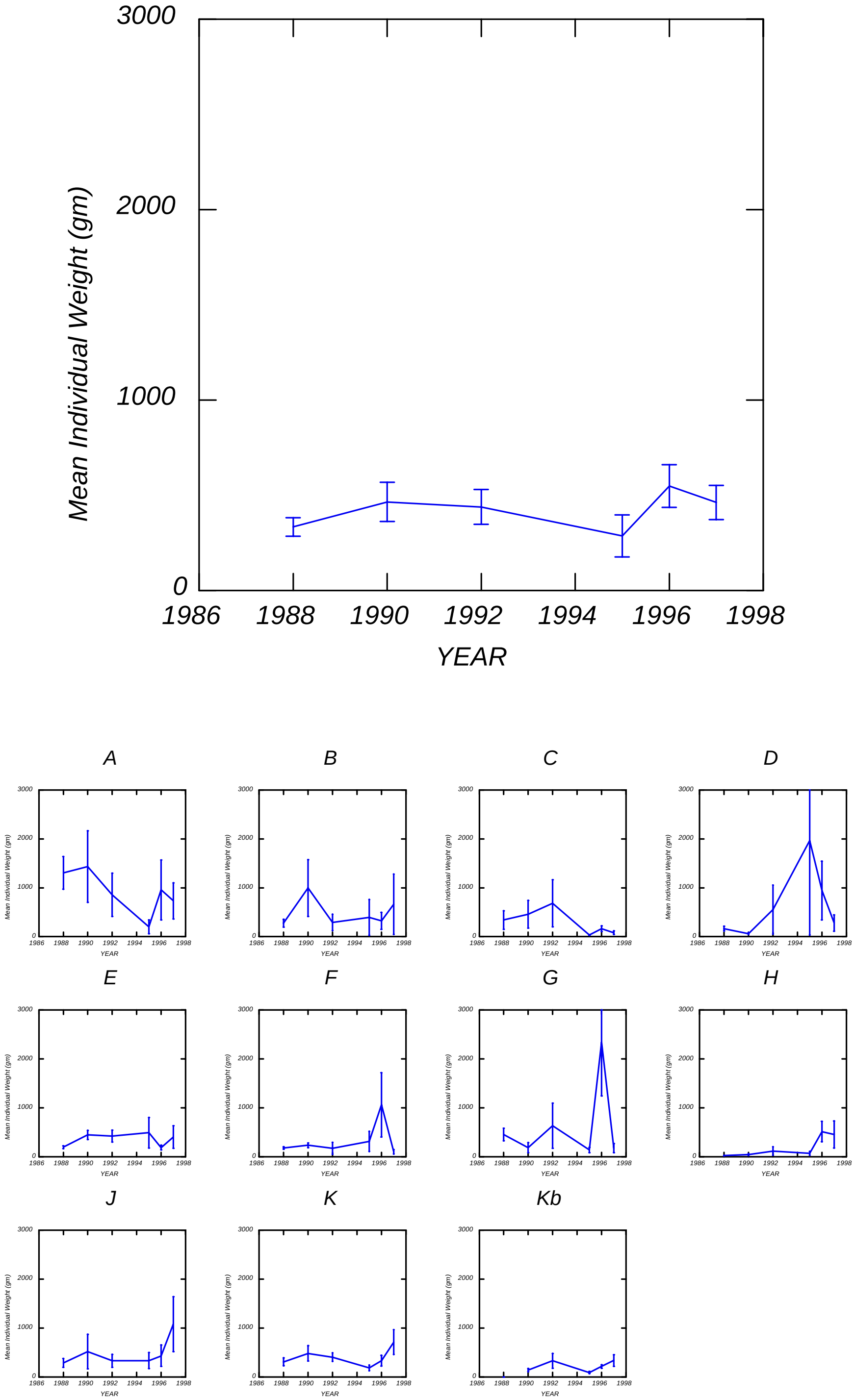


Figure 7: Mean Individual Weights (g) over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

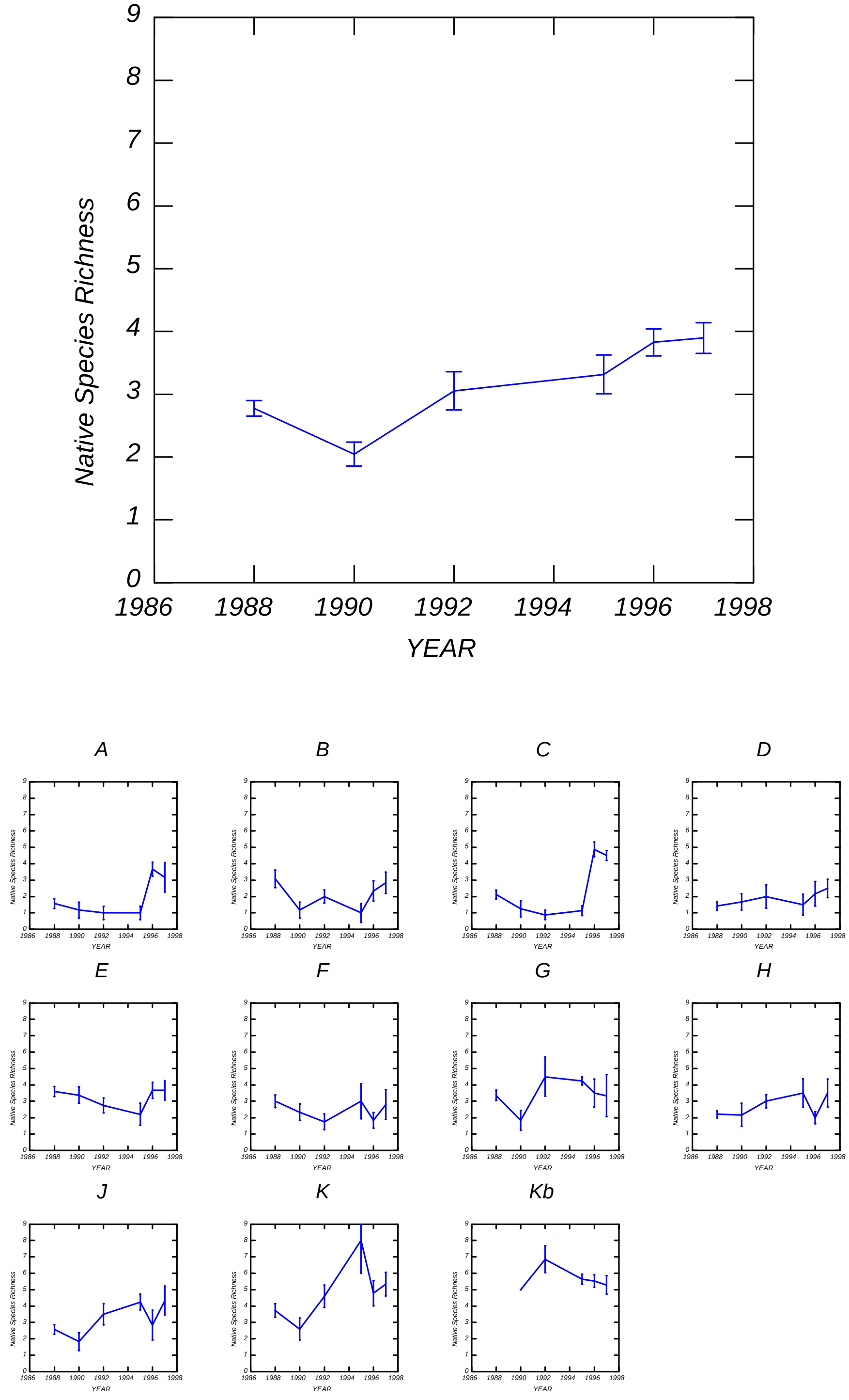


Figure 8: Native Species Richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

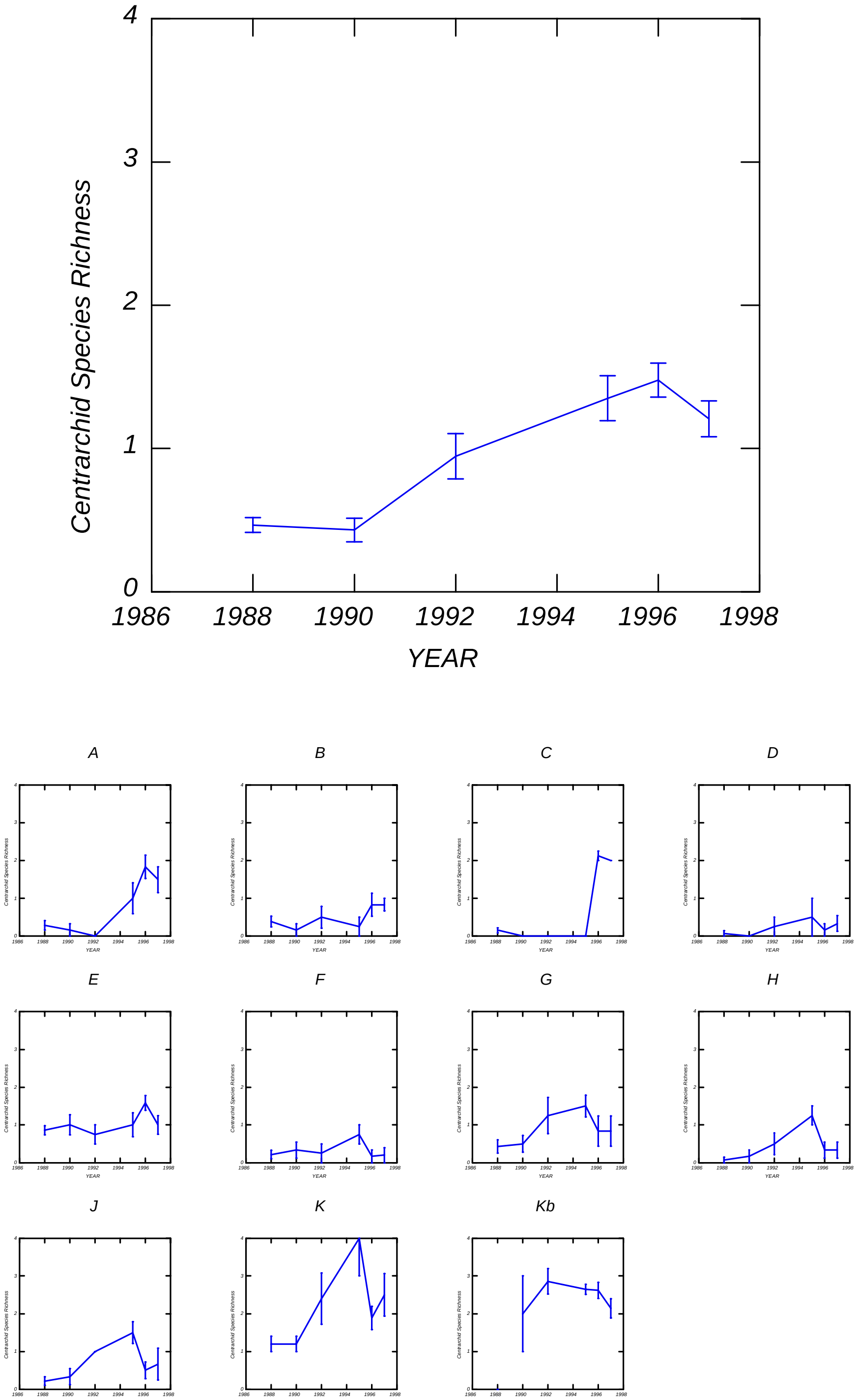


Figure 9: Centrarchid Species Richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

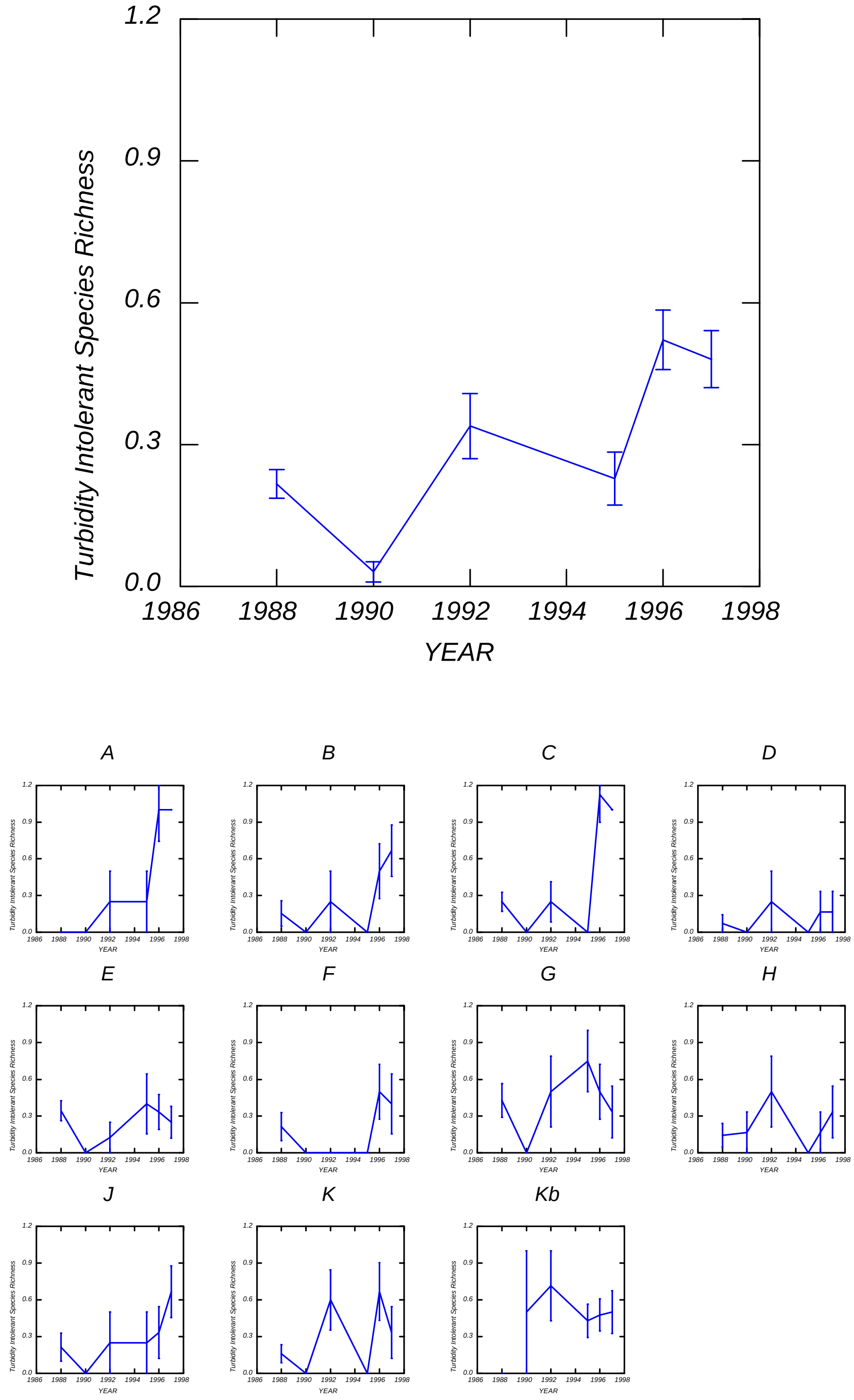


Figure 10: Turbidity Intolerant Species Richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

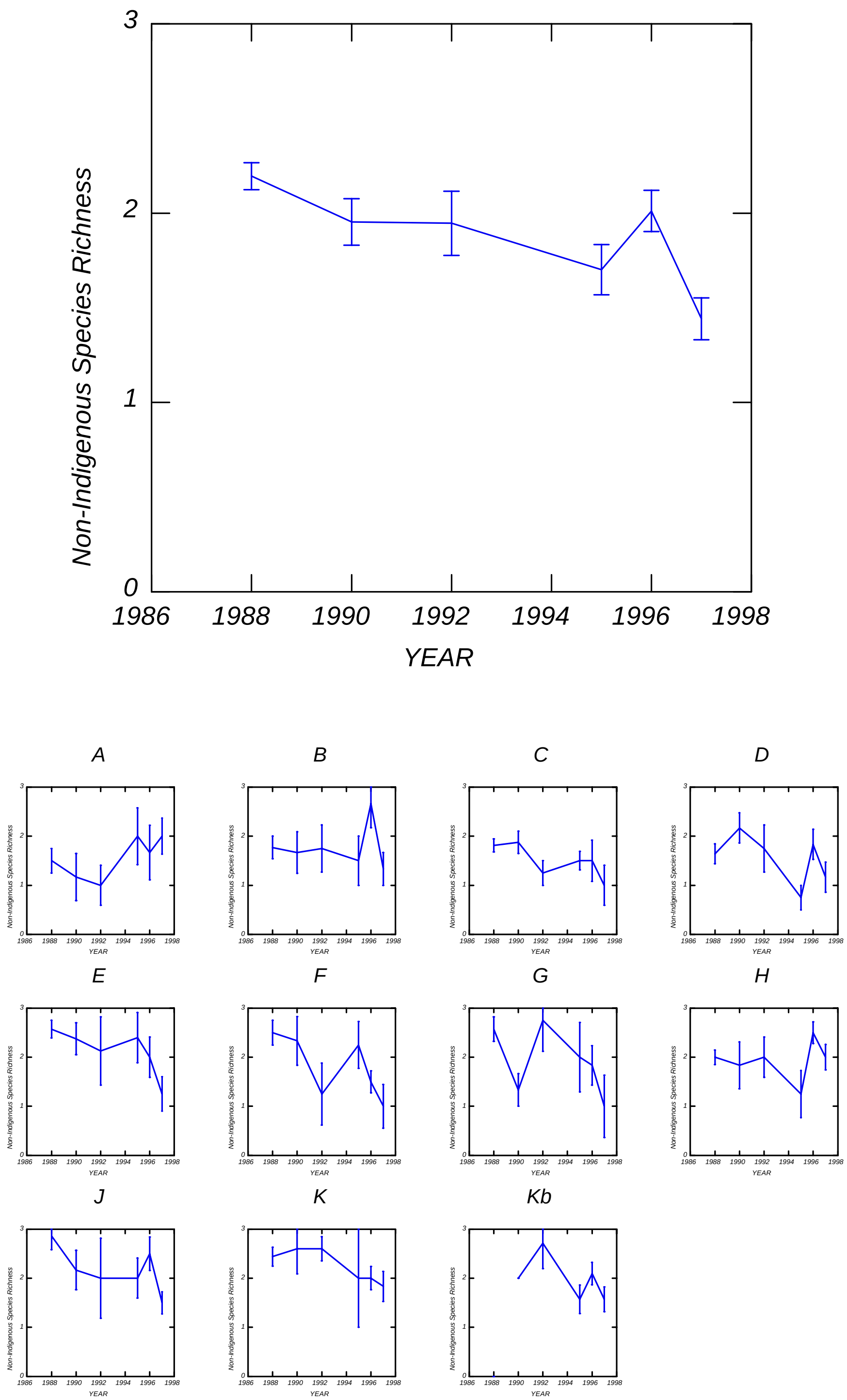


Figure 11: Non-Indigenous Species Richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

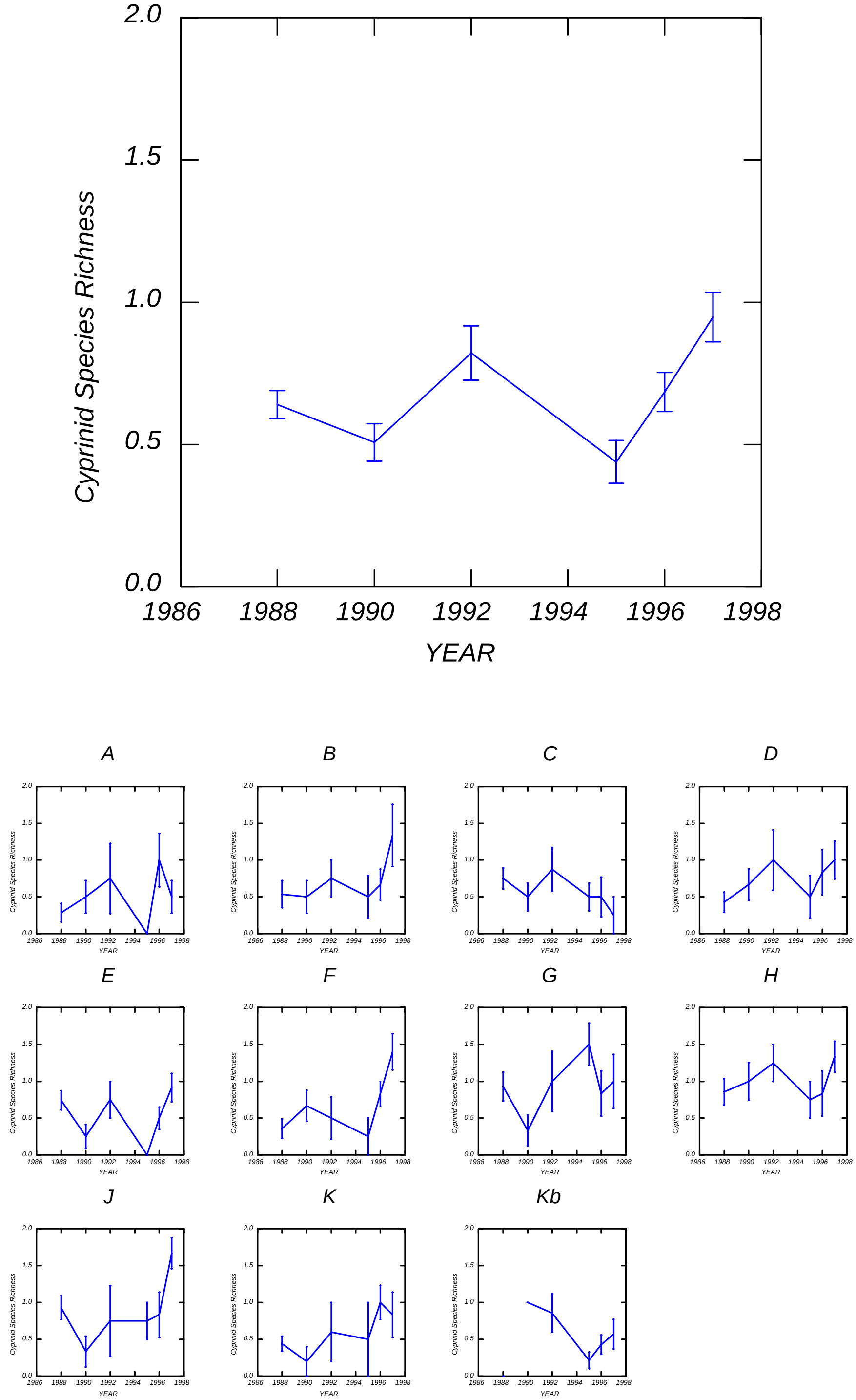


Figure 12: Native Cyprinid Species Richness over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

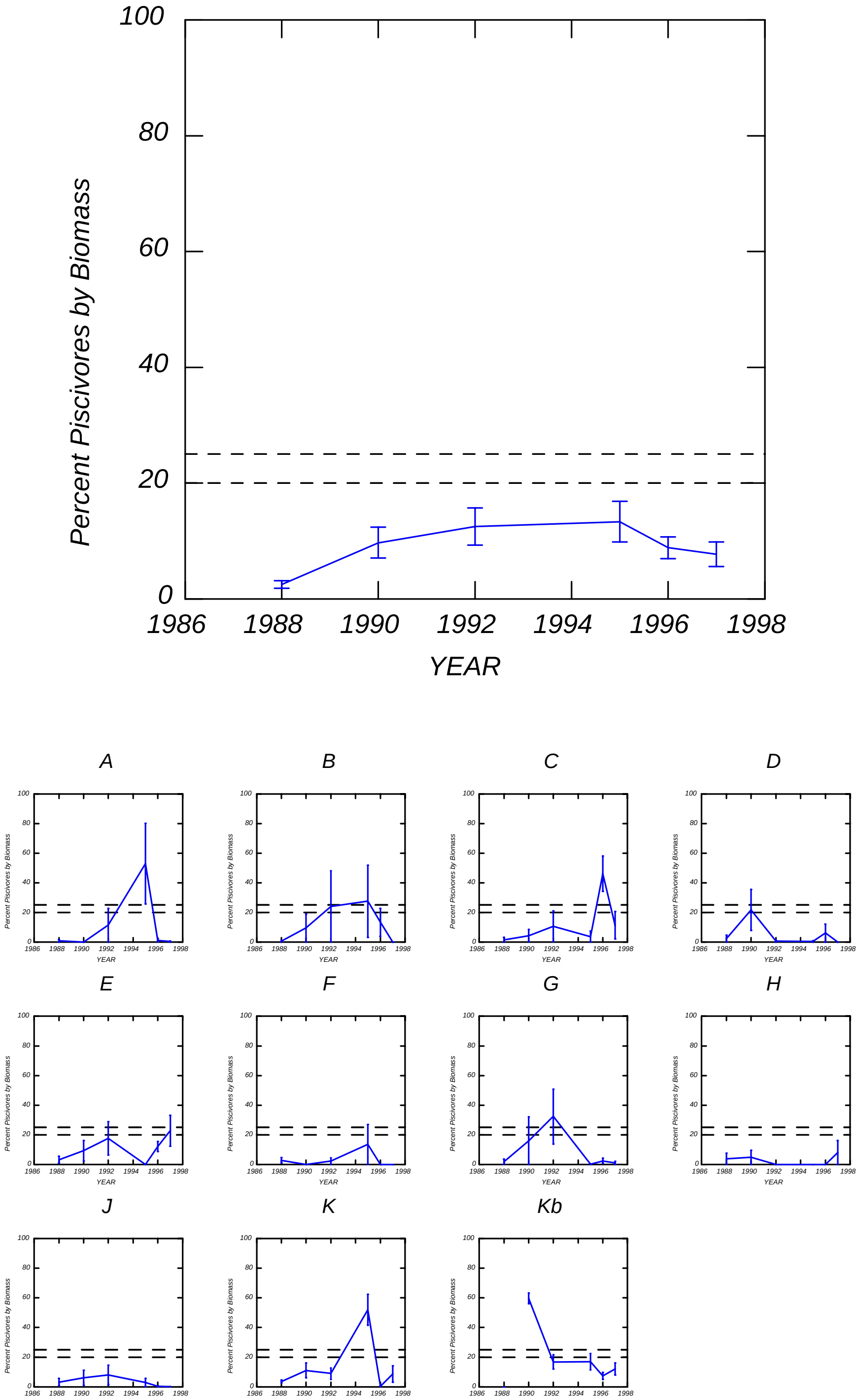


Figure 13: Percent Piscivores by Biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

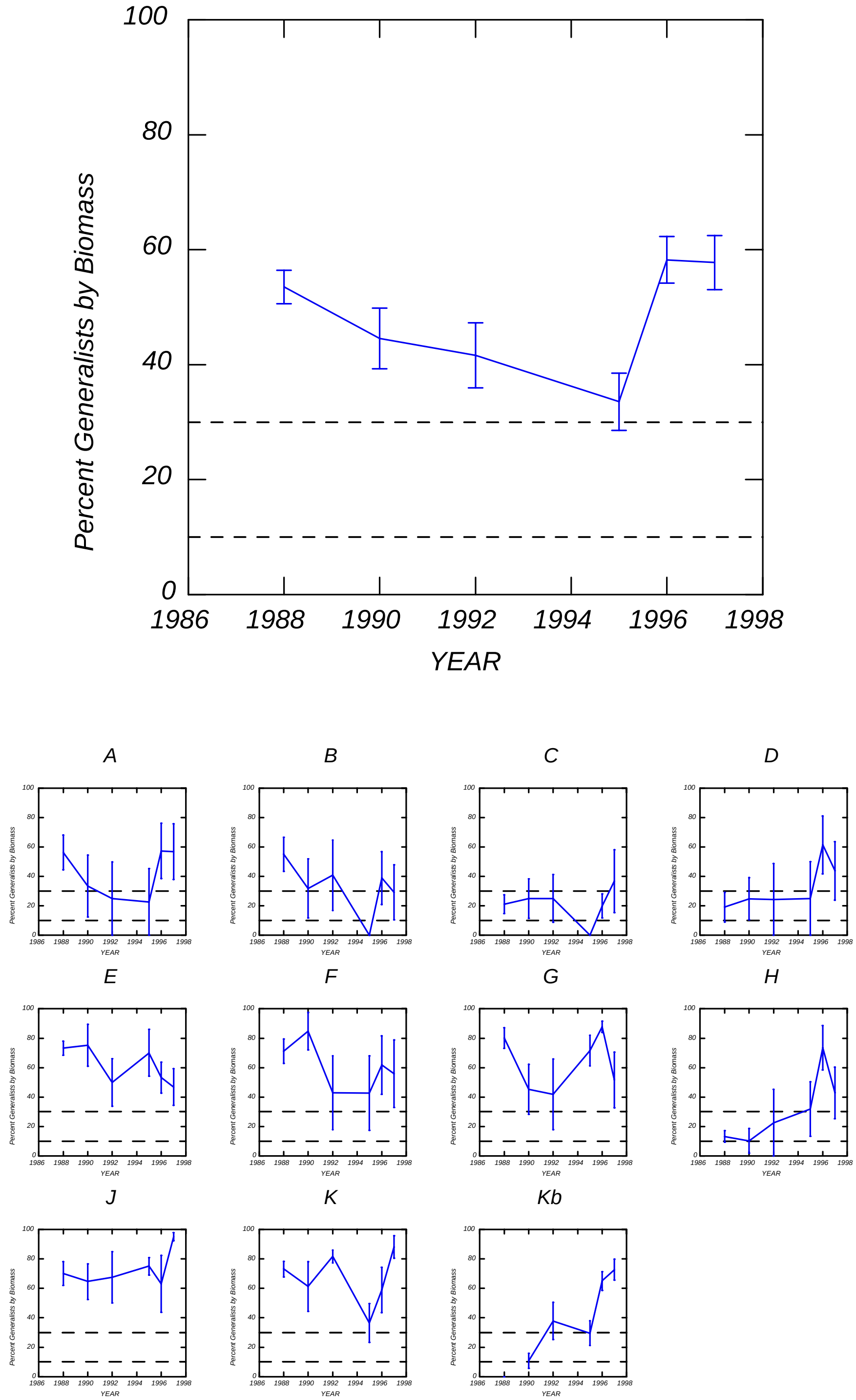


Figure 14: Percent Generalists by Biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

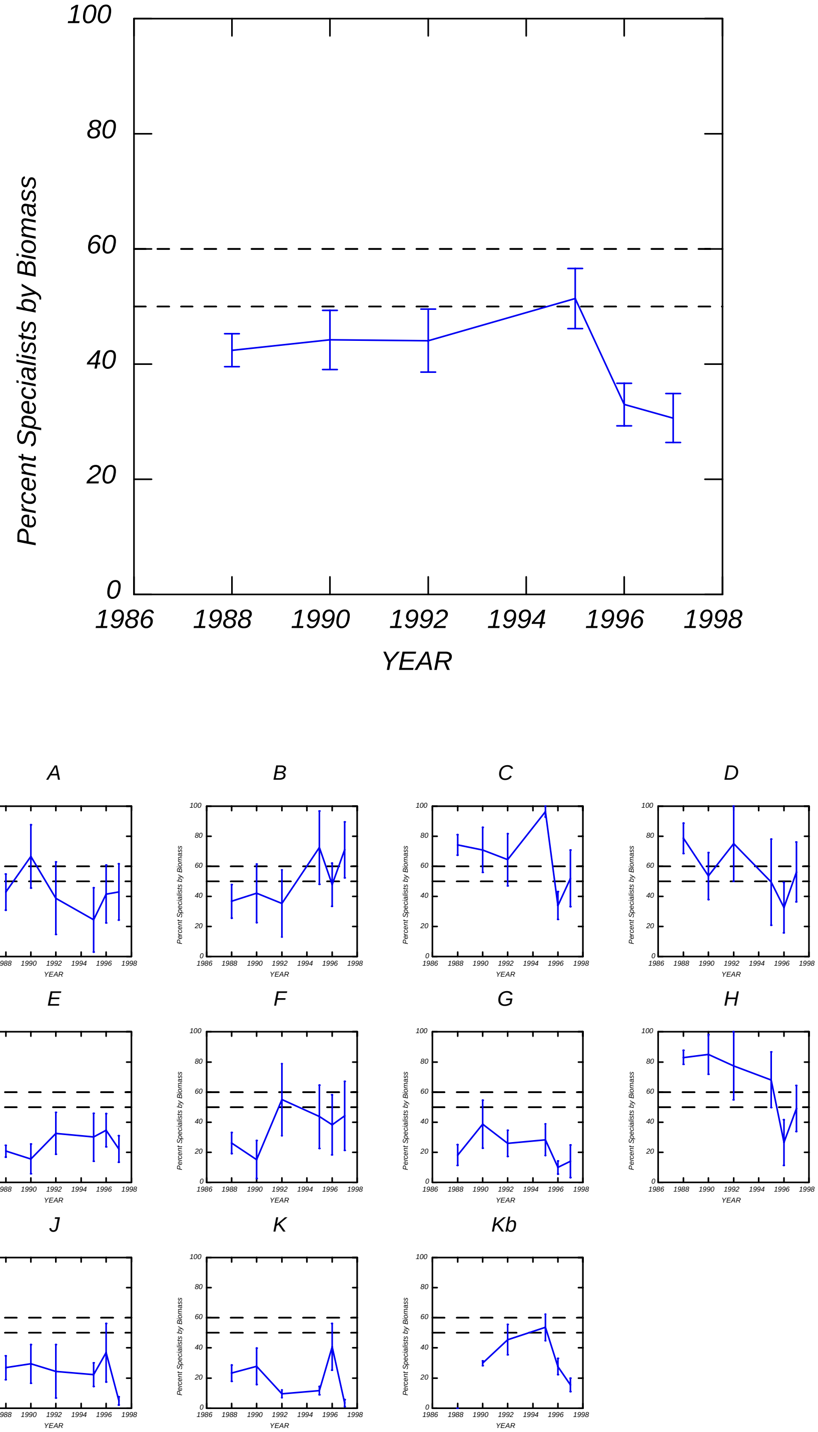
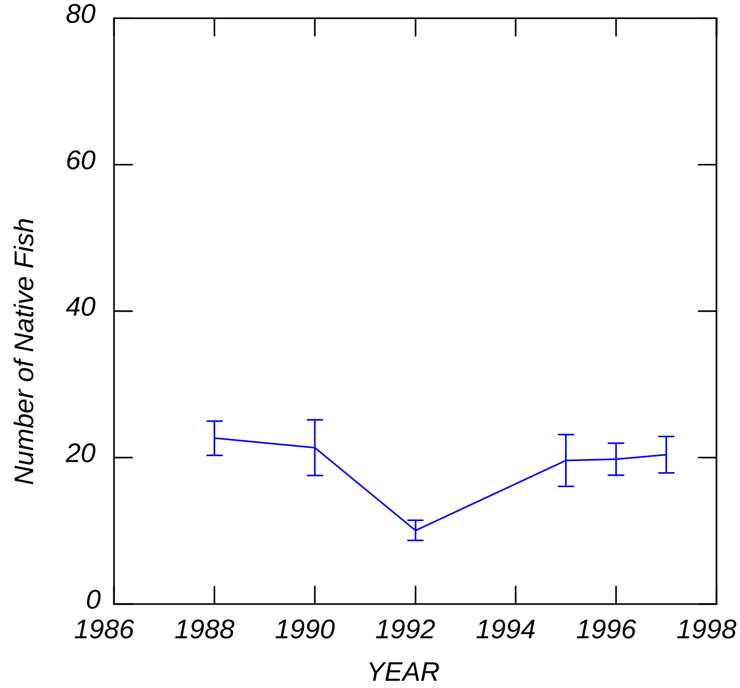


Figure 15: Percent Specialists by Biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.



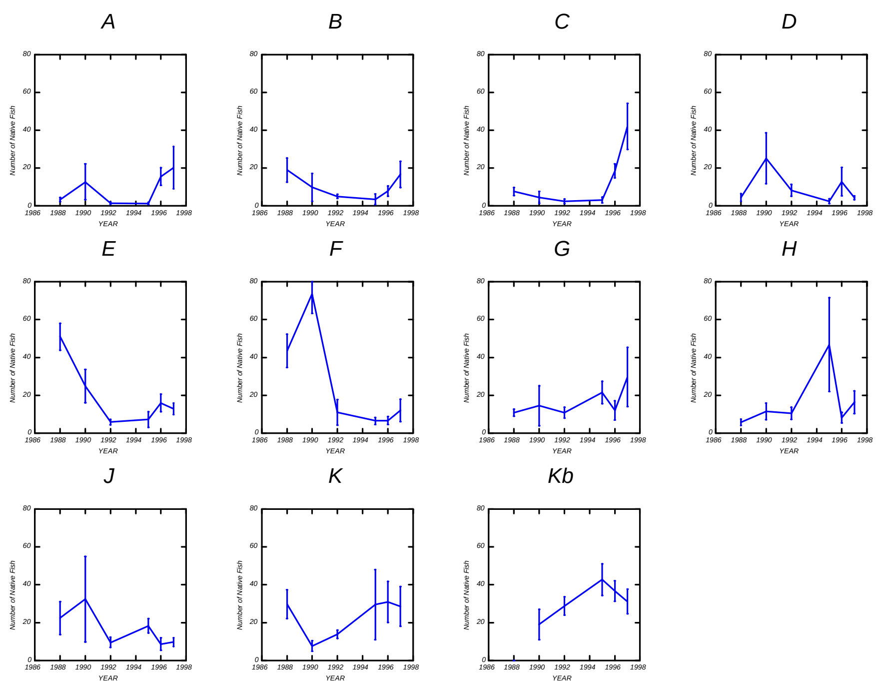


Figure 16: Number of Native Fish per Transect over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

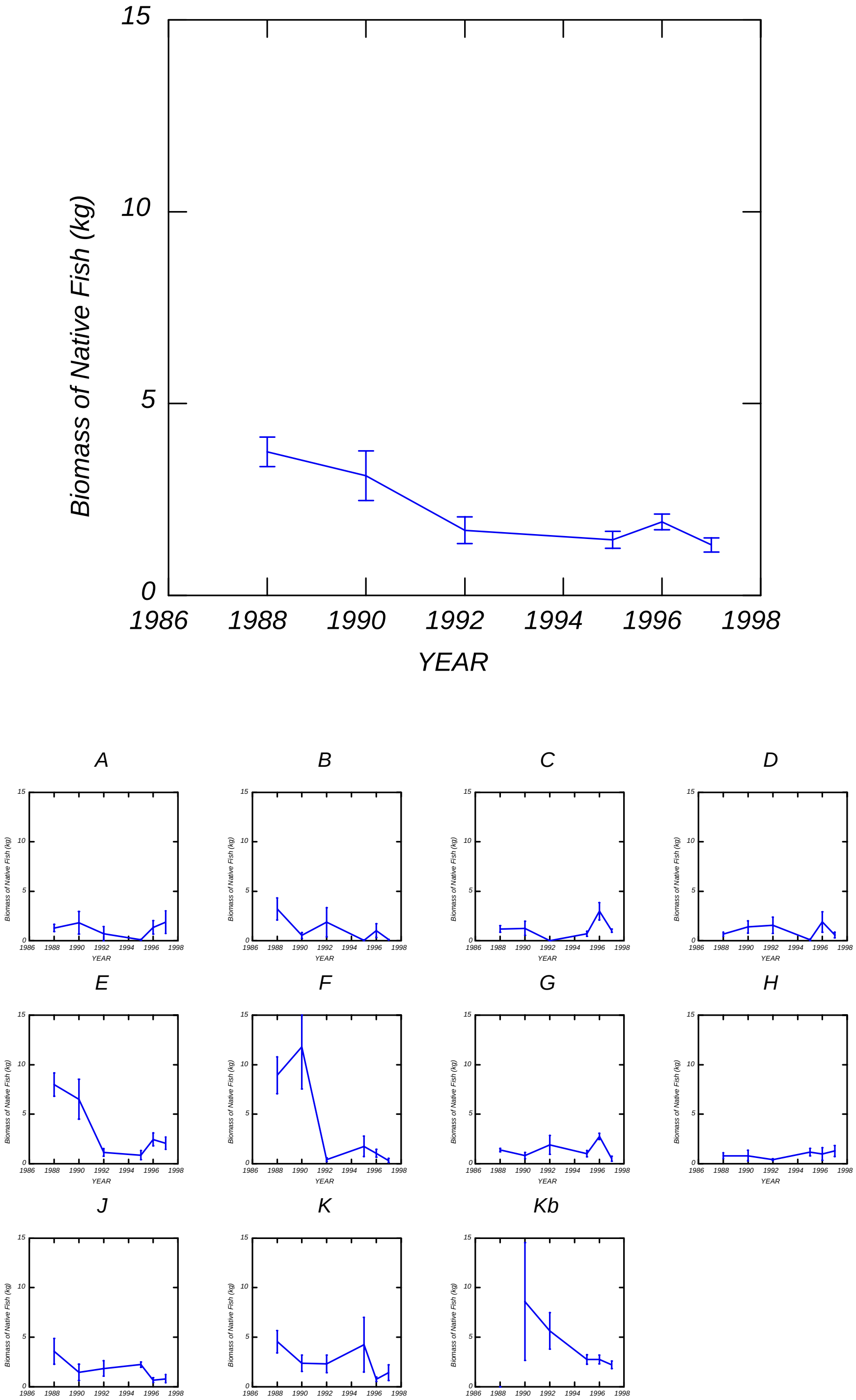


Figure 17: Biomass of Native Fish over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

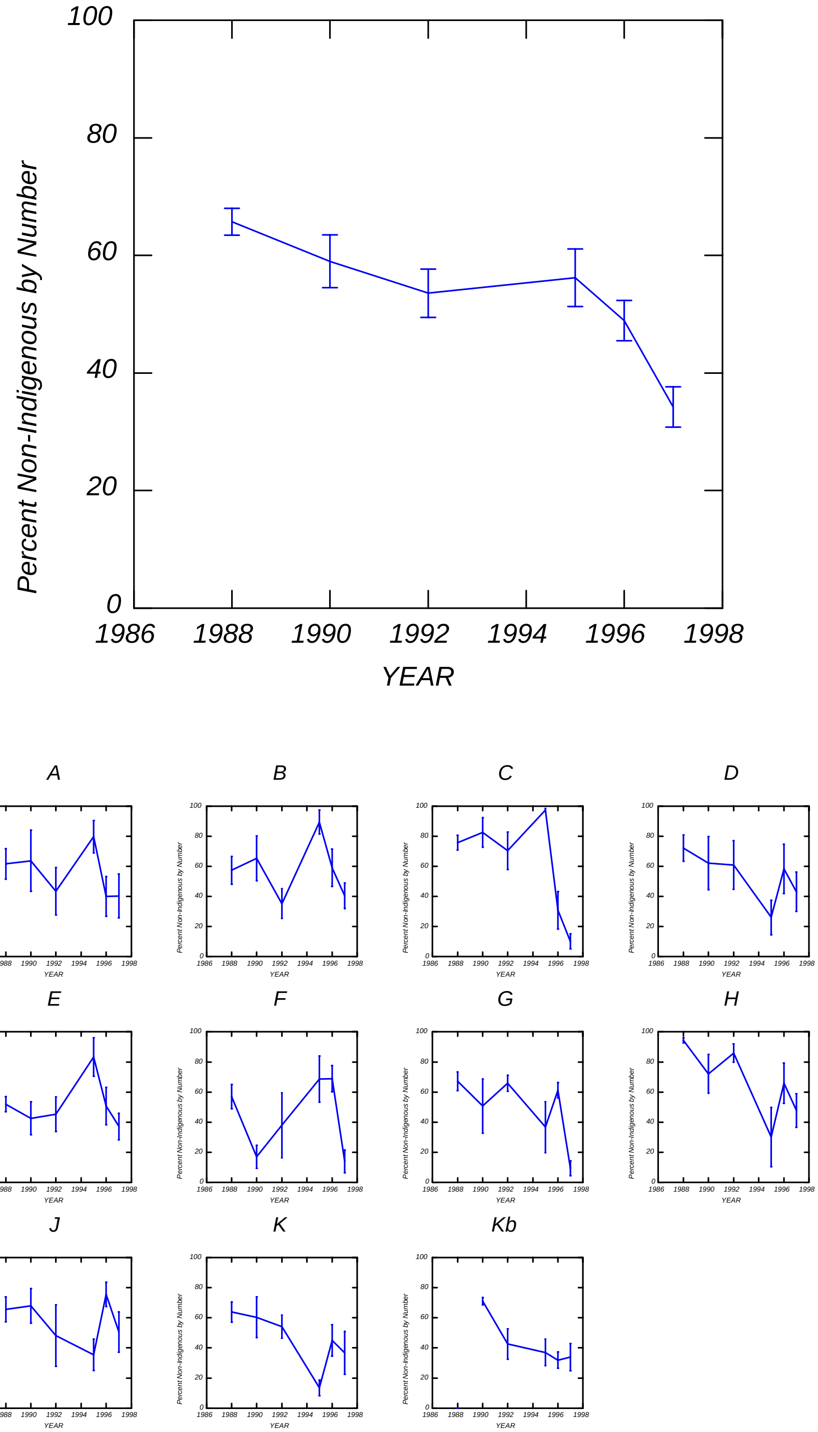


Figure 18: Percent Non-Indigenous Fish by Number over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

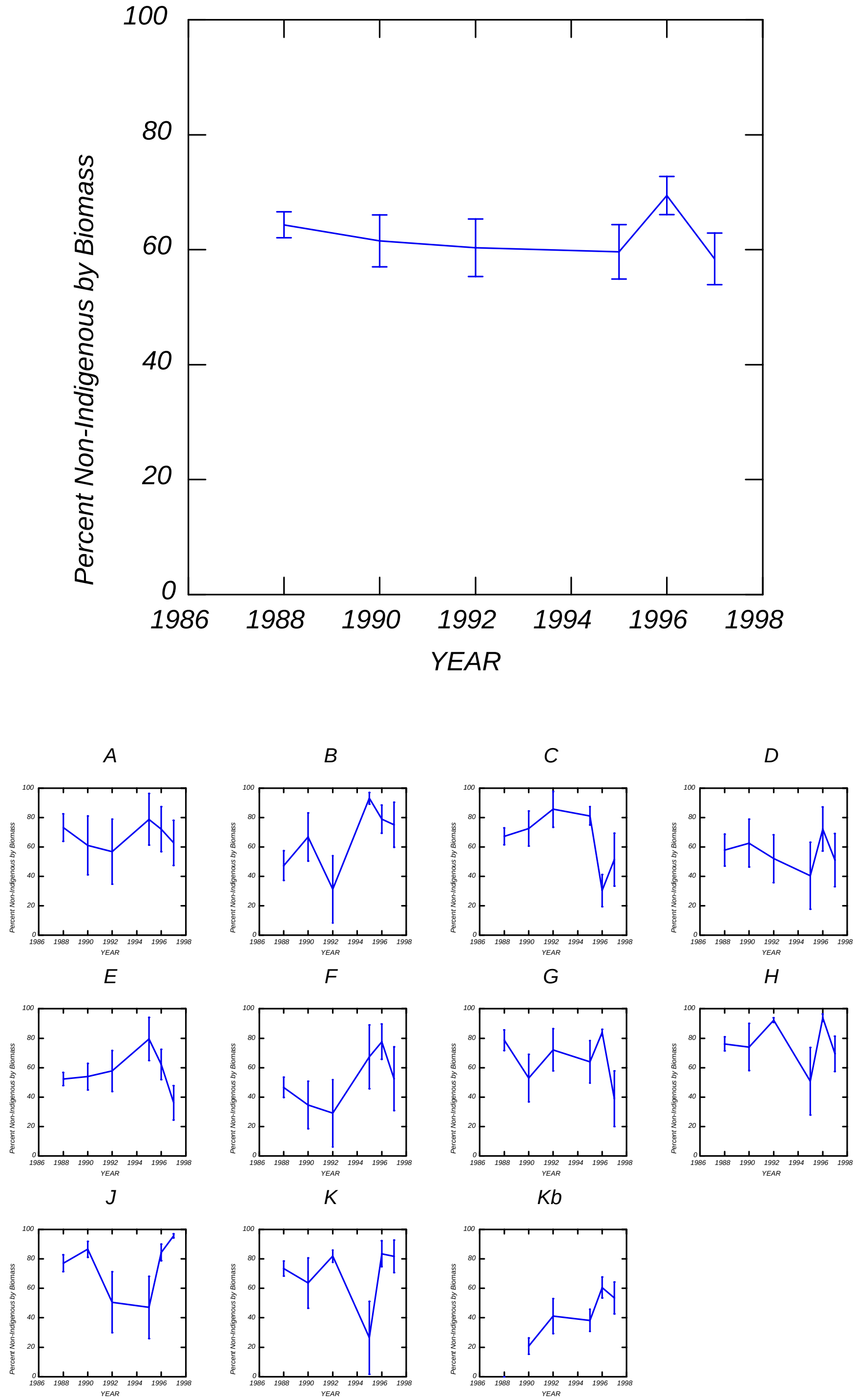


Figure 19: Percent Non-Indigenous Fish by Biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

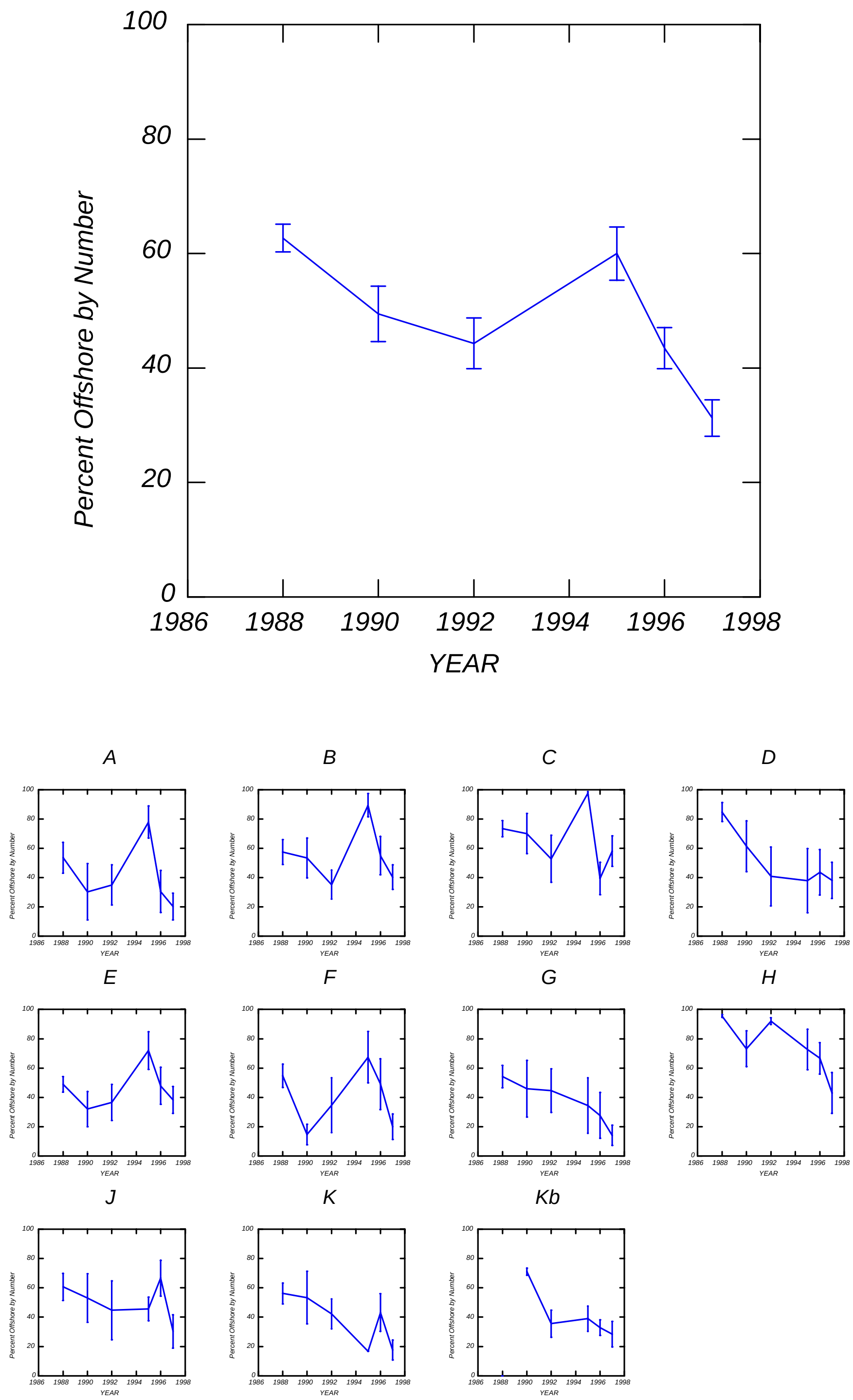


Figure 20: Percent Offshore Fish by Number over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

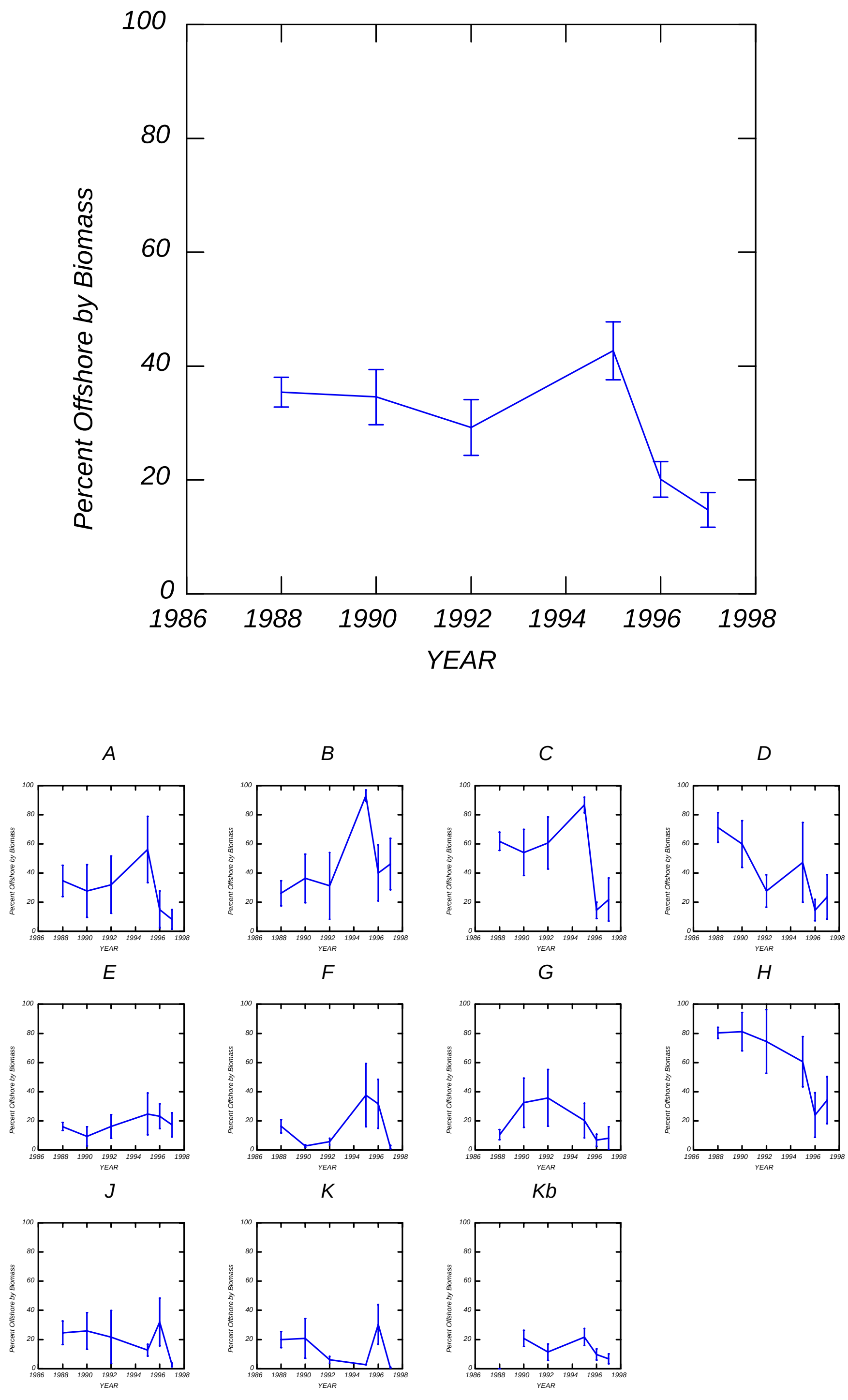


Figure 21: Percent Offshore Fish by Biomass over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

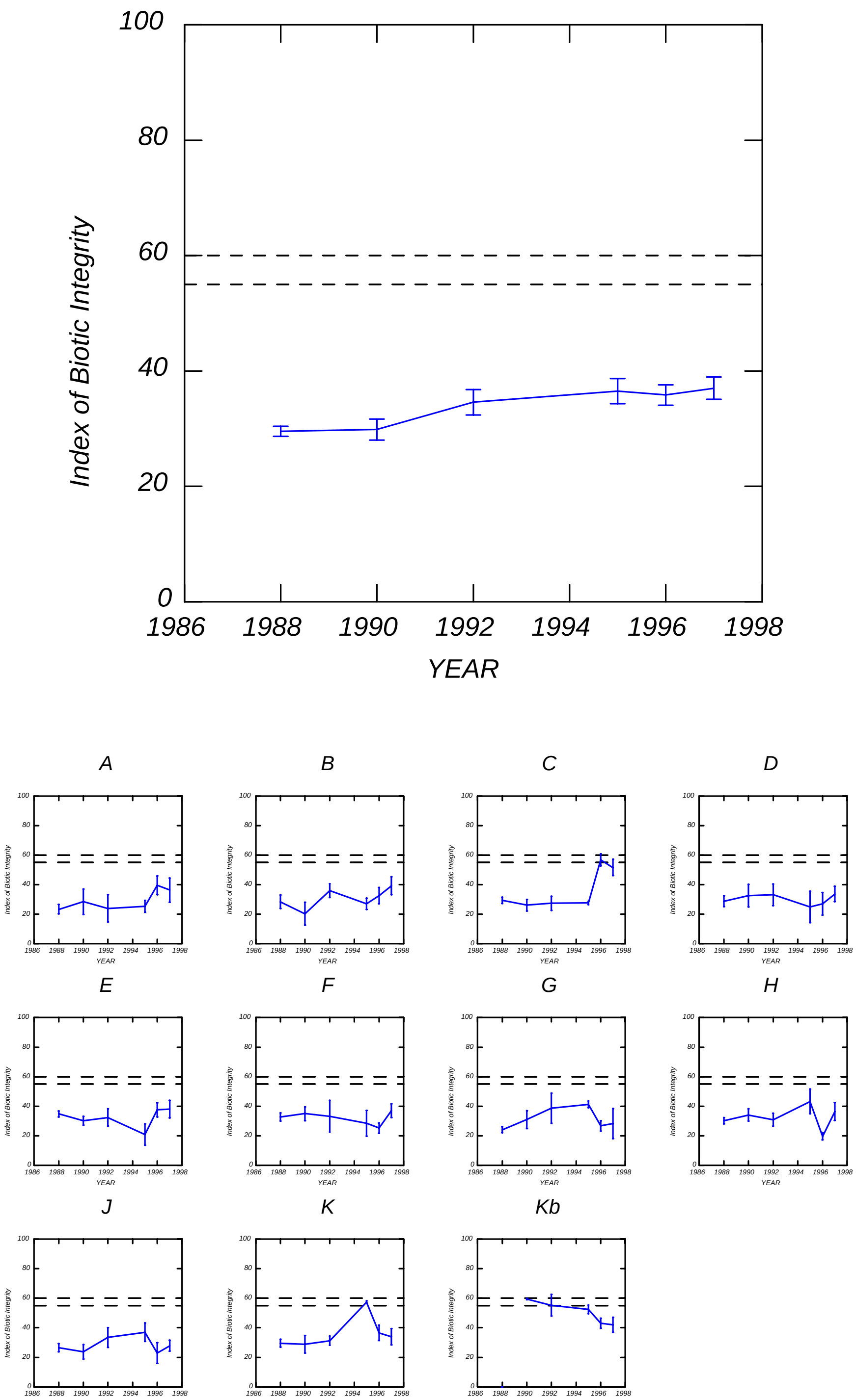


Figure 22: Index of Biotic Integrity Scores over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

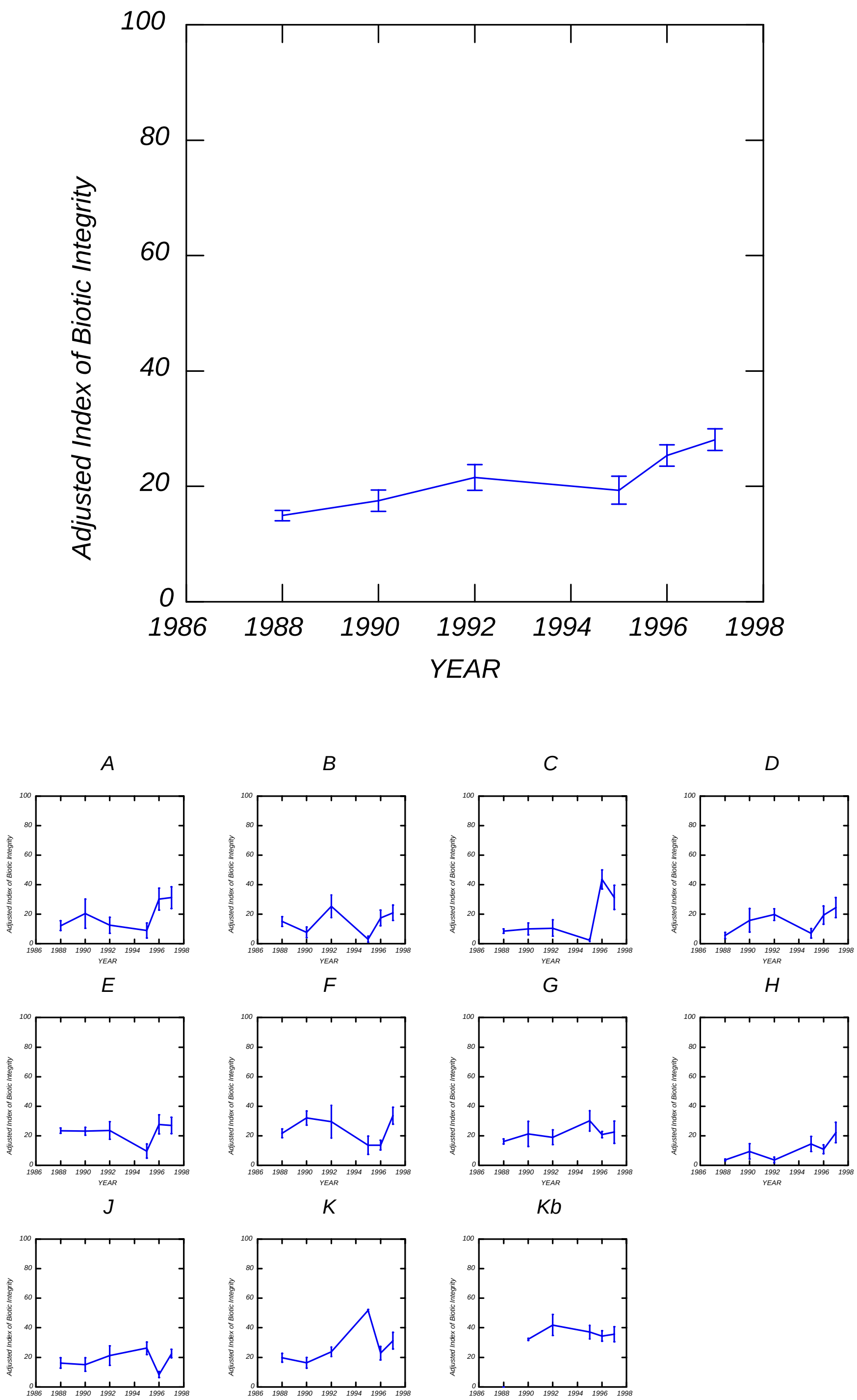


Figure 23: Adjusted Index of Biotic Integrity Scores over time in Hamilton Harbour (annual mean ± SE). Large figure represents an average of all repeat transects, (excluding Kb). Smaller figures represent individual sites.

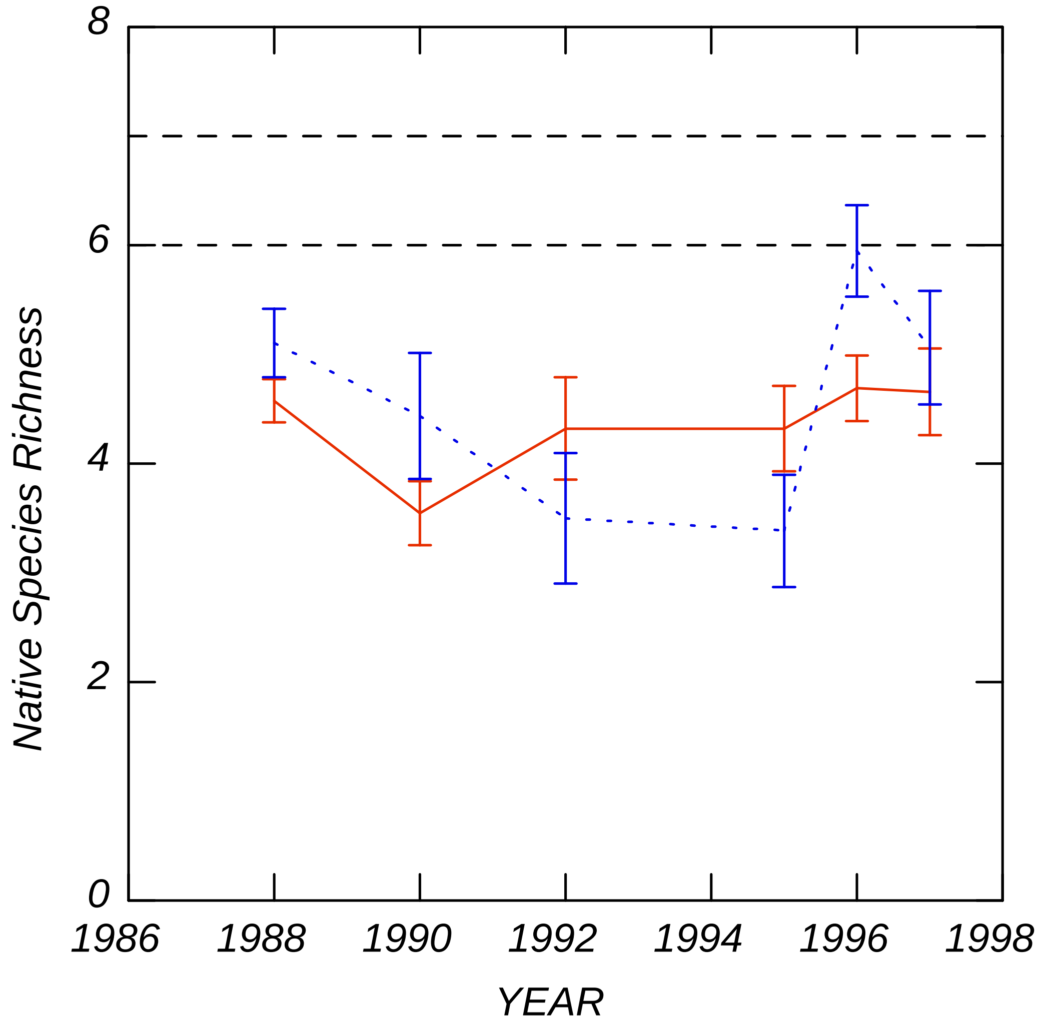


Figure 24: Comparison of Native Species Richness (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

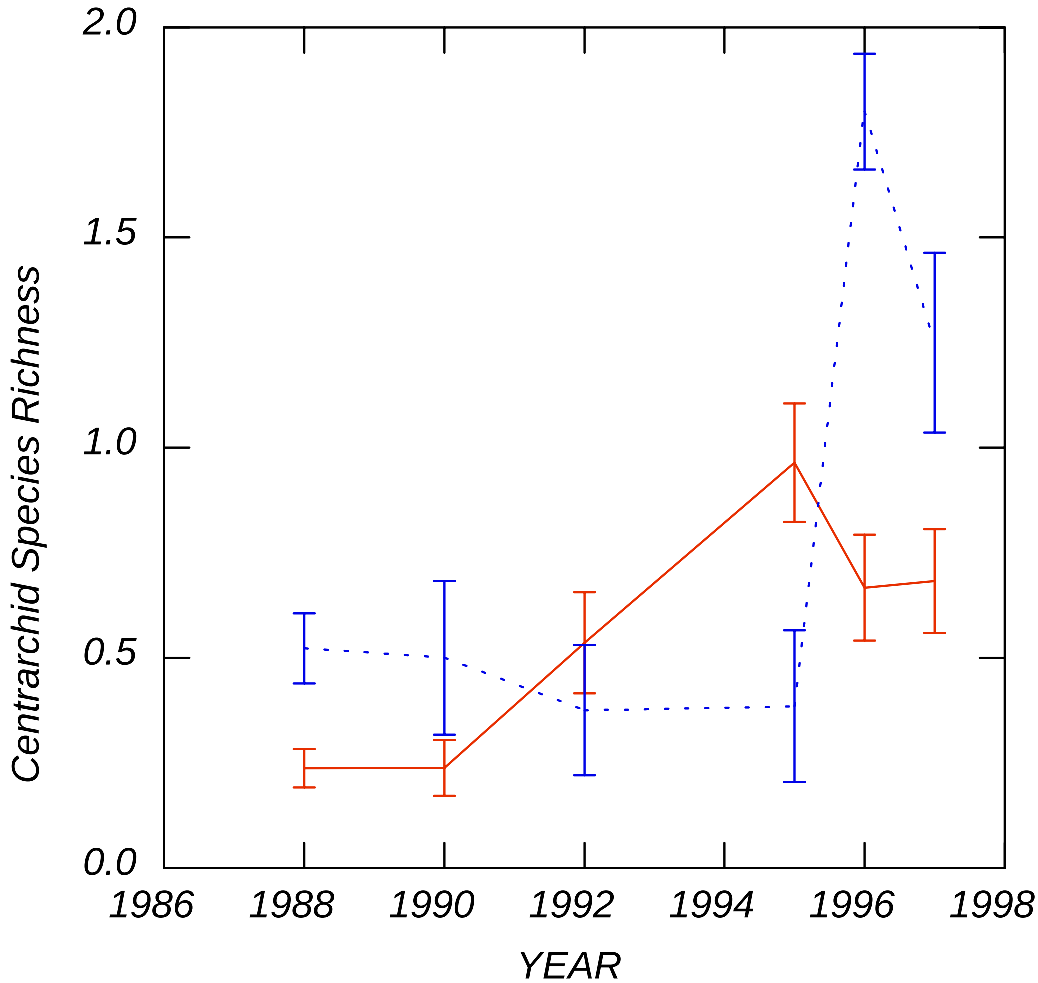


Figure 25: Comparison of Centrarchid Species Richness (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

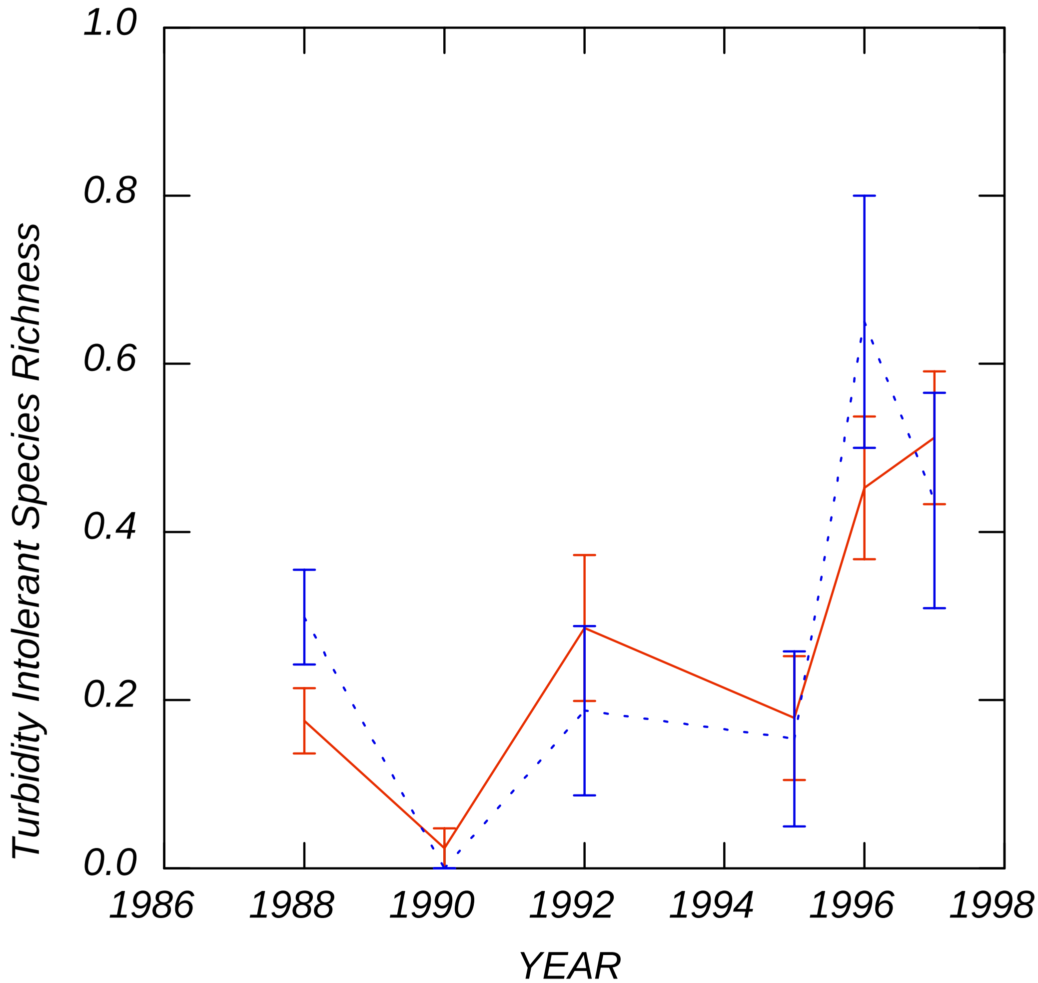


Figure 26: Comparison of Turbidity Intolerant Species Richness (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

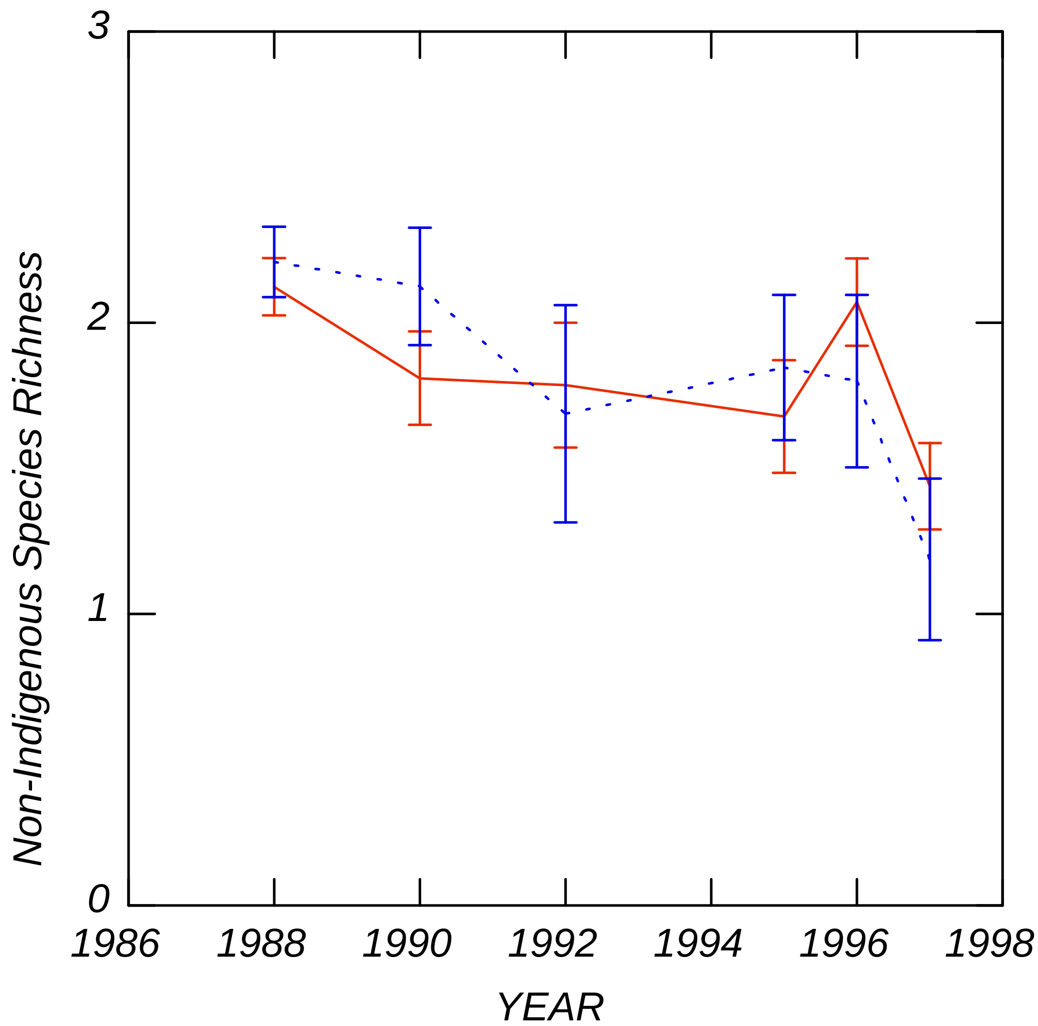


Figure 27: Comparison of Non-indigenous Species Richness (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

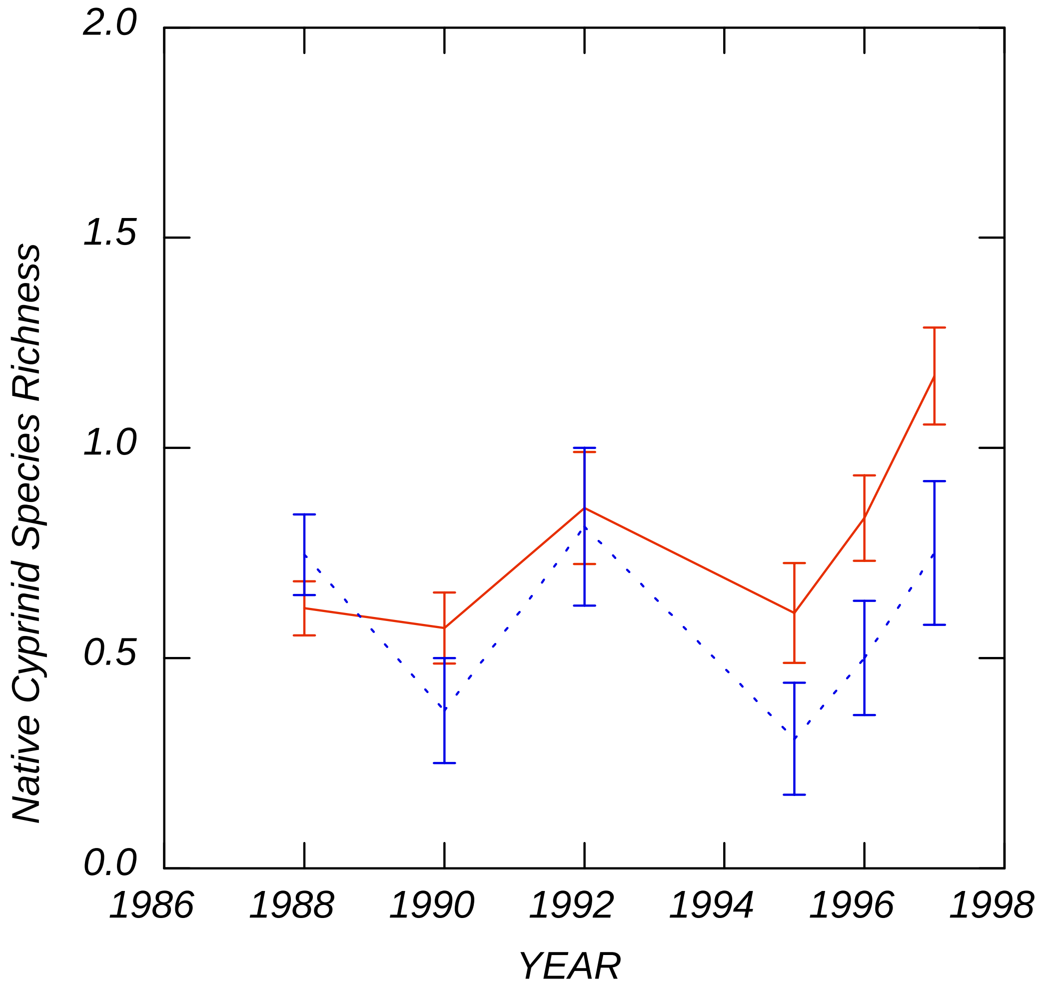


Figure 28: Comparison of Native Cyprinid Species Richness (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

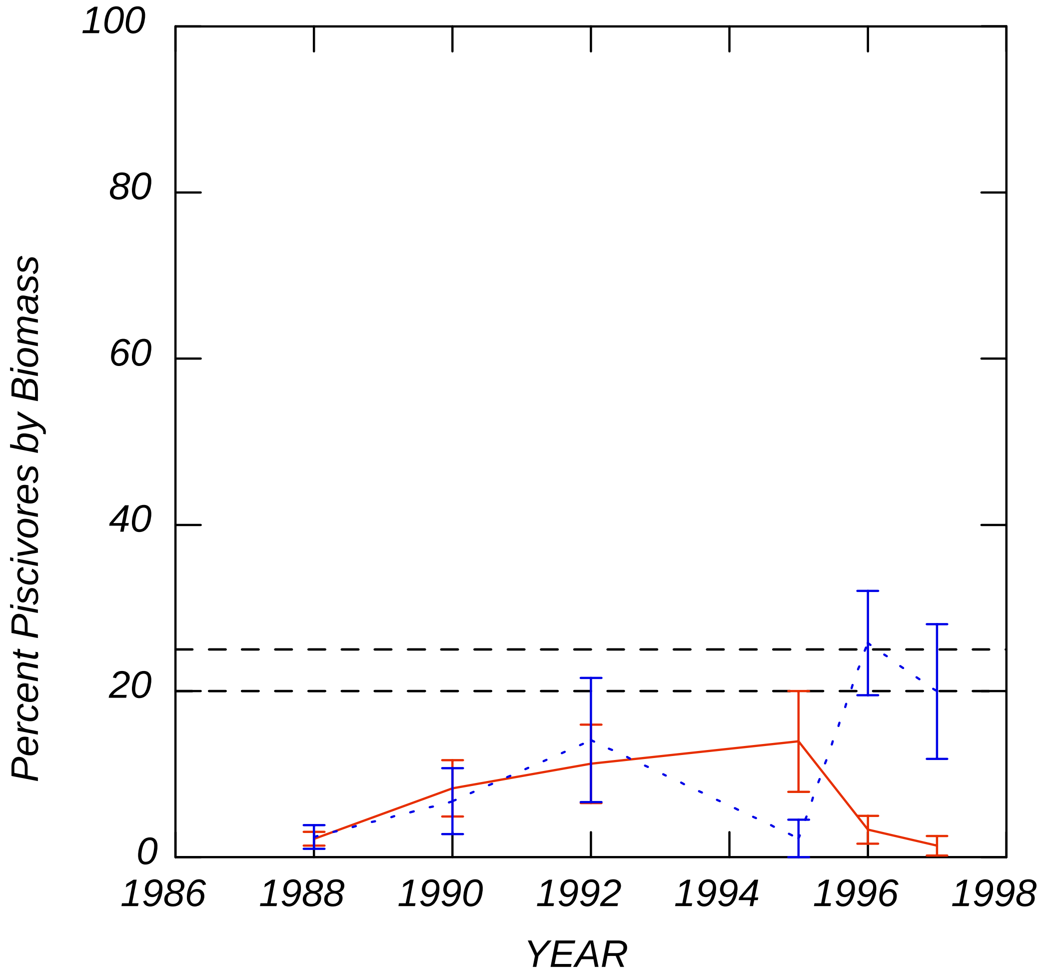


Figure 29: Comparison of Percent Piscivores by Biomass (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

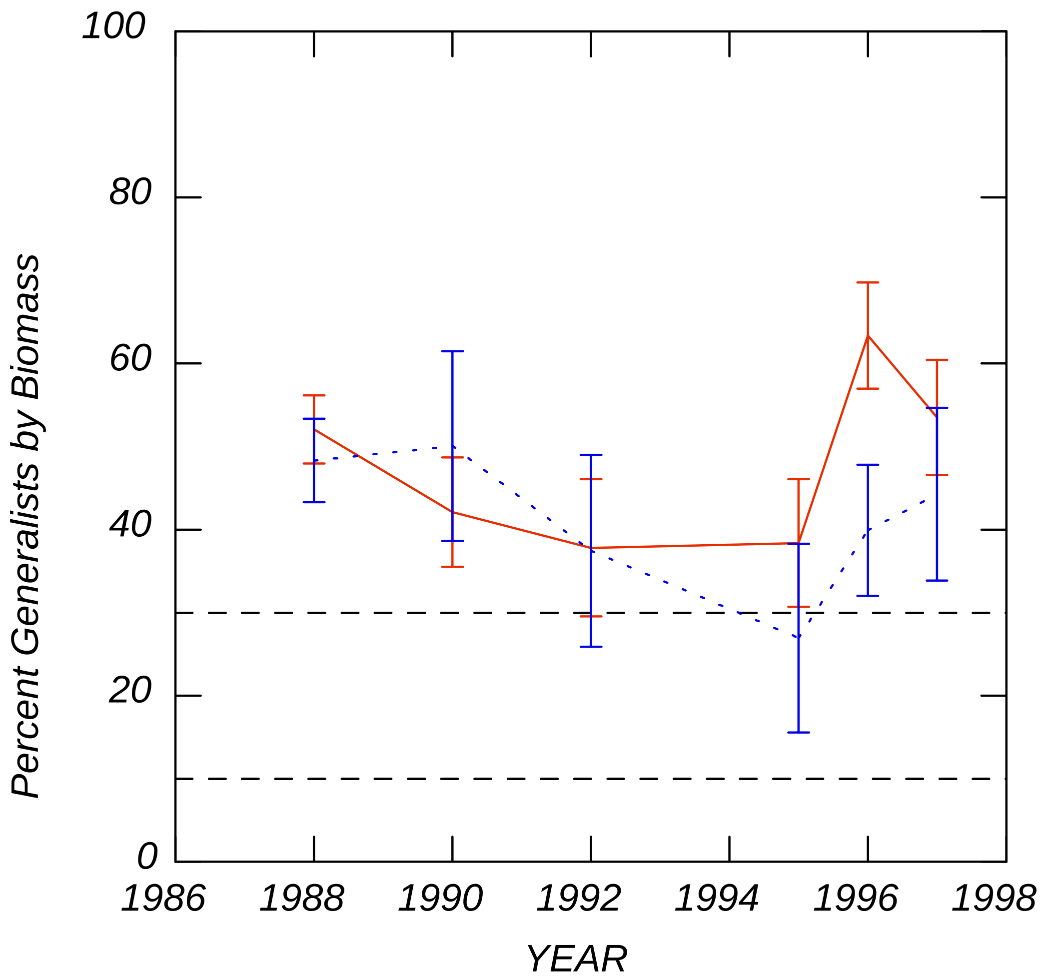


Figure 30: Comparison of Percent Generalists by Biomass (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

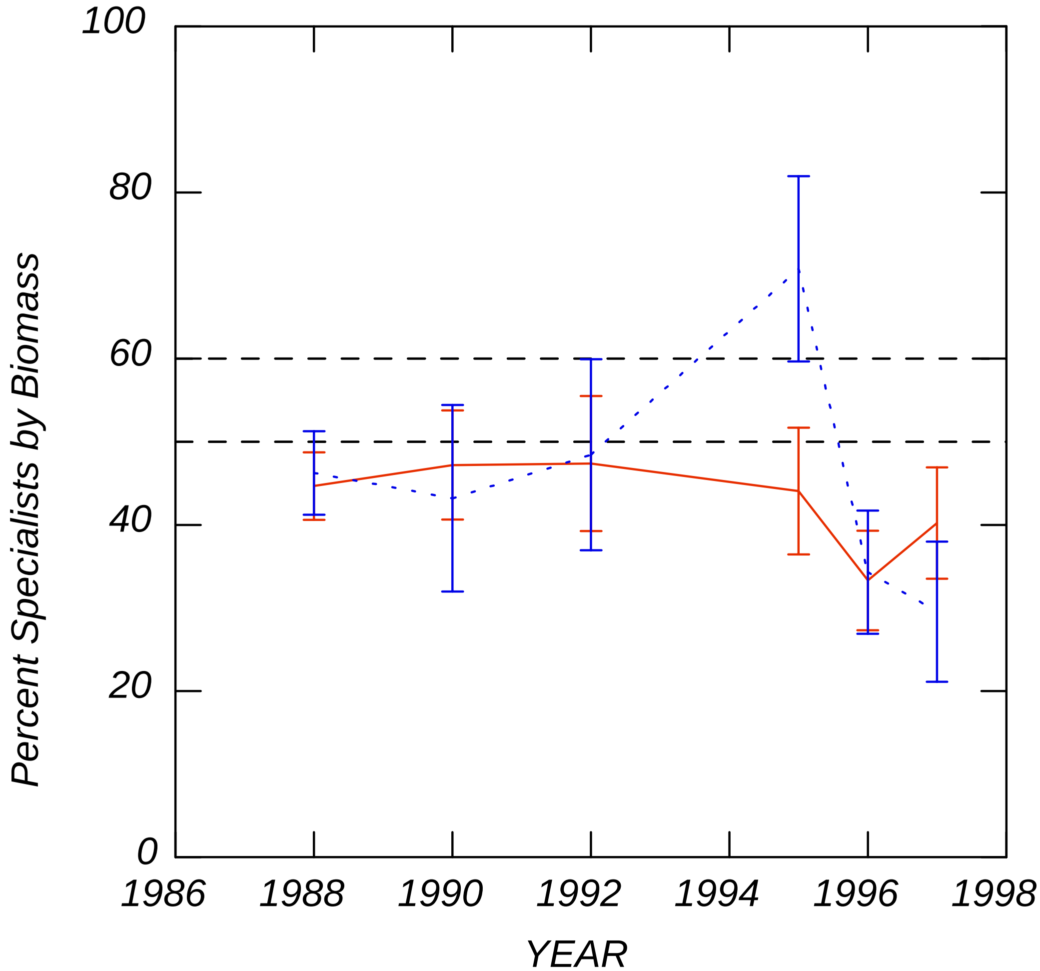


Figure 31: Comparison of Percent Specialists by Biomass (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

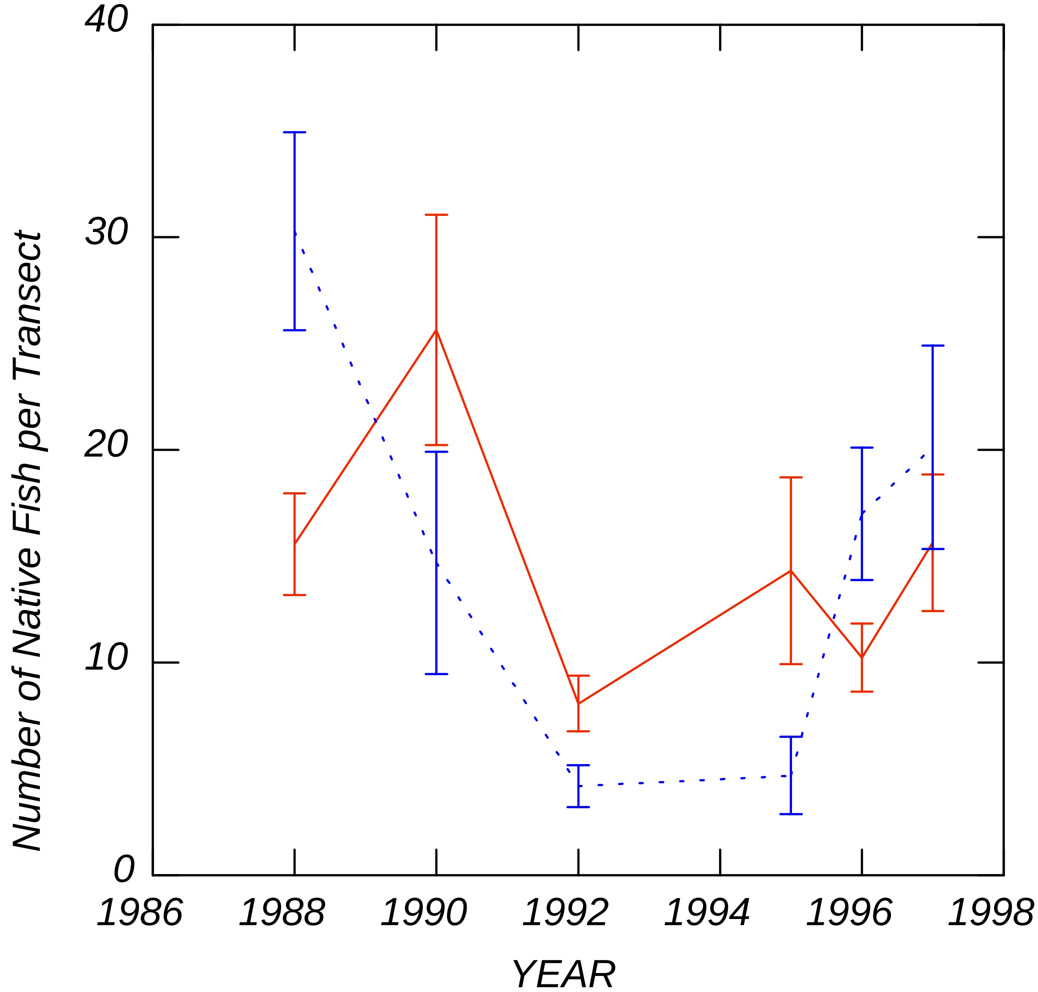


Figure 32: Comparison of the Number of Native Fish (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

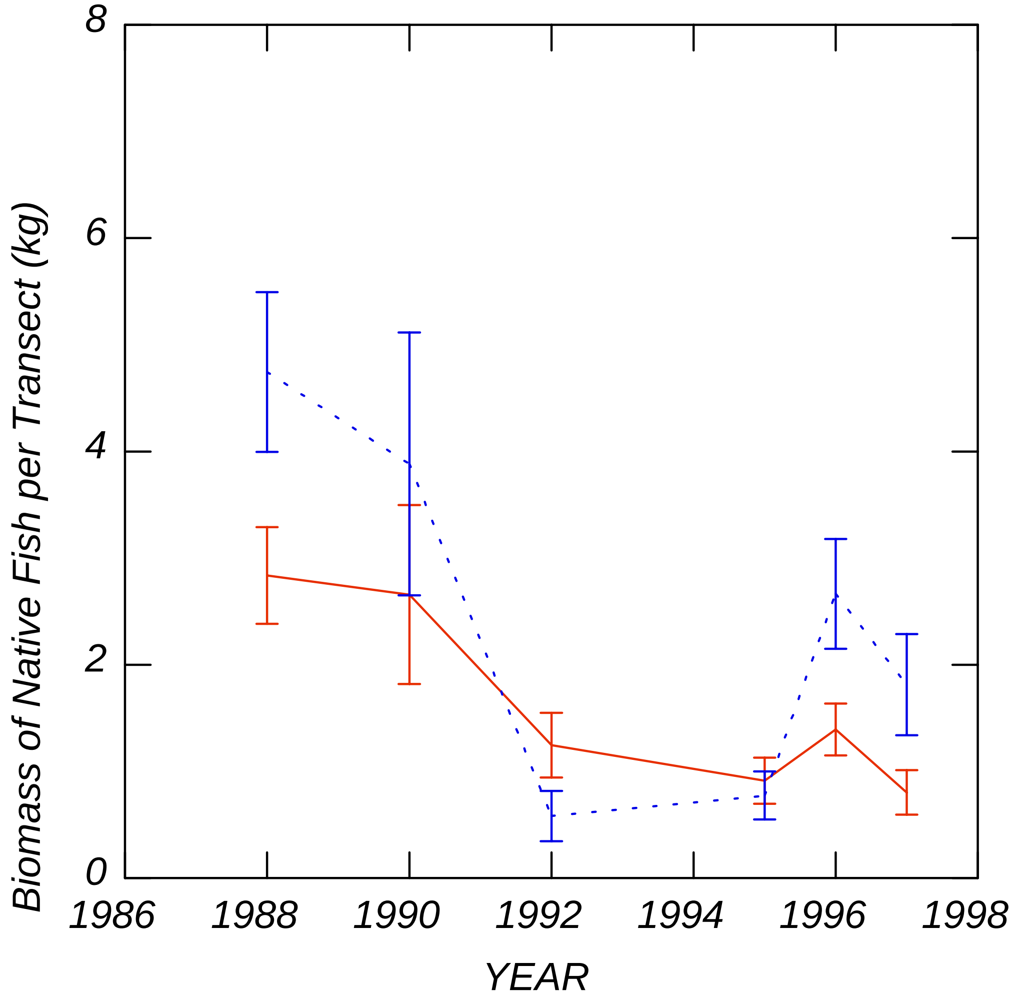


Figure 33: Comparison of the Biomass (kg) of Native Fish (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

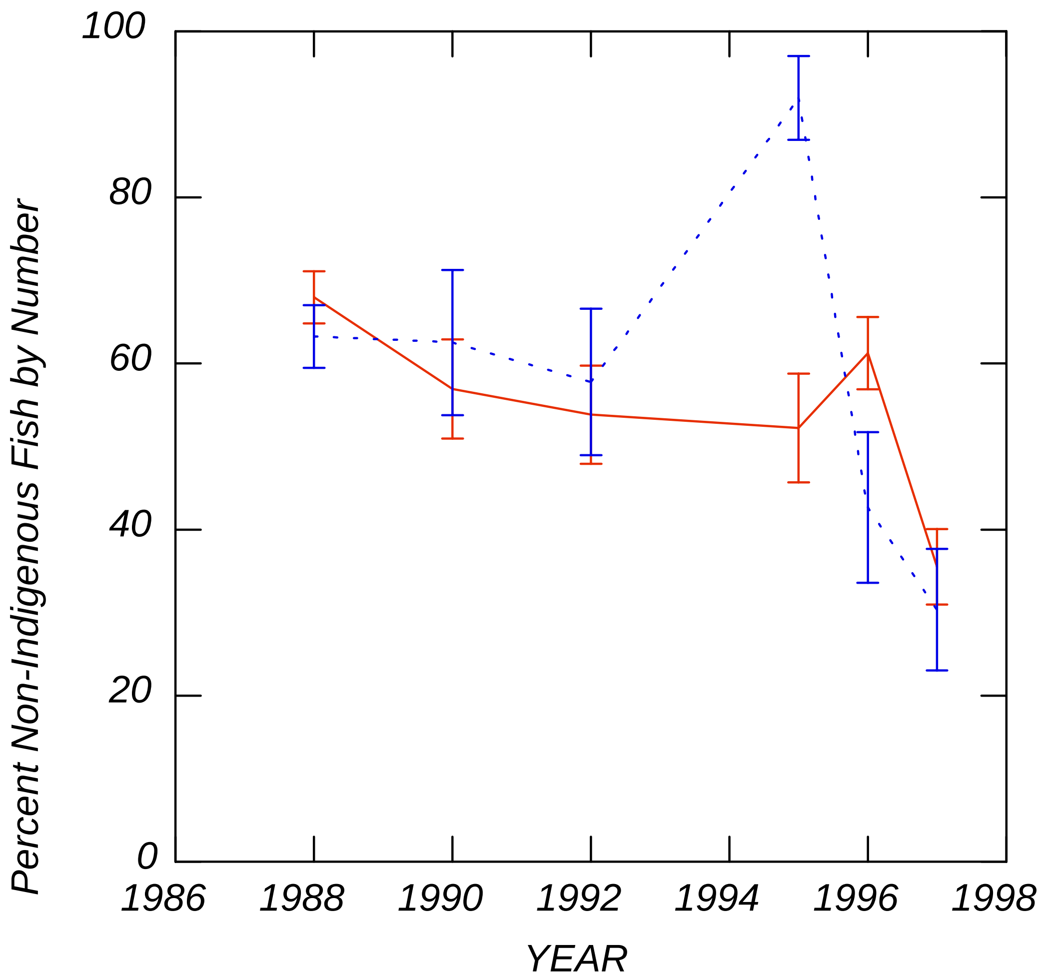


Figure 34: Comparison of Percent Non-indigenous Fish by Number (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

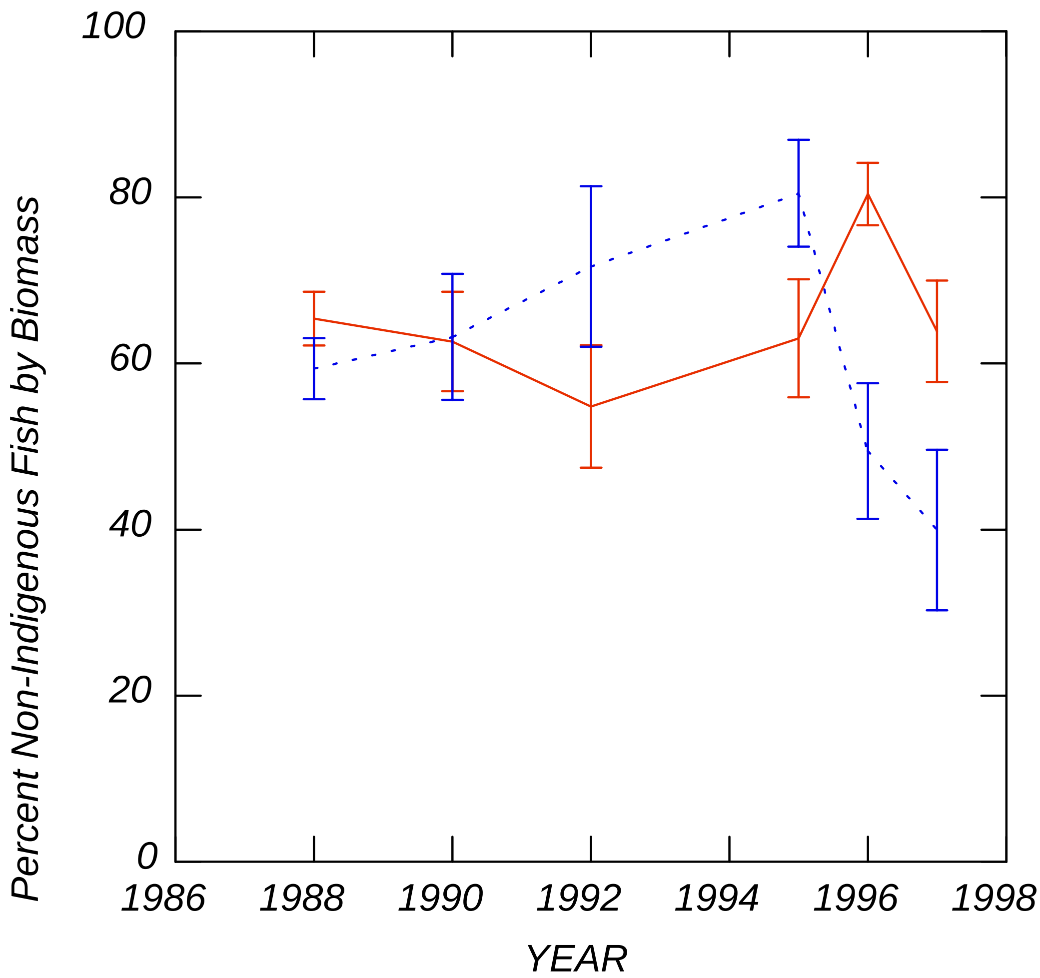


Figure 35: Comparison of Percent Non-indigenous Fish by Biomass (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

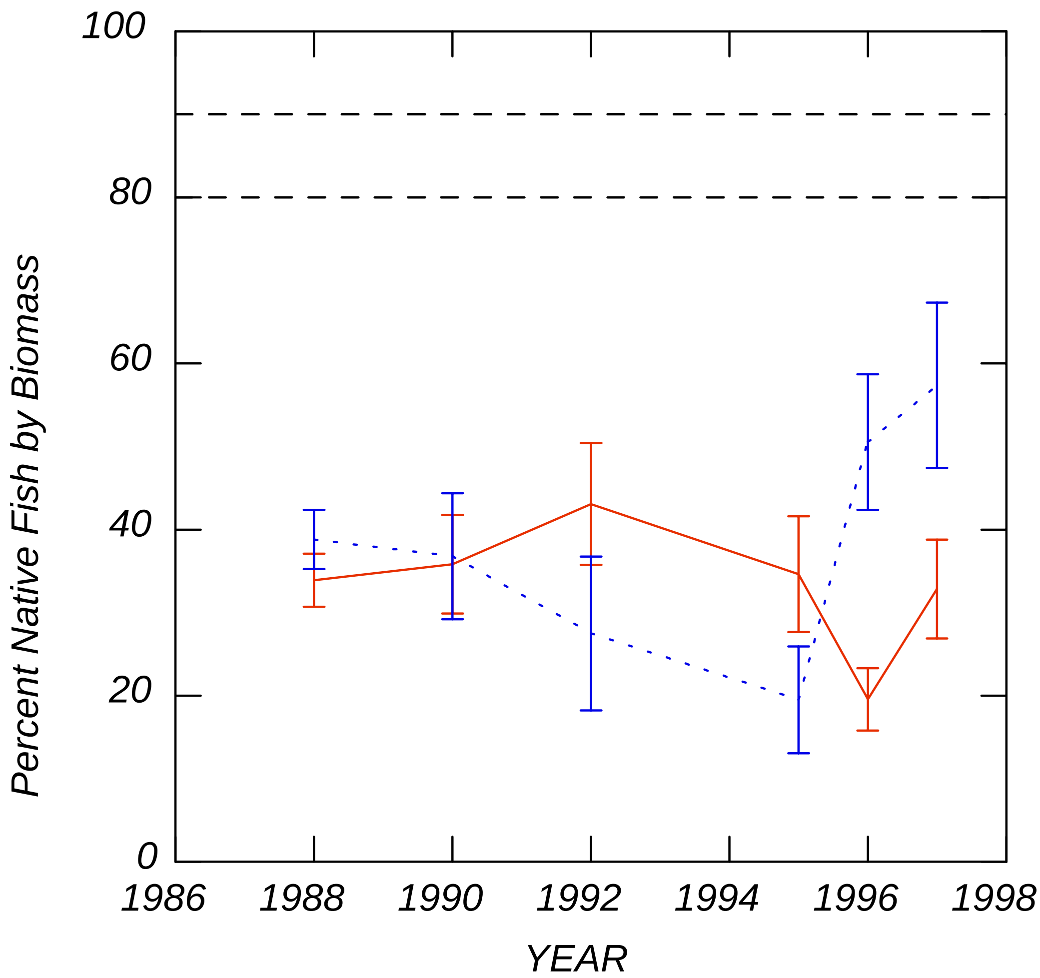


Figure 36: Comparison of Percent Native Fish by Biomass (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

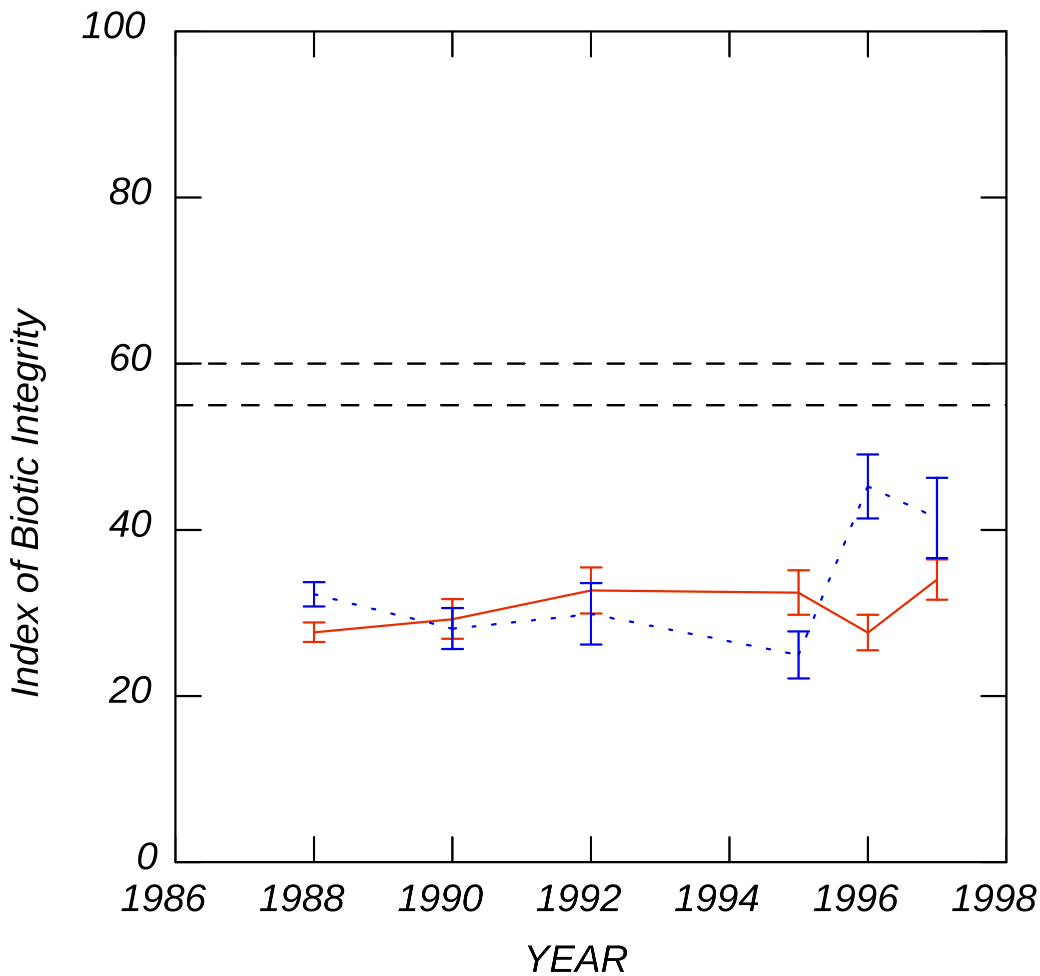


Figure 37: Comparison of Index of Biotic Integrity Scores (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.

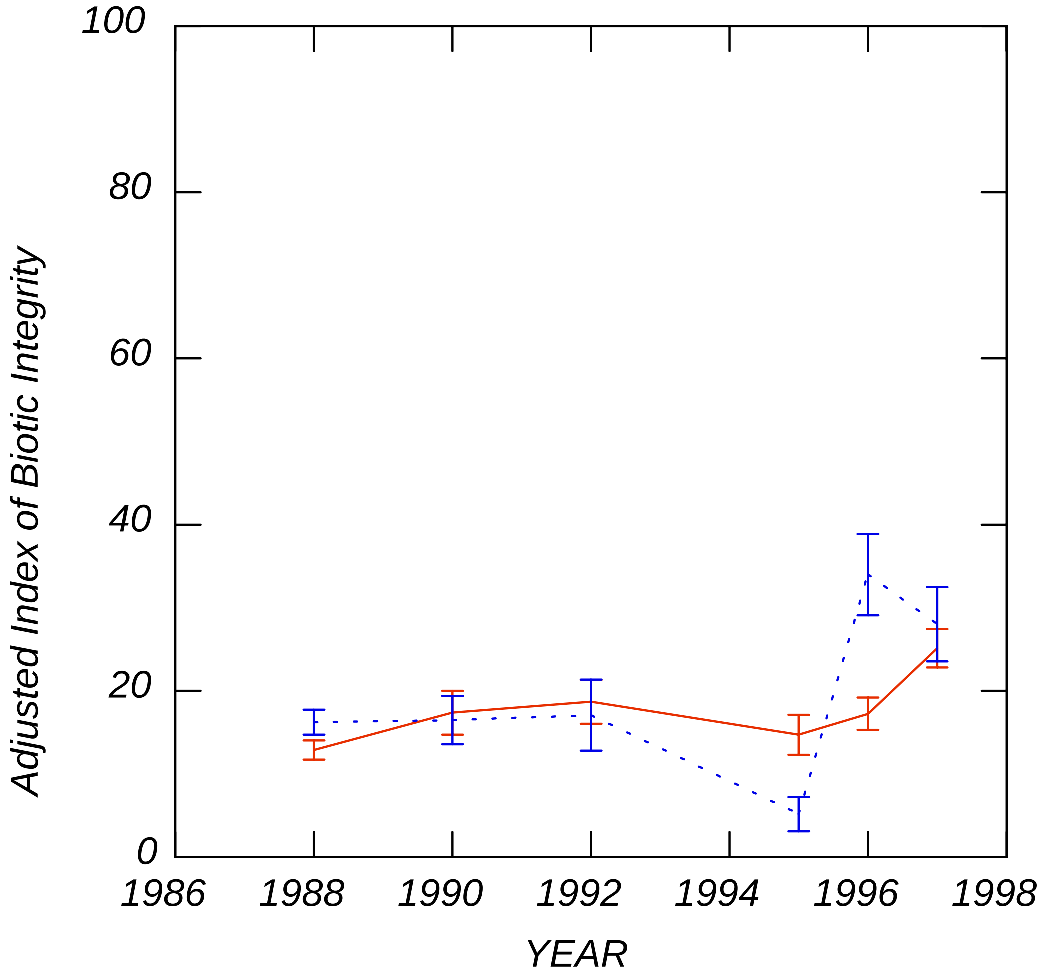
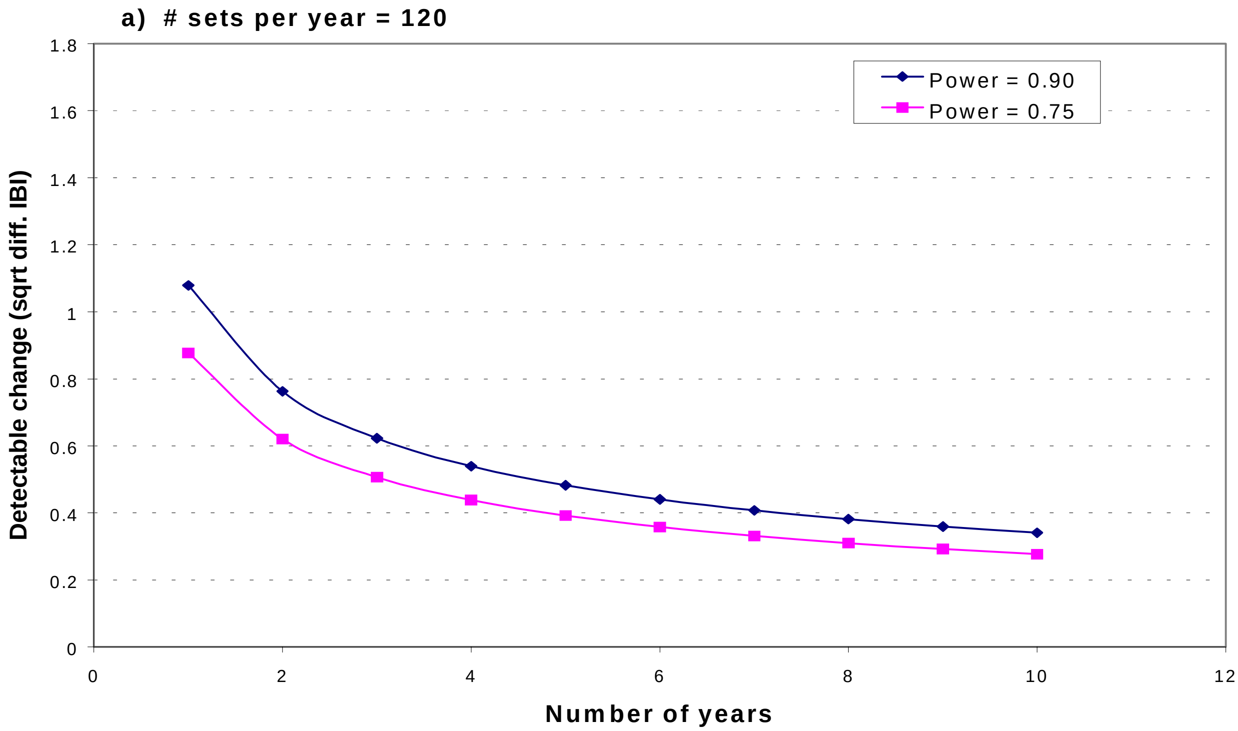


Figure 38: Comparison of Index of Biotic Integrity Scores, adjusted for presence of offshore species (annual mean ± SE) at restoration sites (dashed line, Sites C and E only), and unaltered sites (solid line) before (1988-1995) and after (1996-1997) completion of physical habitat restoration work in Hamilton Harbour.



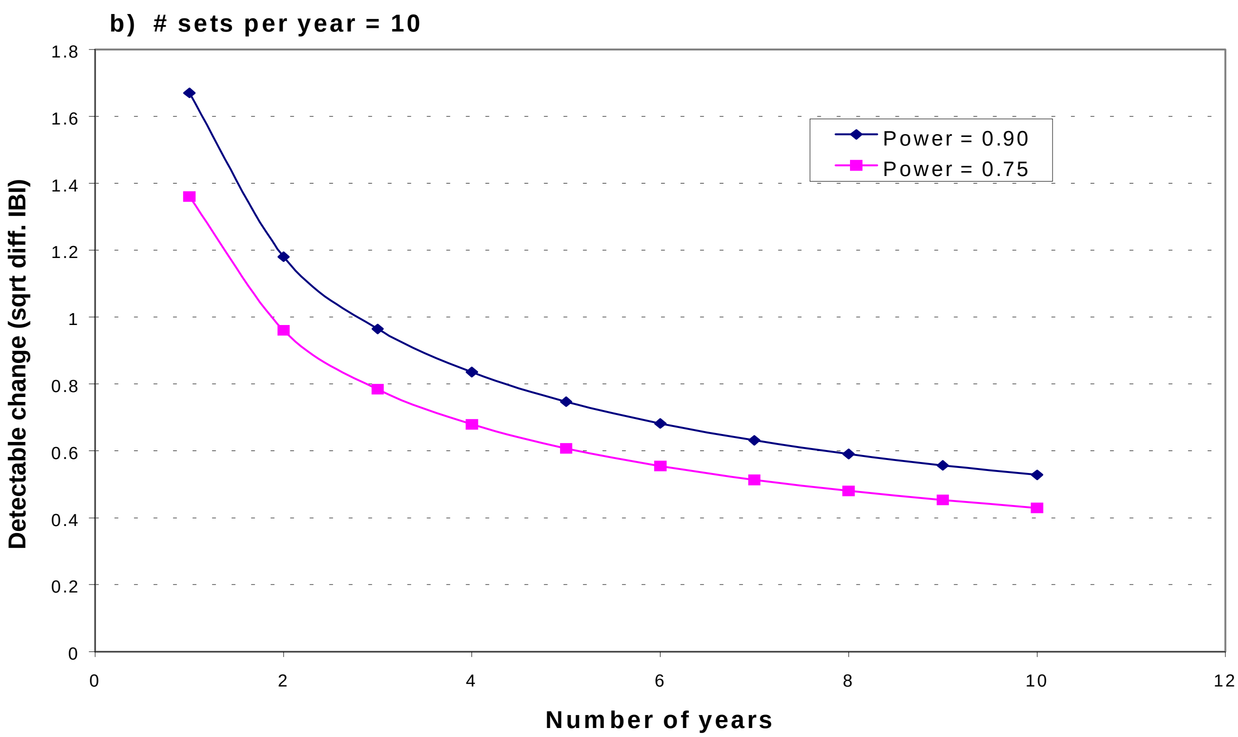


Figure 39a-b: Estimates of the detectable change in the square root IBI scores at two power levels (0.75, 0.90) as a function of the number of years of sampling, given a sampling intensity of a) 120 samples per year, and b)10 samples per year.

Appendix A: Objectives to be achieved in order to permit delisting of Hamilton Harbour, in terms of: water quality; contaminants in fish and wildlife; sediment quality; loading targets for contaminants affecting the beneficial uses; the extent of habitat for fish and wildlife; and the population size and structure for fish and wildlife. Reproduced from Canada-Ontario Agreement (COA) (1992b).

USE IMPAIRMENT		PROPOSED HAMILTON HARBOUR DELISTING OBJECTIVES
(i)	Restriction on fish and wildlife consumption.	That there be no restrictions on consumption of fish and wildlife from the Harbour attributable to local sources.
(ii)	Tainting of fish and wildlife flavour.	When survey results confirm no tainting of fish or wildlife flavour.
(iii)	Degraded fish and wildlife populations.	That the fish community has the following structure: 1. Shift from a fish community indicative of eutrophic environments, such as white perch, alewife, bullheads, and carp to a self sustaining community more representative of a mesotrophic environment, containing pike, bass, yellow perch, and sunfish. 2. Attain a littoral fish biomass of 200 - 250 kg/ha. 3. Increase the species richness from 4 species to 6-7 species per transect. 4. Increase the native species biomass from 37% to 80-90% of the total biomass. 5. Reduce the spatial variability in fish biomass within the Harbour. 6. Proposed nearshore fish community of Hamilton Harbour: **Category** — **Littoral Biomass (kg/ha)** Piscivores (pike, bass) — 40 - 60 Specialists (Insectivores like pumpkinseeds and yellow perch) — 70 - 100 Generalists (omnivores like carp and brown bullheads) — 30 - 90 The percent of fisheries biomass allocated to the three trophic groups was based on the effects of improved water quality in the Bay of Quinte and Severn Sound. The littoral fish biomass of 200-250 kg/ha was based on electrofishing data collected from Hamilton Harbour, Bay of Quinte and Severn Sound in 1990.

USE IMPAIRMENT		PROPOSED HAMILTON HARBOUR DELISTING OBJECTIVES
		5. Colonial waterbirds: The overall objective is to have a self sustaining mixed community of colonial waterbirds generally with an increase of the rarer species and a reduction in the number of ring-billed gulls which currently nest in the Harbour. These figures are subject to revision once these general levels have been reached. Management of colonial waterbirds is experimental and achieving specific populations of particular species is highly speculative. Colonial waterbirds: (Suggested Interim Targets) — Number of Pairs Ring-billed gulls (Larus delawarensis) — 5,000 Common terns (Sterna hirundo) — 600 Herring gulls (Larus argentatus) — 350 Caspian terns (Sterna caspi) — 200 Double-crested cormorants (Phalacrocorax auritus) — 200 Black-crowned night herons (Nycticorax nycticorax) — 200 6. Other wildlife including waterfowl: No target will be suggested for other species of birds or animals, but a target for habitat has been suggested which will enhance wildlife populations generally. In addition, management of some species may be necessary as a result of habitat enhancement. 7. Fish and wildlife bioassays confirm no significant toxicity from water column or sediment contaminants.
(iv)	Fish tumours or other deformities.	When incidence rates of fish tumours or other deformities do not exceed rates at unimpacted control sites that are locally relevant and when survey data confirm the absence of neoplastic or preneoplastic liver tumours in bullheads or suckers.
(v)	Bird or animal deformities or reproductive	When the incidence rates of deformities or reproductive problems in sentinel wildlife species do not exceed background levels in control populations.

USE IMPAIRMENT		PROPOSED HAMILTON HARBOUR DELISTING OBJECTIVES
	problems.	
(vi)	Degradation of benthos.	1. Biomass estimates for mesotrophic conditions to range from 25 to 50 g/m^2 wet weight of benthos. 2. Shift in oligochaete assemblages (benthic sludge worms) from Limnodrilus hoffmeisteri, Tubifex tubifex, indicators of eutrophic environments, to mesotrophic indicators such as Spirosperma ferox, Stylodrilus heringianus, and Llyodrilus templetoni. 3. An increase in the contribution of other species in Hamilton Harbour sediment indicative of mesotrophic conditions such as midges (Tanypus and Strictochironomus), fingernail clams (Pisidium), mayflies (Haxagenia) and the amphipod (Pontoporeia hoyi). 4. Reduction in oligochaete (sludge worm) density from an average 10,000 animals per m^2 found in 1984 to between 2,000 and 3,000 per m^2 in profundal sediments. 5. Appearance of crustaceans, such as freshwater shrimp, (Mysis relicta) in the deep water basin and the amphipod (Pontoporeia hoyi) in the surficial sediments throughout the hypolimnion. 6. Absence of acute and chronic toxic effects attributable to trace metals or organics in benthic macroinvertebrates throughout the Harbour and Cootes Paradise (Station 270 at the west end of the Harbour has been selected as an interim, local target). See also Dredging delisting criteria (vii).
(vii)	Restrictions on dredging activities.	When contaminants in sediments do not exceed biological and chemical standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities.
(viii)	Eutrophication or undesirable algae.	That there are no persistent adverse water quality conditions for each of the components attributable to cultural eutrophication. The following net loading targets provide the specific objectives. Eutrophication goals and anticipated conditions in Hamilton Harbour, Cootes Paradise, and the Grindstone Creek area:

USE IMPAIRMENT		PROPOSED HAMILTON HARBOUR DELISTING OBJECTIVES

TABLE (a): **Net Loading Targets (Kg/d)**

	Phosphorous Initial Goals	Phosphorous Final Goals	Ammonia Initial Goals	Ammonia Final Goals	Suspended Solids Initial Goals	Suspended Solids Final Goals
Hamilton STP	140	60	2270	530	3750	900
Burlington STP	30	12	470	115	500	200
CSOs	70	5	160	20	1400	200
Streams(*)	90	65			30000	20000
Industry (gen'l)			400	270		
Stelco					4000	1500
Dofasco					3500	1500

TABLE (b): **Environmental Conditions**

	Hamilton Harbour Initial Goals	Hamilton Harbour Final Goals	Cootes Paradise Final Goals	Grindstone Creek Area Final Goals
P conc (ug/1)	34	17	60-70	60-70
Un-ionized NH_3 conc (mg/1)	< 0.02	< 0.02		
Chlorophyll a conc (ug/1)	15-20	5-10	20	20
Secchi Disc Trans (m)	2.0	3.0	1.0	1.0
Min. DO conc (ppm)	1-4	> 4		
Aquatic Plant Area ha	105	170	240	50
Seston conc (mg/1)			10	10

***** Stream loadings are extremely variable from year-to-year. The percentage of reduction is based on the estimated effect of best management practice.

(ix)	Restrictions on drinking water consumption or taste and odour problems.	Maintenance of water quality conditions in the Harbour pertinent to standards for human health where a water supply would only require standard treatment procedures (settling, coagulation, disinfection).
(x)	Beach closings. (Water contact sports.)	1. That Hamilton Harbour effluent to Lake Ontario not give rise to conditions which would cause restrictions on open Lake water contact sports. 2. That water quality conditions in the west-end and in the north-half of the Harbour, be such as to permit opening of beaches and which would cause no significant restriction on water

USE IMPAIRMENT		PROPOSED HAMILTON HARBOUR DELISTING OBJECTIVES
		contact sports.
(xi)	Degradation of aesthetics.	When the waters are free of any substance which produces a persistent objectionable deposit, unnatural colour or turbidity, or unnatural odour (e.g. oil slick, surface scum).
(xii)	Added cost to agriculture or industry.	When there are no significant additional costs required to treat water prior to use for agricultural purposes (i.e. including, but not limited to livestock watering, irrigation and crop-spraying) and industrial purposes (i.e. intended for commercial or industrial applications and non-contact food processing). Cost associated with zebra mussels or other invasive organisms are excepted.
(xiii)	Degradation of phytoplankton and zooplankton populations.	When phytoplankton and zooplankton community structure does not significantly diverge from unimpacted control sites of comparable physical and chemical characteristics. Further in the absence of community structure data, this use will be considered restored when phytoplankton and zooplankton bioassays confirm no significant toxicity in ambient waters.
(xiv)	Loss of fish and wildlife habitat.	1. Increase quantity of emergent and submergent aquatic plants in Hamilton Harbour, Cootes Paradise, Grindstone Creek delta, and Grindstone Creek marshes to approximately 500 hectares in accordance with the Fish and Wildlife Habitat Restoration Project. 2. Provide an additional 10 km of littoral shore by creating 5 km of narrow islands. 3. Create an additional 344 ha of lagoon habitat for waterfowl. 4. Create 270 ha of colonial nesting habitat. 5. Water clarity targets for the summer season (June to September) as measured by Secchi Disc: Harbour 3.0 m Cootes Paradise & Grindstone Creek 1.0 m

Appendix B

A Program to Calculate Index of Biotic Integrity Scores for Great Lakes' Areas of Concern: Summary and Operating Instructions

April 1, 1997
Mike Stoneman

Introduction

The Index of Biotic Interity (IBI) is a composite variable produced by summarizing a variety of descriptors of fish communities. The IBI is intended to provide an indicator of the general health of a site and versions have been developed for a wide variety of lotic and lentic environments. In order to assess and monitor the health of the Great Lakes' Areas of Concern, a version of the IBI was developed specifically for the littoral zones of the Great Lakes. The theory and methodology of this IBI are contained in Minns, 1994.

The purpose of this report is to outline the workings of an Access database which has been developed to calculate the IBI scores for sites using standardized electrofishing data. The Access database file IBI_CALC.MDB contains the data tables and the programs necessary to generate the IBI scores. This program relies on the use of the ELECFISH.EXE front end to extract data from the GLLFAS electrofishing database.

Operations

Upon opening the IBI_CALC.MDB database, an opening screen will be displayed, showing the name of the program and the credits for the programming and the methodology. The opening screen will disappear after 15 seconds, or immediately upon pressing any key or clicking the mouse anywhere on the picture.

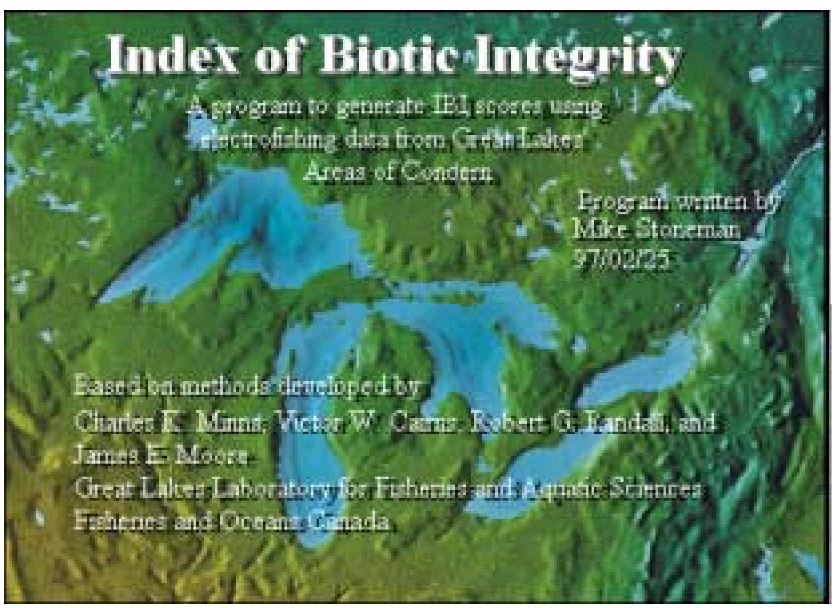


***Figure 1**: Opening Screen*

Closing the opening screen, either by clicking the mouse or allowing the timer to run out, brings up the main switchboard, which offers choices to perform all of the main functions of the program.

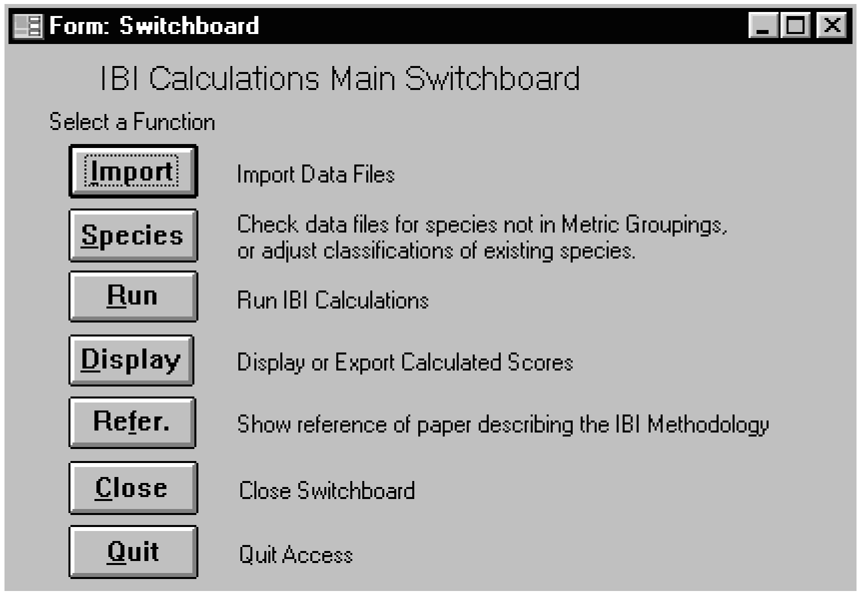


Figure 2: *Main Switchboard*

Import Extraction Files

As GLLFAS electrofishing data are stored in a separate database, they must first be imported into the IBI calculation system. The ELECFISH.EXE front end is used to extract data from the electrofishing database. One of the functions of the Elecfish front end is to use regressions from existing data to interpolate missing values. For this reason, IBI_CALC.MDB does not directly access the data stored in ELECFISH.MDB. Instead, the Elecfish front end must be used to extract the data, with estimations for missing values, and store them in text files. These text files are then imported into IBI_CALC.MDB. When producing biomass or counts, the front end produces "cross-tab" style files, with a row for each sample and a column for each species. For this reason, three separate extractions must be performed, one each for biomass and counts by species, as well one for total biomass. When performing the extractions, do not limit the species in any way. In order for the IBI calculations to be meaningful, all species captured should be considered. If any limits are put on the locations used in the extractions, it is essential that the same locations be used for all three extractions. Keep track of the names and locations of the extraction files, as this information is required in the import procedure. Once the three extractions are complete, close ELECFISH.EXE and open the IBI_CALC.MDB database. Select the "Import" button on the Main Switchboard and choose the biomass, count, and total extraction files when prompted. The Import routine will then import each extraction file and append the records to the empty tables "Imported Biomass", "Imported Counts", and "Imported Totals", respectively. Before they can be analyzed, the biomass and counts tables must be normalized. This means to change them from having one record for each sample to having one record for each sample and species present. Instead of having a column for each species in the dataset, a normalized table has a column called "Species" and one called "Biomass" or "Counts". As part of the import routine, the program automatically generates a combined, normalized biomass and counts table, called, not surprisingly, "Normalized Biomass and Counts".

Set Fish Species Parameters:

In order to accurately calculate an IBI score for a site, each species of fish captured has to be categorized with regards to its native or non-indigenous status, trophic level, taxonomy, turbidity tolerance and on- or off-shore tendencies. The table "Metric Memberships" contains an entry for each classified species, with fields for each of the categories. After a set of data is imported, the species captured are compared against this table and any new species are presented in the form shown below. In this example, the data contained capture records for sea lamprey and gravel chub, neither of which are contained in the species classification list.

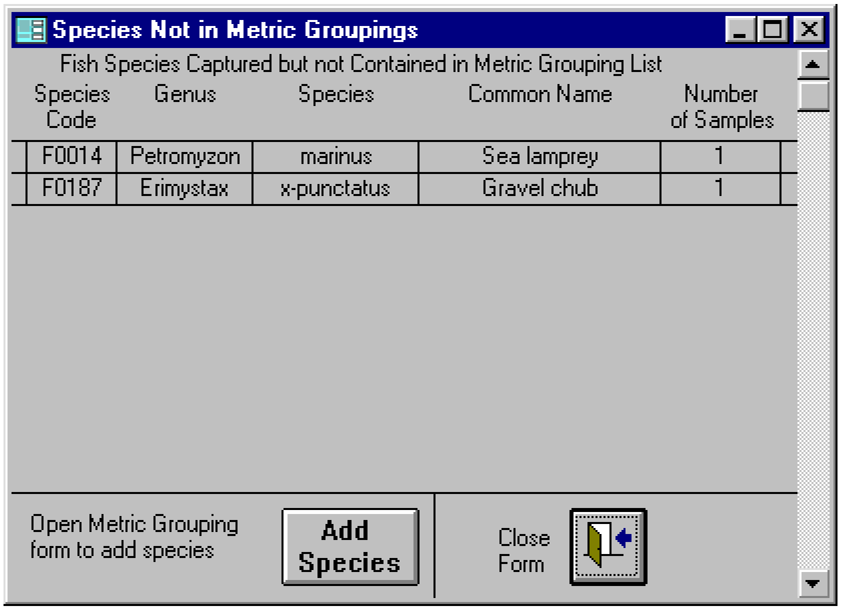


Figure 3: *New Species List*

If a captured species is considered to be inconsequential, it can be ignored at this point. This would result in the exclusion of all records involving this species in all subsequent calculations. Alternatively, clicking the "Add Species" button will open the table of fish species and allow new species to be added and classified. This form can also be opened at any time by clicking on the "Species" button in the Main Switchboard.

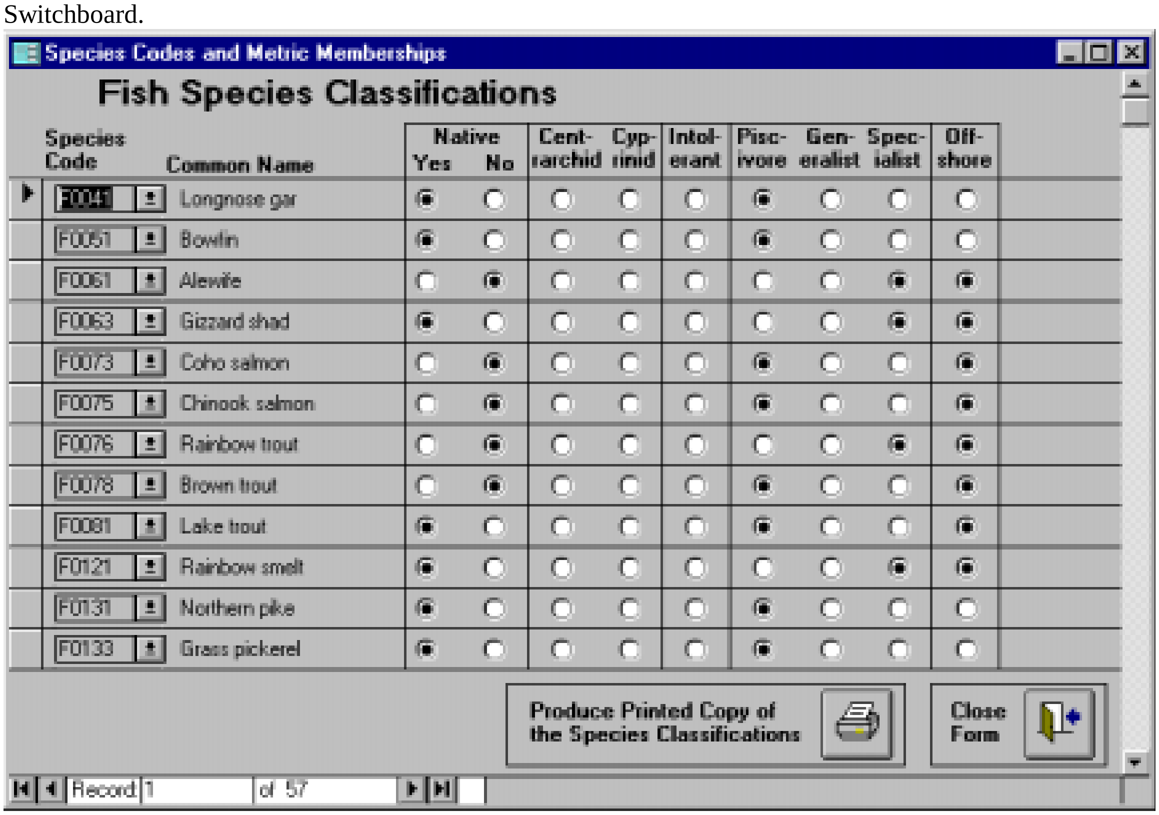


Figure 4: *Species Classification Screen*

To add a new species, use the arrow buttons at the bottom of the form to go to the blank record at the end of the table. Click on the pull-down arrow next to the species code box and select the desired species from the list, or simply type the species code into the species code box. Then click on each of the radio buttons to indicate the species characteristics. Likewise, existing entries in the list can be modified by clicking the radio buttons to change the species' classifications. If desired, a printed list of the species and their characteristics can be generated by clicking the printer button at the bottom of the form.

In the time since Minns et al, 1994, a more comprehensive knowledge of species characteristics has developed. In particular, literature searches performed during the development of the Defensible Methods habitat quantification have resulted in changes to the species classifications contained in the IBI. The following table outlines the changes. In addition, the trophic status of several species are currently under review and may be revised in the near future. The contents of the current species classification list is attached as Appendix B1.

Species Code	Species Name	Old Category	Current Category
F0121	Rainbow smelt	Non-Indigenous	Native
F0166	Bigmouth buffalo	Native	Non-Indigenous

Several other tables contain information regarding the metrics themselves. The table "Metric Parameters" contains one record for each metric which defines the way in which the raw metric is converted into a standardized score. Appendix B2 contains the descriptions of each of the metrics included in the IBI.

<u>Run IBI Calculations:</u>

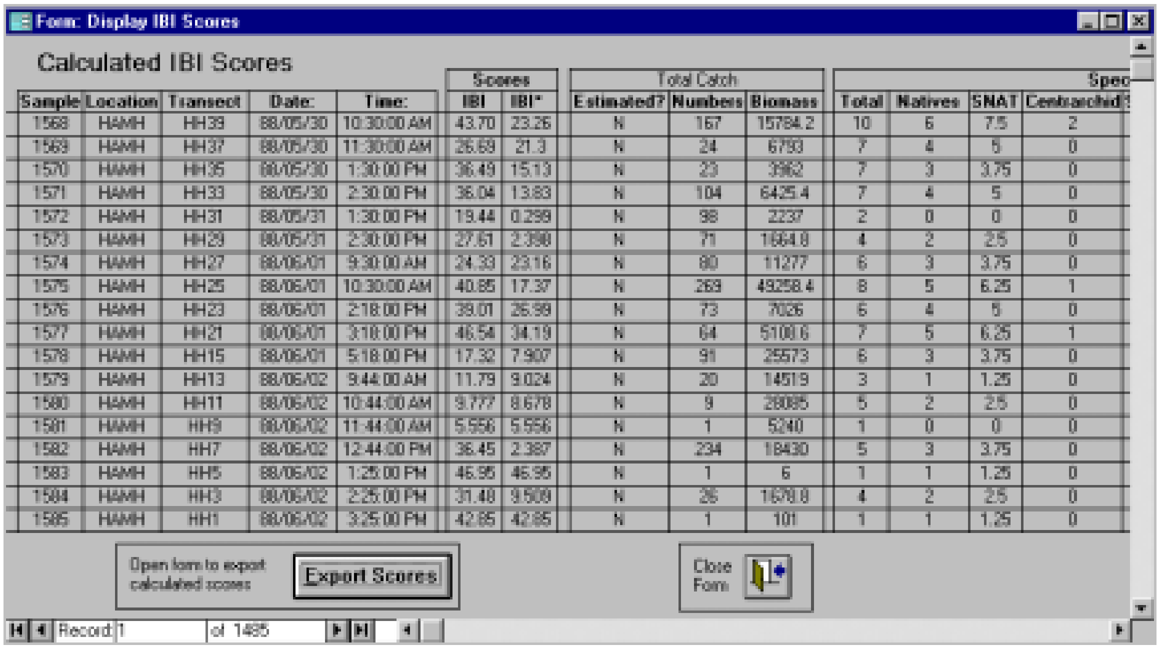
Clicking the "Run" button on the Main Switchboard calls the program which actually calculates the IBI score. The Access Basic program Calc_IBI, contained in the module Calculate IBI, runs a series of SQL queries to prepare the input and output tables, and then calculates the IBI metrics. First, existing records in the output table "IBI Scores" and the input table "Sum of Spc, Biomass and Numbers by Metric Group" are deleted. Then a new set of records is created in "IBI Scores", with one record for each record in the table "Imported Totals". Each record in "IBI Scores" contains the sample identification fields (Location, Transect, Date, Time, and Sample) as well as the total biomass, total count, total number of species, and a flag which indicates whether estimation was used to fill in missing values. The next step is to create new records in the table "Sum of Spc, Biomass, and Numbers by Metric Group". This table contains one record for each sample and metric. The sum of the biomass, counts, and number of species which were caught in the sample, and which are included in the metric, are contained in each record. This table is used as input to the IBI calculations.

Once the data tables have been prepared, the program begins the actual calculations of the IBI metrics. Structurally, the program consists of two nested loops, stepping through each record in "IBI Scores" and each record in "Sum of Spc, Biomass, and Numbers by Metric Group". The parameters contained in "Metric Parameters" are used to calculate the standardized metrics once the raw metrics are calculated. The raw and standardized metrics are then written to "IBI Scores", along with IBI, the composite IBI index, and IBI* the composite index adjusted for the presence of offshore species.

Each time the IBI calculation routine is run, the contents of all intermediary and output files ("Sum of Spc, Biomass and Numbers by Metric Group", and "IBI Scores") are deleted before the new results are written. The tables containing the imported data are deleted each time the import routines are run. This means that there is no need to manually clear these tables.

<u>Display Results:</u>

Once the calculations are completed, the results can be examined by clicking on the "Display" button on the Main Switchboard. This opens a form which displays all of the calculated metrics for each sample.



Form: Display IBI Scores

Calculated IBI Scores

					Scores		Total Catch			Spec			
Sample	Location	Transect	Date:	Time:	IBI	IBI*	Estimated?	Numbers	Biomass	Total	Natives	SNAT	Centrarchid
1568	HAMH	HH39	88/05/30	10:30:00 AM	43.70	23.26	N	167	15784.2	10	6	7.5	2
1569	HAMH	HH37	88/05/30	11:30:00 AM	26.69	21.3	N	24	6793	7	4	5	0
1570	HAMH	HH35	88/05/30	1:30:00 PM	36.49	15.13	N	23	3962	7	3	3.75	0
1571	HAMH	HH33	88/05/30	2:30:00 PM	36.04	13.83	N	104	6425.4	7	4	5	0
1572	HAMH	HH31	88/05/31	1:30:00 PM	19.44	0.298	N	98	2237	2	0	0	0
1573	HAMH	HH29	88/05/31	2:30:00 PM	27.61	2.398	N	71	1664.8	4	2	2.5	0
1574	HAMH	HH27	88/06/01	9:30:00 AM	24.33	23.16	N	80	11277	6	3	3.75	0
1575	HAMH	HH25	88/06/01	10:30:00 AM	40.85	17.37	N	269	49258.4	8	5	6.25	1
1576	HAMH	HH23	88/06/01	2:18:00 PM	39.01	26.98	N	73	7026	6	4	5	0
1577	HAMH	HH21	88/06/01	3:18:00 PM	46.54	34.19	N	64	5100.6	7	5	6.25	1
1578	HAMH	HH15	88/06/01	5:18:00 PM	17.32	7.907	N	91	25573	6	3	3.75	0
1579	HAMH	HH13	88/06/02	9:44:00 AM	11.79	9.024	N	20	14519	3	1	1.25	0
1580	HAMH	HH11	88/06/02	10:44:00 AM	9.777	8.678	N	9	28085	5	2	2.5	0
1581	HAMH	HH9	88/06/02	11:44:00 AM	5.556	5.556	N	1	5240	1	0	0	0
1582	HAMH	HH7	88/06/02	12:44:00 PM	36.45	2.387	N	234	18430	5	3	3.75	0
1583	HAMH	HH5	88/06/02	1:25:00 PM	46.95	46.95	N	1	6	1	1	1.25	0
1584	HAMH	HH3	88/06/02	2:25:00 PM	31.48	9.509	N	26	1678.8	4	2	2.5	0
1585	HAMH	HH1	88/06/02	3:25:00 PM	42.85	42.85	N	1	101	1	1	1.25	0

Open form to export calculated scores — Export Scores

Close Form

Record: 1 of 1485

Figure 5: *IBI Score Display*

Not surprisingly, this is a large and unwieldy form, which is really only useful for doing a cursory check of the results. For more detailed analyses, the results must be exported to another application. Clicking the “Export Scores” button brings up a form which allows for the export of all, or only a subset, of the calculated scores. The program prompts for a name and location for the export file. The default export format is an Excel 3.0 spreadsheet. This format was chosen as it is easily imported into most analysis packages, including SYSTAT 6.0 for Windows.

<u>Display Reference:</u>

Clicking on the “Reference” button in the Switchboard opens a small form which displays the full reference for Minns, et al 1994.

<u>Close Switchboard:</u>

This option closes the Switchboard and opens the normal Access database window, allowing any of the normal Access functions to be performed. This option should only be used by operators knowledgeable in the operation of Access. Changes to tables, queries, forms, reports, macros, or modules could cause the entire program to cease functioning.

<u>Quit Access:</u>

This option shuts down the database, saving all tables and objects, and then exits from Access, returning to Windows. If unsaved changes have been made to any objects, a prompt will appear to ask if the changes should be saved. Answering Yes will save them.

<u>Technical Information</u>

This database was initially developed under Access version 2.0, running under Windows for Workgroups version 3.11 on a 486 66 with 8 Mbytes of RAM. Later developments were conducted using Access 2.0 running under Windows 95 on a Pentium 120 with 16 Mbytes RAM. No testing has been performed using Access 95 or Access 97, so there is no guarantee that it will work. According to Microsoft, it should work under Access 95 if opened as an Access 2.0 database, but will likely require changes in order to work as a converted Access 95 database.

All screens are designed to work with a video resolution of 800X600 pixels, though they will fit on 640X480 screens. Likewise, though the screens were designed to look best with 16 bit High Colour, they will work fine with fewer colours. Of course, by the time you get down to 16 colours, the opening screen picture looks pretty awful!

References

Minns, C.K., V.W. Cairns, R.G. Randall, and J.E. Moore. 1994. An Index of Biotic Integrity (IBI) for fish assemblages in the littoral zones of Great Lakes' Areas of Concern. Can. J. Fish. Aquat. Sci. 51:1804-1822

Appendix B1

Appendix B1,Cont'd

Appendix B1, Cont'd

Appendix B2: Contents of Metric Parameters table in IBI_CALC.MDB

ID	Metric Code	Metric Name	Metric Group	Metric	Include in	Metric	Interce	Slope	Minimum	Maximum	Ms=0	Ms=10
1	SNAT	Native Species Richness	Native	CountOfSpecie	Yes	1	0	1.25	0	10	0	8
2	SCEN	Centrarchid Species Richness	Centrarchid	CountOfSpecie	Yes	1	0	3.33	0	10	0	3
3	SINT	Intolerant Species Richness	Intolerant	CountOfSpecie	Yes	1	0	5	0	10	0	2
4	SNIN	Non-Indigenous Species	Non-Indigenous	CountOfSpecie	Yes	1	10	-3.33	0	10	3	0
5	SCYP	Native Cyprinid Species	Cyprinid	CountOfSpecie	Yes	1	0	5	0	10	0	2
6	PPIS	Percent Piscivore Biomass	Piscivore	Biomass	Yes	6	0	0.3	0	10	0	33.3
7	PGEN	Percent Generalist Biomass	Generalist	Biomass	Yes	6	15	-0.15	0	10	100	33.3
8	PSPE	Percent Specialist Biomass	Specialist	Biomass	Yes	6	0	0.3	0	10	0	33.3
9	NNAT	Number of Native Individuals	Native	Number	Yes	3	0	0.083	0	10	0	120
10	BNAT	Biomass of Natives (kg)	Native	Biomass	Yes	5	0	0.83	0	10	0	12
11	PNNI	Percent Non-Indigenous by	Non-Indigenous	Number	Yes	4	10	-0.1	0	10	100	0
12	PBNI	Percent Non-Indigenous by	Non-Indigenous	Biomass	Yes	6	10	-0.1	0	10	100	0
13	POFN	Percent Off-Shore by Number	Offshore	Number	No	4	0	1	0	100	0	100
14	POFB	Percent Off-Shore by Biomass	Offshore	Biomass	No	6	0	1	0	100	0	100

Descriptions of fields in Metric Parameters Table

Field Name	Description
ID	Machine generated sequential identifier
Metric Code	Four letter code to identify each metric
Metric Name	Name of Calculated Metric
Metric Group	Group of species which are included in metric
Metric Variable	Name of summary variable used to calculate metric
Include in IBI	Indicates which metrics are included in the composite IBI score
Metric	Code indicating type of summary to perform
Intercept	Y intercept of line used to generate standardized metric score from raw summary score
Slope	Slope of line used to generate standardized metric score from raw summary score
Minimum	Minimum value of standardized metric
Maximum	Maximum value of standardized metric
Ms = 0	Value of raw metric when standardized metric equals 0
Ms = 10	Value of raw metric when standardized metric equals 10

Appendix C

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