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Effect of Habitat Degradation on the Species Composition and Biomass of Fish In Great Lakes Areas of Concern

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ABSTRACT

Randall, R. G., C.K. Minns, V.W. Cairns, and J.E. Moore. 1993. Effect of habitat degradation on the species composition and biomass of fish in Great Lakes Areas of Concern. Can. Tech. Rept. Fish. Aquat. Sci. No. 1941.

The biomass and species composition of fish communities inhabiting near shore areas of the Great Lakes showed the effects of habitat degradation and eutrophication. Five bays surveyed for this study, ranked from low to high on the basis of eutrophication (total phosphorus) and habitat degradation (contaminant loads, habitat alteration), were: 1. Matchedash Bay 2. Hog Bay and 3. Penetang Bay of Severn Sound, Georgian Bay, and 4. Bay of Quinte and 5. Hamilton Harbour in Lake Ontario. All study bays were located within areas designated as Great Lakes 'Areas of Concern'. Average fish community biomass ranged between 3.6 and 9.1 kg (per 100 m survey transect) among the five bays. Biomass was correlated with seasonal mean total phosphorus concentrations. Preliminary estimates of fish production rate indicated that the productivity of the littoral habitats was high in all areas; mean production ranged between 92 and 179 kg $ha^{-1}yr^{-1}$. Although fish production was high, habitat degradation had a negative impact on the structure of the fish communities. Species richness, the biomass of piscivorous fish, and turnover rates were highest in the least degraded bays (Matchedash and Hog bays). In contrast, the proportion of total fish biomass which was comprised of exotic fish species (particularly *Cyprinus carpio*) was highest in the most degraded bays (Hamilton Harbour, and to a less extent, Quinte and Penetang Bay). Spatial variability in fish biomass within the study bays was high in all areas (coefficients of variation ranged between 0.71 and 1.40). Information on community fish biomass provided information on both the relative health of the ecosystems and on productivity.

RÉSUMÉ

Randall, R. G., C.K. Minns, V.W. Cairns, and J.E. Moore. 1993. Effect of habitat degradation on the species composition and biomass of fish in Great Lakes Areas of Concern. Can. Tech. Rept. Fish. Aquat. Sci. No. 1941.

La biomasse et la composition spécifique de l'ichtyofaune occupant le littoral des Grands Lacs ont affiché les effets de la dégradation et de l'eutrophisation de l'habitat. Cinq baies examinées dans le cadre de la présente étude accusaient des taux variant de faible à élevé du point de vue de l'eutrophisation (phosphore total) et de la dégradation de l'habitat (charges de contaminants, perturbation de l'habitat); ce sont: 1. le port d'Hamilton, 2. la partie supérieure de la baie de Quinte (les deux dans le lac Ontario), 3. la baie Penetang, 4. la baie Hog et 5. la baie Matchedash, au fond de Severn Sound (baie Georgienne). Toutes les baies visées par l'étude étaient situées à l'intérieur de zones désignées comme «secteurs préoccupants» des Grands Lacs. La biomasse moyenne de l'ichtyofaune variait de 3,6 à 9,1 kg (par transect d'étude de 100 m) dans les cinq baies. On a établi une corrélation entre la biomasse et la moyenne des concentrations saisonnières de phosphore total. Des estimations préliminaires des taux de production de poisson ont indiqué que la productivité des habitats du littoral était élevée dans toutes les régions; la production moyenne allait de 92 à 179 kg ha^{-1}. La production de poisson était élevée, mais la dégradation de l'habitat avait un impact négatif sur la structure des communautés ichtyologiques. La diversité des espèces, la biomasse des poissons piscivores et les taux de renouvellement étaient les plus élevés dans les baies les moins dégradées (les baies Matchedash et Hog). En comparaison, la proportion des espèces exotiques (*Cyprinus carpio* en particulier) dans la biomasse totale des poissons était plus élevée dans les baies les plus dégradées (le port d'Hamilton, et dans une moindre mesure les baies de Quinte et Penetang). La variabilité spatiale de la biomasse de poisson dans les baies étudiées était élevée dans toutes les régions (les coefficients de variation allaient de 0,71 à 1,40). Les données sur la biomasse de l'ichtyofaune fournissaient de l'information tant sur l'état de santé relatif des écosystèmes que sur la productivité.

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1.0 INTRODUCTION

Water quality throughout the Great Lakes basin is reported annually by the International Joint Commission (IJC). As a result of assessment programs, the Water Quality Board (WQB) of IJC identified 43 different 'Areas of Concern' with impaired beneficial uses. Areas of Concern were defined as localized areas within the Great Lakes (harbours, embayments, or interconnecting channels) where water quality had deteriorated to the point where human use of the particular area was impaired (Hartig and Thomas 1988). Loss of fish habitat and degradation of fish populations were included in the criteria used to identify specific Areas of Concern. Seventeen of the 43 listed 'Areas of Concern' are in Ontario.

Research on the fish communities of littoral habitats in Great Lakes' Areas of Concern (Hamilton Harbour and Bay of Quinte in Lake Ontario, and Severn Sound in Georgian Bay) was initiated by the Great Lakes Laboratory for Fisheries and Aquatic Sciences, Department of Fisheries and Oceans, in 1988. The primary objective of the project was to identify how fish production varied spatially in different littoral habitats, and to develop models whereby fish production could be predicted from different habitat features. Ultimately, the habitat and fish data, and the resulting predictive models, would be used in future remedial action plans designed to restore aquatic habitats in each Area of Concern.

Before considering the possible links between micro-habitat features and fish abundance within the study areas, however, we compared the fish data among the five study bays. Macro-habitat conditions, including both eutrophication and the degree of habitat degradation, varied among the study areas. For this preliminary analysis, we had two objectives: 1. to define the variability in biomass and species composition of fish among the study bays, and to identify the macro-habitat factors that contributed to the variability, namely eutrophication and habitat degradation. We address the hypothesis that although fish biomass is positively correlated with eutrophication (Lee and Jones 1991), species composition and community structure may be altered. Habitat degradation may result in a reduction in species richness, increased dominance of exotic species, and shortened food-chain length (Odum 1985; Rapport 1992). 2. A second objective was to evaluate the utility of using fish biomass as an index of habitat productivity and health. Future studies will focus on how biomass is linked to specific micro-habitat features (macrophyte abundance, substrate, slope etc.) within each individual Area of Concern. Thus, in analyzing the fish data from the nearshore habitats, we are proceeding from a general macro-habitat study to a more detailed micro-habitat study.

2.0 DESCRIPTION OF THE STUDY AREAS

Fish data were collected from three Areas of Concern, Hamilton Harbour and Bay of Quinte in Lake Ontario, and Severn Sound in southern Georgian Bay (Fig. 1). At

Severn Sound, three different bays were surveyed, Penetang, Hog and Matchedash bays. Data were therefore available from five different bays.

2.1 Hamilton Harbour

Hamilton Harbour is a triangular shaped body of water, 22 km^2 in size, located at the western end of Lake Ontario (Fig. 2). The mean and maximum depths of Hamilton Harbour are 13 and 26 m, respectively. The harbour is connected to Lake Ontario by the Burlington canal; substantial exchanges of water between the Harbour and Lake Ontario occur through the canal. Cootes Paradise is a shallow (mean depth 0.5 m) but extensive wetland (area 2.5 km^2) located to the west of the Harbour. Several streams drain the watershed surrounding Hamilton Harbour. The annual mean discharge of two of the largest streams, Spencer Creek and Grindstone Creek, is about 3.6 m^3sec^{-1}; about 58% of the discharge drains into Cootes Paradise.

Hamilton Harbour is one of the most polluted sites in the Great Lakes (Barica 1989) because toxic substances in bottom sediments and in the water column are high (metals, PCB's and organochlorine pesticides), high nutrient loads have contributed to harbour eutrophication, oxygen depletion has occurred in the hypolimnion, fish consumption is restricted for certain species because of contaminants, and bacterial levels are often high, and water clarity is poor (Table 1). Fish populations in the harbour have been impacted: coldwater fish species, lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*) and lake herring (*Coregonus artedii*) which once supported an important commercial fishery, have disappeared (Holmes and Whillans 1984). Warmwater fish communities in the littoral habitats are presently dominated by carp (*Cyprinus carpio*), white perch (*Morone americana*) and brown bullheads (*Ictalurus nebulosus*), species which are tolerant of enriched environments (Holmes 1988).

For this study, 49 transects were surveyed in littoral habitats of Hamilton Harbour. Transects were located on the east, north and west shores of the Harbour, and in Cootes Paradise (Fig. 2).

2.2 Bay of Quinte

The Bay of Quinte is a large (257.4 km^2) irregular-shaped bay located on the northeastern shore of Lake Ontario. The watershed of the Bay of Quinte has an area of 18,200 km^2, and drains the Precambrian shield in the north and Palaeozoic limestones in the south. Several major rivers discharge into the Bay of Quinte, including from west to east, the Trent River, Moira River, Salmon River and Napanee River; together, their mean annual discharge is 157 m^3sec^{-1}. The lower Bay of Quinte is connected to Lake Ontario by two passages, one on each side of Amherst Island. The upper Bay of Quinte is connected to Lake Ontario by Murray Canal, which was built for navigational purposes in 1890.

Eutrophication is the major environmental problem in the Bay of Quinte, although significant improvements in water quality have occurred in recent years since point-source loadings of phosphorus were reduced by 50% in 1978 (Minns et al. 1986). With decreases in total phosphorus, the Bay has gradually shifted from being hypereutrophic in the 1960's and 1970's to eutrophic in the 1980's (Hurley 1986). In addition to eutrophication, other environmental problems include contaminated sediments and fish, fish tumours, and localized areas of elevated bacterial levels (Table 1). The fish community structure has fluctuated over the long term in the Bay of Quinte.

For this study, fish surveys were conducted in the upper Bay of Quinte only, from Trenton to Big Island. Thirty-three transects were surveyed in total (Fig. 3). The upper Bay is approximately 35 km long, and has an average depth of about 4 m.

2.3 Severn Sound

The Severn Sound Area of Concern is located in southeastern Georgian Bay, extending from Beausoleil Island eastward to Port Severn. On the south shore, Severn Sound consists of a series of bays including, from west to east, Penetang Bay, Midland Bay, Hog Bay, Sturgeon Bay and Matchedash Bay. The topography ranges from gentle to steeply sloping, and the soils are comprised mainly of sandy loam. On the north shore, there are several small rocky islands and bays. The north shore is the southern boundary of the Canadian shield, and is comprised of precambrian granitic rock with shallow soils.

Severn River is the largest river discharging into Severn Sound. The Severn is the western extension of the Trent-Severn Waterway which is regulated with a series of locks and dams. The Severn River drainage area is large (5800 km^2), and includes Lake Simcoe. Several smaller rivers flow into the small bays on the south shore, and a few streams drain the precambrian shield on the north shore.

Environmental concerns identified for the Severn Sound Area of Concern include: 1. nutrient enrichment, particularly in Penetang Bay, 2. a decline in certain sport fish populations, particularly walleye (*Stizostedion vitreum*), and 3. the presence of contaminants in the larger size ranges of certain sport fishes (Hartig and Thomas 1988; Anon. 1988; Table 1).

For this study, a total of 55 survey transects were established in Severn Sound, 29 in Penetang Bay (Fig. 4a), and 14 in Hog Bay and 12 in Matchedash Bay, respectively (Fig. 4b and 4c).

3.0 METHODS

3.1 Habitat Conditions and Eutrophication

We ranked the five bays according to degree of habitat degradation and degree of eutrophication. Habitat degradation was based on two indicators, the human population within the drainage area of each embayment, and the list of water quality problems identified by Hartig and Thomas (1988) as summarized in Table 1. Human population (Table 2) was used as an indicator of industrial and residential activity that would, directly or indirectly, impact on water and habitat quality. Based on these criteria, the ranking of the study areas, from least degraded to most degraded, was:

Area	Rank of Habitat Degradation
Matchedash Bay	1 (least degraded)
Hog Bay	2
Penetang Bay	3
Bay of Quinte	4
Hamilton Harbour	5 (most degraded)

Average seasonal concentration of total phosphorus (μg^{-1}) (Table 2) was used as an indication of eutrophication and water productivity. Ranking of the five bays from lowest to highest concentrations of total phosphorus was the same as the above ranks for habitat degradation. There were also gradients in phosphorus concentrations within the Areas of Concern. In Penetang Bay, average phosphorus concentrations ranged from 37.8 $\mu g\ l^{-1}$ in the inner bay, to 15.6 $\mu g\ l^{-1}$ in the outer bay (Table 2). In Bay of Quinte, concentrations in the upper bay ranged from 45 $\mu g\ l^{-1}$ at Trenton to 37.3 $\mu g\ l^{-1}$ at Napanee.

3.2 Fish Surveys

Fish surveys were carried out using a Smith-Root electric fishing boat. The boat was 6.1 m in length, and was operated with two anode arrays which were extended from the bow. The aluminum hull of the boat acted as the cathode. Electricity was generated from an on-board gas powered generator (16 HP), which had the following output capacity: rated output maximum of 62 A; D.C. output peak volts of 0 to 1000 in 4 steps; and an output pulse frequency of 7.5, 15, 30, 60 and 120 cycles. Normally during the surveys, the generator was operated with a metered output of 340 V, from 6 to 9 A, and at 60 pulses per second. The electrofishing crew consisted of 4 members, all of whom were trained with the proper operating procedures. One crew member operated the boat and generator, two crew members working off the bow of the boat used long-handled dip nets to capture stunned fish, and the final crew member helped the netters release captured fish into the onboard live well. Each crew member operated a separate foot switch, connected in series, for safety.

A line transect survey design was used. Each line transect was parallel to shore, 100 m in length, and approximately followed the 1.5 metre depth-contour. The beginning and end of each transect was measured and marked prior to electrofishing. At each study bay, transect locations were stratified such that replicate samples were collected at each of four macrophyte categories: heavy, medium, sparse and no aquatic vegetation. Transects were also selected to cover a variety of exposure (fetch) and substrate conditions.

A total of 654 transects were surveyed from 1988 to 1990. Transects in Hamilton Harbour were surveyed on a weekly basis from May to August in 1988 (Table 3). In 1989, all Bay of Quinte transects were surveyed during August. In 1990, all five study areas were surveyed, usually 3 times at monthly intervals from May or June until August (Hog Bay was surveyed only twice, in July and August).

Fish captured at each 100 m transect were netted as the boat progressed and held in a live well. Most fish up to a limit of 20 per species were measured (nearest mm) and weighed (nearest g). Length measurements for most species of fish was the fork length; fish with no pronounced fork in the caudal fin, were measured for total length (eg. bullheads). For transects where more than 20 specimens of a species was captured, a batch weight was recorded for the sample exceeding 20 fish. All fish were returned alive into an area adjacent to the transect after the survey was completed.

Three key fish measurements used in this study were fish density (number captured per 100 m transect), biomass (kg per transect), and species richness (number of species per transect).

In addition to the fish data, the following physical information was usually recorded at the time of sampling: date, time, electrofishing duration (seconds), wind speed, wind direction, secchi disc reading (cm), water temperature (°C), voltage setting and amperage output.

3.3 Estimates of Biomass by Trophic Groups

Total biomass (kg wet weight) at each transect was calculated by summing the weights of individual fish. For each of the five bays, fish biomass was calculated for the following categories: individual fish species, native versus exotic species, trophic groups, and status of residence (littoral or offshore). Our objective was to compare the biomass of these subgroups to see if differences existed between bays.

Fish species were designated as being native or exotic to the Great Lakes using the list of exotic species provided by Emery (1985).

Each fish species was assigned to one of three trophic groups: piscivores, generalists, or specialists. Assignment to the trophic groups was based on the criteria outlined by Minns et al. (1993). General descriptions of the diet were obtained from Scott and Crossman (1973). Species were classified as piscivores if their diet (fish older than age O) consisted predominantly of fish. Piscivores included 10 species: longnose gar (*Lepisosteus osseus*), bowfin (*Amia calva*), chinook salmon (*Oncorhynchus tshawytscha*), brown trout (*Salmo trutta*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius)*, American eel (*Anguilla rostrata*), smallmouth bass (*Micropterus dolomieui)*, largemouth bass (*Micropterus salmoides*), and walleye. Species were classified as being generalists if their diet spectrum was diverse and omnivorous. Generalists included central mudminnow (*Umbra limi*), quillback (*Carpiodes cyprinus*), goldfish (*Carassius auratus*), carp, golden shiner (*Notemigonus crysoleucas*), bluntnose minnow (*Pimephales notatus*), brown bullhead, and channel catfish (*Ictalurus punctatus*). All other species were classified as specialists, and included planctivores (eg. *Alosa pseudoharengus*), insectivores (eg. *Perca flavescens*) and the herbivore, gizzard shad. Assignment to the four trophic groups gave only a rough indication of the major food source for each of the fish species.

Two categories of 'residence' were identified: species were assigned as being either littoral or pelagic. Selection of the appropriate category was based on a trophic status. Littoral species included fish which used the inshore areas to feed and grow during a significant part of their life cycle. Fish which utilized the littoral habitat only for spawning were classified as being pelagic offshore species. Pelagic offshore species included alewife, all salmonids, rainbow smelt (*Osmerus mordax*), white perch (*Morone americana*), white bass (*M. chrysops*), walleye, johnny darter (*Etheostoma nigrum*), and logperch (*Percina caprodes*).

3.4 Estimates of Fish Production

Annual fish production was estimated for each transect surveyed during 1990. Production rate was calculated using the equation:

$$\log P = a + b \log W + c \log B$$ (from Boudreau and Dickie 1989)

where P = production rate (kg ha^{-1} yr^{-1})
W = average fish weight (kg) per transect
B = average fish biomass (kg ha^{-1})

Average biomass (B) was calculated as the arithmetic mean biomass for the three visits made to each transect during 1990 (two visits for Hog Bay sites). For estimating annual production rate, average annual biomass was assumed to equal average seasonal biomass as calculated above. Average weight (W) was the arithmetic mean weight of all fish captured at each transect. Coefficients for the constants ***a, b*** and ***c*** were assumed to be 0.46, -0.32 and 1.01, respectively (Boudreau and Dickie 1989). Thus, production was positively correlated with mean biomass, but negatively correlated with average weight of the fish at each transect.

Fish biomass was converted from a relative unit (kg per transect) to an absolute unit (kg per hectare) using the following assumptions: 1. the catch efficiency of the electrofishing boat was assumed to average about 0.30 (preliminary observations on catch efficiency were made during summer of 1991 in Hamilton Harbour. Experimental enclosures were deployed in nearshore habitats, and recapture data from known numbers of released fish were used to estimate catch rates.), and 2. an effective survey width of 10 m was assumed (the experimental enclosure used to estimate catch efficiency was 10 m in width). Thus the total survey area was assumed to be 1000 square metres (100 m transect X 10 m = 0.10 ha). Because of the assumptions associated with the catch efficiency and the effective area surveyed, estimates of production were preliminary.

3.5 Statistical Methods

Field data were entered on computer, verified, and prepared as SYSTAT (Wilkinson 1990) data files which are on file at the Great Lakes Laboratory for Fisheries and Aquatic Sciences. Preliminary analysis of the data collected from Hamilton Harbour in 1988 (n = 326) indicated that the frequency distributions of biomass and numbers per transect were positively skewed (Fig. 5). Variances greatly exceeded the means for both biomass and numbers (Table 4). To normalize the distributions, data were log transformed (Fig. 5). Numbers of species per transect were approximately normally distributed (Fig. 5), and therefore were not transformed.

Comparisons of fish biomass, density or species richness between time periods or study bays were done using unbalanced Analysis of Variance (ANOVA). Significant group differences were isolated using Tukey's test (Wilkinson 1990). Multiple regression techniques were used to compare fish biomass (dependent variable) among transects with various independent variables (fish density, species numbers, and numbers of fish by species). Regression or ANOVA outputs were considered significant at alpha levels equal to or less than 0.05.

4.0 RESULTS

4.1 Temporal Variation in Biomass

<u>4.1.1 Weeks</u>

To determine the extent of temporal variability in fish densities during summer, transects were surveyed on a weekly basis from late May until late August, 1988, in Hamilton Harbour (Table 3). Mean numbers of fish per transect, biomass (kg) per transect, and numbers of species per transect were calculated for 9 weeks. Between 20 and 40 transects were surveyed; data from two weeks (weeks 25 and 34, Table 3) were eliminated from the analysis because sample sizes were less than 20.

Average biomass was not significantly different among weeks (unbalanced ANOVA, P>0.05), and there was no obvious trend over the season (Fig. 6). The average weekly biomass per transect was 13.3 kg (SE 0.76). The average number of species per transect also remained constant over the weeks (Fig. 6). Mean species per transect varied among weeks from 4.5 to 5.7, but differences among weeks were not significant (P>0.05). The overall mean number of species of fish per transect was 5.1 (SE 0.12).

Average numbers of fish per transect remained constant during weeks 23 to 29, but then decreased in weeks 30 and 33 (Fig. 6). Unbalanced ANOVA indicated that differences in numbers among weeks were significant (P<0.01). However, the only significant difference was between the two weeks with the highest numbers (weeks 26 and 27) and the week with the lowest mean numbers of fish (week 33; Tukey's test, P<0.10).

4.1.2 Months

Data collected at all five study bays in 1990 were used to test for monthly differences in biomass, numbers and species richness. Significant differences in fish biomass were found at Hog and Matchedash bays (Fig. 7). Generally, changes in mean biomass among monthly samples within each area paralleled changes in the mean density of fish. Significant differences among months in species diversity were found in three of the five survey areas (Fig. 8). However, as for biomass and density, there were no consistent seasonal trend in the different survey areas; mean numbers of species per transect decreased over the summer at Hamilton, increased in Quinte and was lowest in mid-season in Matchedash Bay.

Seasonal variability in fish density, biomass and diversity was less in Penetang Bay than in any of the other areas surveyed. The biomass of fish remained remarkably constant within transects during the survey period. Transects that had high biomasses of fish early in the season tended to have high biomasses late in the season as well. Similar trends within transects were found for species richness and fish density. No significant differences among months were found for any of the three variables. In the other bays surveyed, variability in fish data within transects over the 1990 survey period was much greater; significant correlations were usually not found.

4.1.3 Years

Between year variation in fish densities, biomass and diversity was compared at two areas - Hamilton Harbour, 1988 and 1990, and Bay of Quinte, 1989 and 1990. Densities, biomass and numbers of species were all significantly less in Hamilton Harbour in 1990 compared to 1988 (Table 5). For Bay of Quinte, biomass and numbers of species were similar in 1989 and 1990, but mean densities were higher in 1990 than in 1989 (P<0.10).

4.2 Spatial Variation in Biomass and Community Structure

4.2.1 Spatial Variation in Biomass Within and Among The Five Bays

Variability of biomass and species richness among transects was high in all five survey areas. Coefficients of variation for biomass ranged between 71% and 140% (Table 6). Coefficients for species richness were less, ranging between 27% and 60%. The variability in fish biomass among transects was highest in Hamilton Harbour, and least in Matchedash Bay and intermediate at the Hog, Penetang and Quinte sites.

The average biomass (kg) of fish per transect varied by a factor of two among the five areas where data were collected in 1990, from about 3.6 (Matchedash Bay) to 9.1 (Hamilton Harbour; Fig. 9). Mean biomass per transect among the three bays in Severn Sound were not significantly different from one another (ANOVA; $P > 0.05$); data from these three areas were therefore pooled. Mean biomasses in Hamilton and Quinte were not significantly different, but mean biomasses in both these areas were significantly higher than at Severn Sound (ANOVA and Tukey test; $P<0.01$).

Mean numbers of fish per transect were least in the three bays of Severn Sound and were highest in Bay of Quinte (Fig. 9). However, the difference in mean numbers among the five areas was only marginally significant (ANOVA; $P=0.06$). Mean numbers per transect varied from 41 (Penetang) to 85 (Quinte). Species richness (mean numbers of species per transect) was significantly higher in Bay of Quinte and Matchedash Bay than in Hamilton Harbour, Penetang Bay and Hog Bay (ANOVA and Tukey tests; $P<0.001$). Mean numbers of species per transect ranged from 4.1 (Hamilton) to 6.9 (Matchedash).

4.2.2 Species Composition and Trophic Structure

A total of 43 species of fish were found during the electrofishing surveys in Hamilton Harbour, Bay of Quinte and Severn Sound (Table 7). Bay of Quinte and Hamilton had the highest number of species (30 and 29, respectively), and Matchedash and Hog bays had the fewest (23 and 17 species, respectively). The lower fishing effort in the latter two bays in 1990 may have affected the number of species observed. Of the 43 species recorded, 9 were not native to the Great Lakes. All 9 exotic species occurred in Hamilton Harbour; fewer exotic species were recorded in the other survey areas.

Alewife, northern pike, white suckers, carp, bullheads, yellow perch and many centrarchid species were ubiquitous. American eels, white perch, bluegills (*Lepomis macrochirus*) and freshwater drum (*Aplodinotus grunniens*) were found at the two Lake Ontario sites but not in Severn Sound. Quillback, blackchin shiner (*Notropis heterodon*) and bluntnose minnow were found only in Severn Sound. Salmonids were restricted mainly to Hamilton Harbour, and probably resulted from hatchery plantings in Spencer and Grindstone Creeks. Walleye were found in all areas except Hamilton Harbour.

Relative abundance of each species was calculated for each bay sampled in 1990. In all three bays of Severn Sound, yellow perch and pumpkinseeds (*Lepomis gibbosus*) dominated the total catch; a variety of species that differed among the three bays made up the rest of the catch (Fig. 10). Yellow perch also dominated the catch in Bay of Quinte, but pumpkinseeds were less abundant than in Severn Sound. Relative species abundance in Hamilton Harbour was different than the other four bays: alewives, bullheads, carp and emerald shiners dominated the nearshore catch at Hamilton.

The composition of the fish community in Hamilton Harbour was obviously different from the other bays when the species were ranked by biomass as well. Three species of fish, carp, alewives and bullheads, made up about 72% of the biomass in Hamilton Harbour (Fig. 11). In the other areas, yellow perch, pumpkinseeds and a variety of other species, depending on the area, dominated the community biomass. The biomass of large predators (northern pike, walleye, small and largemouth bass and bowfins) was higher in all other areas than in Hamilton Harbour.

Within each study area, fish biomass at individual transects was significantly and positively correlated with both numbers of fish, and numbers of species. Coefficients of determination for regression models (dependent variable, biomass; independent variables, numbers and numbers of species) were usually low, however, ranging from 0.25 (Quinte) to 0.66 (Penetang).

The contribution of individual species of fish to total variability in biomass among transects within the study bays was examined using a more detailed multiple regression analysis. For each area, Biomass (B) was related to number of species (Nsp) by:

$$B_i = \text{constant} + N_i + Nsp_{x,i} + \ldots + Nsp_{n,i} + \varepsilon$$

where B_i = total biomass (kg) of transect i
N_i = total numbers of fish at transect i
Nsp_i = numbers of species x
n = total number of fish species
ε = error term

A forward stepwise regression procedure was used; the 'alpha-to-enter' value was set at 0.01.

Highly significant regression models were found for all five study areas; coefficients of determination ranged between 0.75 and 0.95 (Table 8). For all areas except Penetang Bay, 3 or 4 species explained most of the variability in biomass among transects. Eight species entered the model at Penetang. Carp contributed to variability among transects in biomass at all sites (Table 9). Other species that contributed to variability varied from one bay to another. In most cases, however, species that remained in the model represented fish of large sizes.

Each species of fish was assigned to three different classification codes based on status (native or exotic), trophic group, and residence (littoral or pelagic/offshore) (Table 10). Biomass was estimated for each group separately by transect. The contribution to total biomass of pelagic/offshore species, when averaged over transects, was highest in Hamilton Harbour (35%) and Bay of Quinte (12.9%) (Fig. 12). Contributions by offshore species were less in Severn Sound, averaging 1.8%, 0.6% and 4.5% in Penetang, Hog and Matchedash bays, respectively.

The distribution of fish biomass among the trophic groups also differed among the bays. The biomass of piscivores was proportionally less in Hamilton Harbour (mean 9.3% of total biomass) and Penetang Bay (17.7%) than in other areas, where the mean percent piscivores exceeded 20% (Fig. 12). In contrast, the biomass of generalists was highest in Hamilton (45.6%) and least in Hog and Penetang Bays (13.3% and 15.6%, respectively). Specialist comprised between 45.1% and 66.6% of total biomass.

The proportion of total fish biomass which was comprised of exotic species of fish was highest in Hamilton (62.5%), intermediate in Bay of Quinte (22.8%) and lowest in Severn Sound (9% -11.9%) (Fig. 12).

4.2.3 Effect of Eutrophication and Habitat Degradation on Biomass, Production and Trophic Structure in the Five Bays

Fish biomass both among and within the study bays, was positively correlated to phosphorus concentrations (Fig. 13). The regression equation relating mean biomass (B) to total phosphorus (TP) was: $B = -0.46 + 0.20\ TP$ ($F = 30.0$; $R^2 = 0.81$; $n = 9$).

Fish production was estimated from information on biomass and average fish size. Average biomass of fish, expressed in terms of kg per hectare of habitat, ranged between 120 (Matchedash) and 302 (Hamilton) in the five study areas.

Trends in fish production among the five study bays followed much the same trends as biomass. Production rate was highest in Hamilton Harbour (mean of 179 kg $ha^{-1}yr^{-1}$) and least in Matchedash Bay (92 kg $ha^{-1}yr^{-1}$). Fish production was significantly correlated with average seasonal phosphorus concentrations ($P<0.05$; Fig. 14). Average P/B rations (specific production) ranged between 0.66 (Penetang) to 0.78 (Matchedash).

Relationships between habitat degradation and the characteristics of the fish communities inhabiting the littoral areas are summarized in Fig. 15. Percent piscivore biomass was lowest, and percent exotic fish biomass was highest in the areas where habitat stress was highest. Coefficients of variation of both species richness and biomass were highest is the most degraded areas, indicating that biomass and trophic structure varied considerably from one localized area to another. Species richness, on average, was least in Hamilton Harbour, and was maximum in Matchedash Bay.

5.0 DISCUSSION

Fish biomass was positively correlated with total phosphorus concentrations among and within the five inshore areas surveyed in this study. Biomass of fish was highest in Hamilton Harbour and least in Matchedash Bay, the two areas with the highest and lowest phosphorus levels, respectively. Eutrophication may be the dominant macro-habitat factor affecting community fish production at these sites, but this needs to be confirmed. Other co-factors, not yet considered (eg. fetch, aquatic vegetation) may have affected biomass as well. Habitat degradation, defined generally as the cumulative impact of human population, which included water quality, contaminants and nearshore habitat alteration from industrial and residential activities, may have had an influence on the fish communities by reducing species diversity and by altering the species composition and trophic structure. The results of this study were consistent with our original hypothesis: although fish biomass was positively correlated with eutrophication, the structure of the fish communities were negatively altered in the most degraded habitats.

Preliminary estimates showed that the community fish biomass was high in the littoral habitats. Few estimates have been made of fish production in littoral habitats of the Great Lakes. In a Lake Erie lagoon, Mahon and Balon (1977) estimated biomass and production of fish to be 277.8 and 87.5 kg $ha^{-1}yr^{-1}$, respectively, which was within the range of biomass and production levels recorded in our study areas. In an inland lake in Quebec, Hanson and Leggett (1985) estimated community biomass levels to be about 126 kg ha^{-1}; *Perca flavescens* and *Lepomis gibbosus* made up 61% of the biomass in that lake, and thus the community structure was similar to the bays in Severn Sound. Recently, Downing et al. (1990) summarized fish community production for 20 different lakes from a wide range of geographic locations. Fish production ranged between 1.2 and 398.0 kg $ha^{-1}yr^{-1}$ among the different lakes, and was directly correlated to total phosphorus (TP) concentrations (Fig. 14). The slope of the Downing et al. (1990) regression line for TP versus fish production was not significantly different from our data for littoral habitats. However, the intercepts were significantly different, and indicated that fish production in the littoral habitats was significantly higher per unit area of habitat than whole lake production for any given concentration of TP. The difference in intercepts reflected the differences in productivity of littoral versus whole lake habitats.

We emphasize that our estimates of fish production were approximations only. Catch efficiencies were assumed to be constant for all species and locations. However, several physical and biological factors can affect efficiency while electrofishing, including water temperature, conductivity, fish density and species specific behaviour and morphology (Zalewski and Cowx 1990). Also, fish size is important. Densities of juvenile fish, which because of their fast growth rate can contribute greatly to production (Chapman 1978), are underestimated when censused with electrofishing gear. Our estimates of community fish production in the littoral habitats were first-order approximations only, which must be updated when more data become available.

Despite the relatively high levels of community fish biomass, habitat degradation may have affected the structure of the fish communities. After the study bays were ranked from low to high in terms of habitat degradation, several trends were suggested. Species richness was least in Hamilton Harbour and highest in Matchedash Bay. The percentage of total fish biomass that was composed of piscivorous fish and native species was highest in the least degraded habitats and lowest in the most degraded habitats. The variability in species richness and biomass among transects was highest in Hamilton and Quinte, and least in Hog and Matchedash Bays. Finally, P/B ratios, an indication of turnover rates of the populations, tended to be least in the most stressed environments. All of these trends need to be confirmed, but the preliminary evidence from the field suggests that the fish populations were being impacted by human influences on the aquatic habitat. Several of the above observations are consistent with symptoms of a 'distress syndrome' as described for degraded aquatic ecosystems by Rapport (1992).

Estimates of community fish biomass from the inshore areas provided both an index of both habitat productivity and relative health. Biomass of the different species (eg. carp) or trophic groups (piscivores) in Hamilton Harbour were indictors of habitat degradation, but the combined biomass of all species of fish indicated that the productivity of the habitat was high. Initially, it may seem paradoxical that fish biomass was highest in Hamilton, the area where human impact and habitat degradation was highest. Despite habitat degradation, the near shore habitat in Hamilton Harbour is still productive. Unfortunately, much of the biotic energy is being utilized by non-desirable exotic species such as carp, while production by valuable top predators is less than in the healthier habitats like Matchedash and Hog bays. Variability in biomass from one localized area to another within Hamilton Harbour indicates that the availability of suitable habitat is patchy. Low species diversity indicates an unstable community where biomass is distributed over a small number of usually undesirable species. Detailed plans have been developed to improve water quality and fish habitat in Hamilton Harbour (Hamilton Harbour RAP Writing Team 1992). One objective of the restoration program will be to direct more of the productivity into desirable species of fish, particularly piscivores. Historically, predators like northern pike and bass were present in large numbers in the Harbour, and they contributed to recreational and commercial fisheries (Holmes and Whillans 1984).

This preliminary analysis has shown that the biomass and structure of the inshore fish communities differed among the five study bays. Spatial variability in fish biomass among transects was also high within all study areas. Much of this variability was probably related to micro-habitat features yet to be examined. The number of transects surveyed in the diverse habitats should provide an adequate data set for detecting fish-habitat links. The next challenge will be to identify the relative importance of various micro-habitat features which control the localized distribution and biomass of fish within the individual study areas. Work to date has given us an appreciation of the valuable data set with which we have to work.

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Table 1. Summary of water quality problems identified in the three Great Lakes Areas of Concern where data was collected for this study. (from Hartig and Thomas 1988.)

Area of concern	Toxic substances in water	Sediment contaminants	Health advisories	Fish tumours	Biota	Elevated bacteria levels	Elevated phosphorus levels
Hamilton	Contaminants found: copper (up to 40 µg/l), nickel (up to 38 µg/l), zinc (up to 129 µg/l), cadmium (up to 1.7µg/l), lead (up to 30 µg/l), iron (up to 2100 µg/l), PCB's (up to 30 ng/l), and organochlor-ine pesticides.	Sediment contaminants in excess of Ontario OWDDG include: arsenic, chromium, copper, iron lead, mercury nickel, PCB's and zinc	Restricted consumption of white perch > 30 cm, brown bullheads >35 cm, and carp >75cm	52% of carp-goldfish hybrids had gonadal tumours in 1976. 39% of white suckers exhibited lip papillomas during 1981-84.	Cootes Paradise marsh has declined to a small fraction of its original size. The fishery and benthos are negatively impacted by poor water quality.	Faecal coliform bacteria levels periodically exceed the provincial objectives for swimming and bathing (100 counts /100 ml).	The provincial water quality objective for total phosphorus (20 µg/l) is frequently exceeded.
Quinte	No problems identified.	Sediments are contaminated with heavy metals and organic contaminants	Restricted consumption of walleye >45cm, northern pike >65cm, largemouth bass >35 cm, american eel >65cm, channel catfish > 45cm, and smallmouth bass >35 cm. No consumption of walleye >65cm and channel catfish >55cm	White suckers collected from 1981-1983 exhibited lip neoplasms in 5% and body neoplasms in 2.7% of specimens collected.	The bay is characterized by high algal densities and a lack of recovery of rooted plants. Some of the components of the fish community continue to fluctuate erratically.	Localized areas of bacterial contamination are found in the vicinity of Belleville, Trenton, Desoronto, and Picton.	Phosphorous concentrations declined substantially by 1978, but have recently increased. Mean phosphorous concentration in the bay during 1984-1985 was 52.5 µg/l.
Severn Sound	Meets use criteria.	Meets use criteria.	Restricted consumption of walleye >55cm, rainbow trout >65 cm, white suckers >35 cm, and smallmouth bass > 35cm.	No data.	Average phytoplankton biomass in Severn Sound remains 10-20 time higher than in adjacent Nottawasaga Bay.	Meets use criteria.	Phosphorous levels are still high enough to produce nuisance algal growths in southern Penetang Bay

Table 2. Physical and limnological characteristics at the study areas (Hamilton Harbour and Bay of Quinte, Lake Ontario, Penetang, Hogs and Matchedash bays, Georgian Bay).

Attribute	Hamilton Harbour	Bay of Quinte	Penetang Bay	Hog Bay	Matchedash Bay
Area of watershed (ha X 10^3)	49.4	1,771			
Area of water surface (ha)	2,150	13,640	570	650	580
River discharge ($m^3 sec^{-1}$)	3.62	157.0	0.12	0.45	2.29
Mean depth (m)	13.0	4.2	4.7		
Secchi depth (m)	1.26	1.00	1.77		
Total phosphorus ($\mu g\ l^{-1}$)[1]	49	45.0 (Trenton) 38.4 (Belleville) 37.3 (Napanee)	37.8 (South Basin) 22.7 (Tannery Pt.) 15.6 (Magazine Is.)	16.0	about 16 (assumed)
Conductivity ($\mu S\ cm^{-1}$	543	248	205		
Flushing rate	4.1	12	slow		
Human population (within watershed)	540,000	60,000	4,950	1,400	761
Waste volume ($m^3 sec^{-1}$)	4.530	0.570	0.040	0.010	0.005

[1] Data sources for phosphorus concentrations: 1. Hamilton - 1986 to 1990 mean; J. Vogt, Ministry of the Environment, Hamilton
2. Trenton - 1991; K. Nichols, Ministry of the Environment, Rexdale
3. Belleville - 1986 to 1990; K. Nichols, Ministry of the Environment, Rexdale
4. Napanee - 1989 to 1991; K. Nichols, Ministry of the Environment, Rexdale
5. Penetang and Hog Bays - 1986 to 1990; A. Gemza, Ministry of the Environment, Rexdale
6. Matchedash - assumed

Table 3. Summary of the numbers of transects surveyed by date in Hamilton Harbour, Bay of Quinte and Severn Sound (Penetang, Hogs and Matchedash Bay), during 1988, 1989 and 1990

Location	Year	Month	Week	Days	Number of transects	Number with 0 fish
Hamilton	1988	May/June	22	30 - 3	20	0
		June	23	5 - 9	31	0
		June	24	12 - 16	23	0
		June	25	20 - 21	6	0
		June	26	26 - 30	40	0
		July	27	4 - 7	40	0
		July	29	17 - 20	40	1
		July	30	24 - 28	39 (7)[1]	0
		Aug	32	7 - 11	34	0
		Aug	33	15 - 18	38	0
		Aug	34	22	8	3
Hamilton	1990	May		23 - 25	25	0
		June		27 - 28	20	0
		July/Aug		30 - 3	40	2
Quinte	1989	August		2 - 10	32 (2)	0
Quinte	1990	June		21 - 25	19	2
		July		23 - 25	20	1
		August		20 - 22	20	0
Penetang	1990	June		5 - 7	26	2
		July		9 - 11	29	0
		August		7 - 9	29	1
Hogs	1990	July		16 - 17	14	1
		August		15	14	0
Matchedash	1990	June		12 - 13	12 (2)	0
		July		18 - 19	12	0
		August		14	12	0

[1]number of replicate samples given in parenthesis

Table 4. Summary statistics for biomass, number, and number of species of fish captured at 326 transects in Hamilton Harbour, 1988. Sample sizes were calculated for specified levels of precision (relative standard errors, RSE) using formula provided by Elliott (1977).

	Biomass (kg per transect)	Numbers	Species richness
Mean	12.9	81.0	4.9
Variance	178.60	5209.5	5.0
Coefficient of variation (%)	104	89	0.45
Sample size for RSE of 0.10	103	74	18
Sample size for RSE of 0.20	26	18	5

Table 5. Comparison between years of the mean numbers of fish, biomass, and numbers of species per transect in Hamilton Harbour (1988 and 1990) and Bay of Quinte (1989 and 1990). Significant differences between years are indicated with asterisks (*t-test*).

Area	Year	N	Numbers of fish		Biomass of fish (kg)		Numbers of species	
			Mean	SE	Mean	SE	Mean	SE
Hamilton	1988	86	72.70	6.86	12.43	1.48	4.86	0.22
	1990	85	*52.31	5.41	*8.46	1.25	*3.93	0.25
Quinte	1989	20	64.85	9.08	9.08	1.60	8.40	0.57
	1990	20	*129.25	31.56	7.28	1.49	8.65	0.82

Table 6. Coefficients of variation (%) for biomass and species richness within each study area surveyed in 1990. Numbers of transects included are indicated.

Area	n	Biomass	Species richness
Hamilton	60	140	60
Quinte	59	87	52
Penetang	84	96	55
Hog	28	86	44
Matchedash	36	71	27

Table 7. Species of fish captured by electrofishing in littoral areas of Hamilton Harbour, Bay of Quinte, and Severn Sound (Penetang Bay, Hog Bay, and Matchedash Bay). The number of transects and samples (in parenthesis) collected in each survey area are given.

Species code	Common name	Latin name	Survey Area				
			Hamilton	Quinte	Penetang	Hog	Matchedash
			45(411)	32(93)	29(84)	14(28)	12(38)
41	Longnose gar	*Lepisosteus osseus*	X	X	X		
51	Bowfin	*Amia calva*	X	X		X	X
61	Alewife	*Alosa pseudoharengus*	X	X	X	X	X
63	Gizzard shad	*Dorosoma cepedianum*	X	X			X
75	Chinook salmon	*Oncorhynchus tshawytscha*	X				X
76	Rainbow trout	*Oncorhynchus mykiss*	X				
78	Brown trout	*Salmo trutta*	X				
81	Lake trout	*Salvelinus namaycush*	X				
121	Rainbow smelt	*Osmerus mordax*	X		X		
131	Northern pike	*Esox lucius*	X	X	X	X	X
141	Central mudminnow	*Umbra limi*		X			
161	Quillback	*Carpiodes cyprinus*			X		X
163	White sucker	*Catostomus commersoni*	X	X	X	X	X
168	Silver redhorse	*Moxostoma anisurum*		X	X		
171	Shorthead redhorse	*Moxostoma macrolepidotum*		X	X		
181	Goldfish	*Carassius auratus*	X		X		X
186	Carp	*Cyprinus carpio*	X	X	X	X	X
194	Golden shiner	*Notemigonus crysoleucas*		X	X	X	X
196	Emerald shiner	*Notropis atherinoides*	X	X	X		
198	Common shiner	*Notropis cornutus*		X			
199	Blackchin shiner	*Notropis heterodon*			X	X	
200	Blacknose shiner	*Notropis heterolepis*					X
201	Spottail shiner	*Notropis hudsonius*	X	X	X		X
208	Bluntnose minnow	*Pimephales notatus*			X	X	X
233	Bullhead	*Ictalurus nebulosus*	X	X	X	X	X
234	Channel catfish	*Ictalurus punctatus*					
251	American eel	*Anguilla rostrata*	X	X			
261	Banded killifish	*Fundulus diaphanus*			X		
291	Trout-perch	*Percopsis omiscomaycus*	X		X		
301	White perch	*Morone americana*	X	X			
302	White bass	*Morone chrysops*	X	X	X		X
311	Rock bass	*Ambloplites rupestris*	X	X	X	X	X
313	Pumpkinseed	*Lepomis gibbosus*	X	X	X	X	X
314	Bluegill	*Lepomis macrochirus*	X	X			
316	Smallmouth bass	*Micropterus dolomieui*	X	X	X	X	X
317	Largemouth bass	*Micropterus salmoides*	X	X	X	X	X
319	Black crappie	*Pomoxis nigromaculatus*	X	X	X	X	X
331	Yellow perch	*Perca flavescens*	X	X	X	X	X
334	Walleye	*Stizostedion vitreum*		X	X	X	X
341	Johnny darter	*Etheostoma nigrum*	X	X			
342	Logperch	*Percina caprodes*		X			X
361	Brook silverside	*Labidesthes sicculus*		X	X	X	
371	Freshwater drum	*Aplodinotus grunniens*	X	X			
	Total species		29	30	27	17	23

Table 8. Summary statistics for multiple linear regressions to predict fish biomass from total fish numbers and numbers by species.

Area	Sample size	DF	F statistic	R^2	Predictors
Hamilton	60	55	135.9	0.90	Num, 3 sp.
Quinte	59	53	36.1	0.75	Num, 4 sp.
Penetang	84	74	192.5	0.95	Num, 8 sp.
Hog	28	23	81.1	0.92	Num, 3 sp.
Matchedash	36	31	27.0	0.75	4 sp.

Table 9. Summary of main fish species that contributed to variability in fish biomass among transects.

Species	Hamilton	Quinte	Penetang	Hog	Matchedash
Bowfin			X	X	X
Alewife			X		
Pike		X	X		
Quillback			X		
White sucker	X		X		
Redhorse			X		
Goldfish			X		X
Carp	X	X	X	X	X
Shiner (-)		X			
Bullhead	X				X
American eel		X			
Largemouth bass				X	

Table 10. Classification of species of fish captured in littoral areas of Hamilton Harbour, Severn Sound and Bay of Quinte during summer 1988, 1989 and 1990. Classification codes are: Status - native (N) or exotic (E); Trophic - piscivores (P), specialists (S), generalists (G); Residence - Littoral (L) or Pelagic (P). Definitions are provided in the text.

Species code	Common name	Latin name	Classification		
			Status	Trophic	Residence
41	Longnose gar	*Lepisosteus osseus*	N	P	L
51	Bowfin	*Amia calva*	N	P	L
61	Alewife	*Alosa pseudoharengus*	E	S	P
63	Gizzard shad	*Dorosoma cepedianum*	N	S	P
75	Chinook salmon	*Oncorhynchus tshawytscha*	E	P	P
76	Rainbow trout	*Oncorhynchus mykiss*	E	S	P
78	Brown trout	*Salmo trutta*	E	P	P
81	Lake trout	*Salvelinus namaycush*	N	P	P
121	Rainbow smelt	*Osmerus mordax*	E	S	P
131	Northern pike	*Esox lucius*	N	P	L
141	Central mudminnow	*Umbra limi*	N	G	L
161	Quillback	*Carpiodes cyprinus*	N	G	L
163	White sucker	*Catostomus commersoni*	N	S	L
168	Silver redhorse	*Moxostoma anisurum*	N	S	L
171	Shorthead redhorse	*Moxostoma macrolepidotum*	N	S	L
181	Goldfish	*Carassius auratus*	E	G	L
186	Carp[1]	*Cyprinus carpio*	E	G	L
194	Golden shiner	*Notemigonus crysoleucas*	N	G	L
196	Emerald shiner	*Notropis atherinoides*	N	S	L
198	Common shiner	*Notropis cornutus*	N	S	L
199	Blackchin shiner	*Notropis heterodon*	N	S	L
200	Blacknose shiner	*Notropis heterolepis*	N	S	L
201	Spottail shiner	*Notropis hudsonius*	N	S	L
208	Bluntnose minnow	*Pimephales notatus*	N	G	L
233	Bullhead	*Ictalurus nebulosus*	N	G	L
234	Channel catfish	*Ictalurus punctatus*	N	G	L
251	American eel	*Anguilla rostrata*	N	P	L
261	Banded killifish	*Fundulus diaphanus*	N	S	L
291	Trout-perch	*Percopsis omiscomaycus*	N	S	L
301	White perch	*Morone americana*	E	S	P
302	White bass	*Morone chrysops*	N	S	P
311	Rock bass	*Ambloplites rupestris*	N	S	L
313	Pumpkinseed	*Lepomis gibbosus*	N	S	L
314	Bluegill	*Lepomis macrochirus*	N	S	L
316	Smallmouth bass	*Micropterus dolomieui*	N	P	L
317	Largemouth bass	*Micropterus salmoides*	N	P	L
319	Black crappie	*Pomoxis nigromaculatus*	N	S	L
331	Yellow perch	*Perca flavescens*	N	S	L
334	Walleye	*Stizostedion vitreum*	N	P	P
341	Johnny darter	*Etheostoma nigrum*	N	S	P
342	Logperch	*Percina caprodes*	N	S	P
361	Brook silverside	*Labidesthes sicculus*	N	S	L
371	Freshwater drum	*Aplodinotus grunniens*	N	S	L

[1] carp-goldfish hybrids (rare) were included as carp

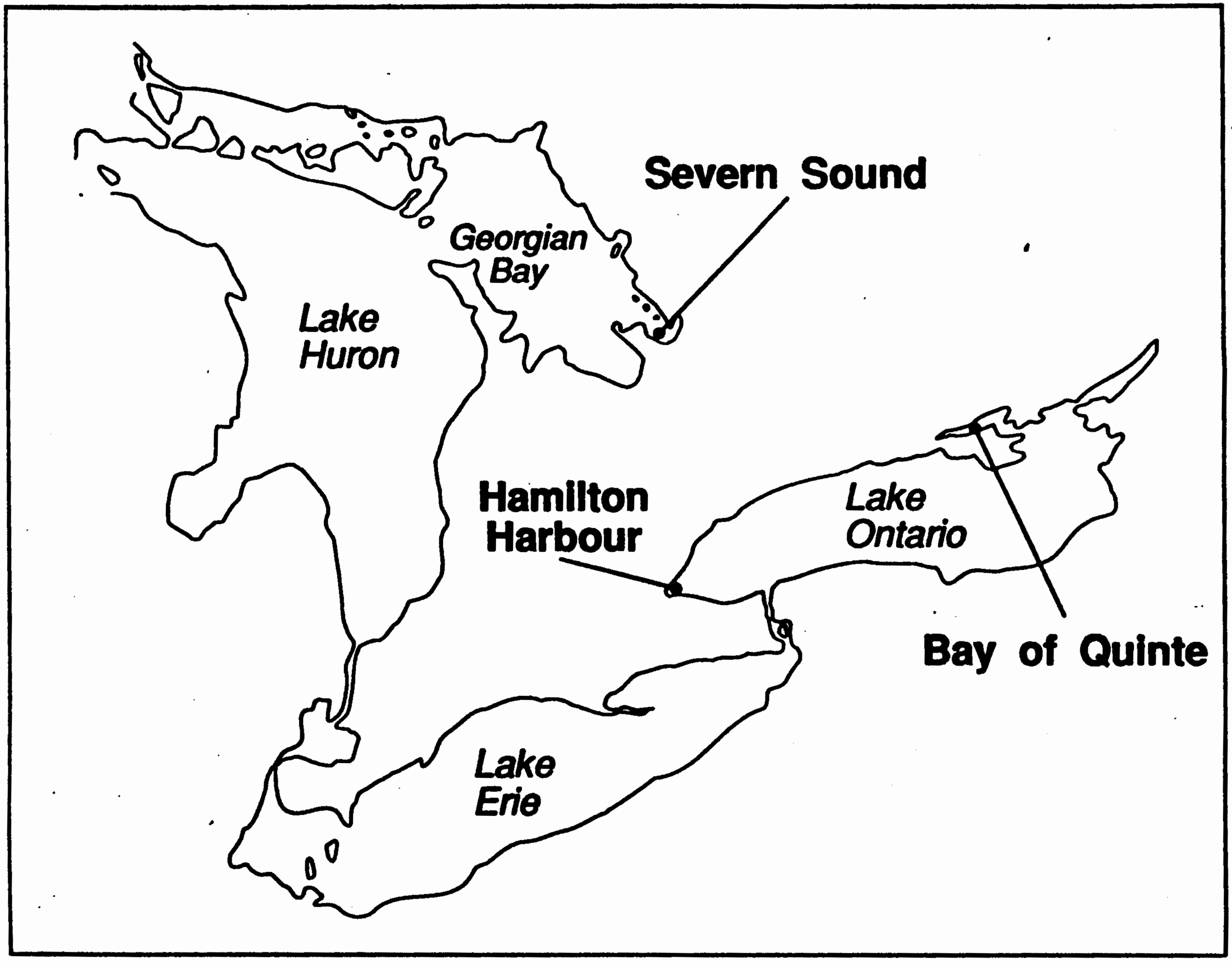

Figure 1. Map showing the location of three Great Lakes' Areas of Concern - Hamilton Harbour, Bay of Quinte and Severn Sound.

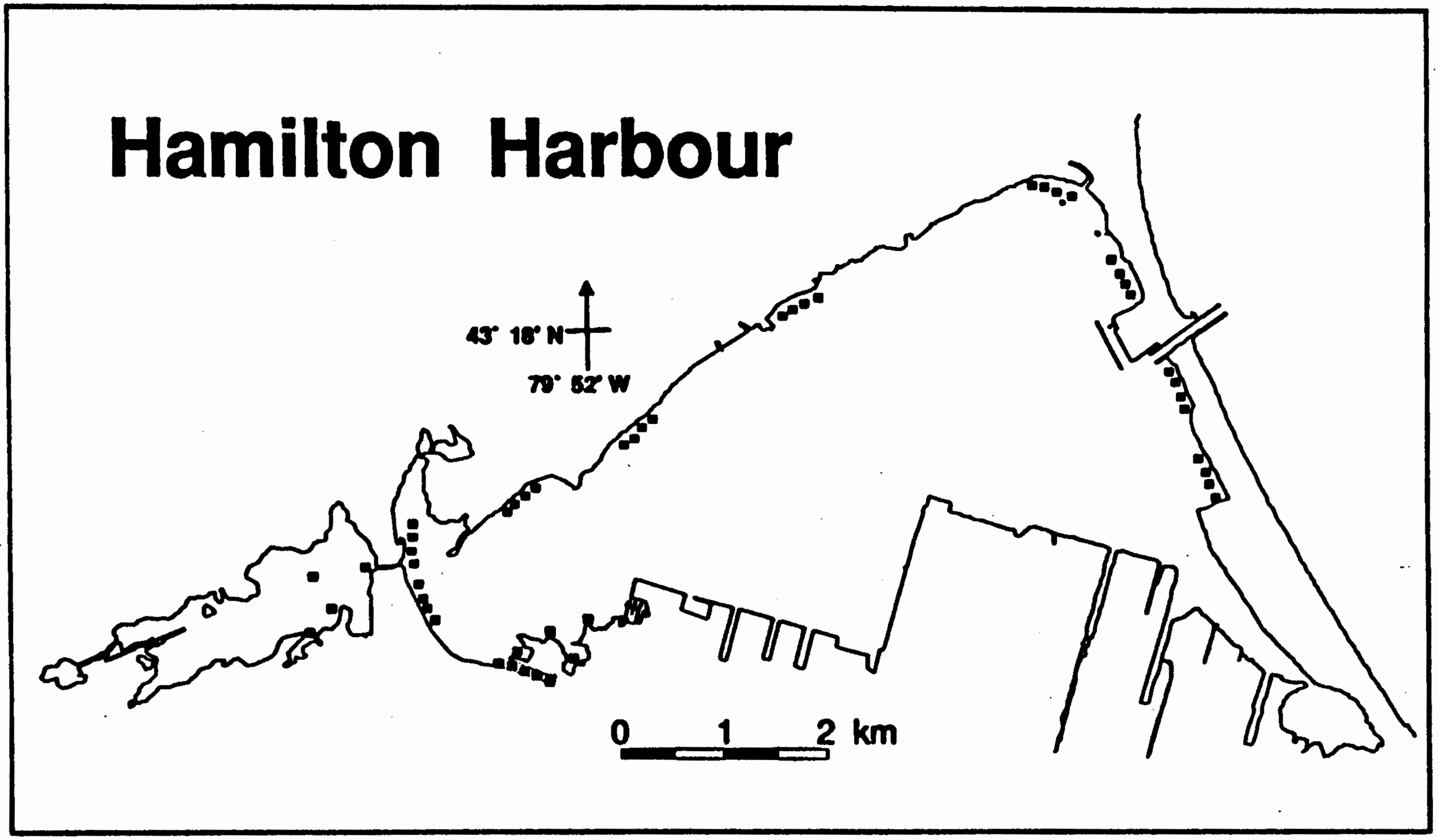

Figure 2. Map showing the location of forty-nine 100 m transects surveyed by electrofishing in Hamilton Harbour. Transect locations are shown with filled squares in the near shore areas.

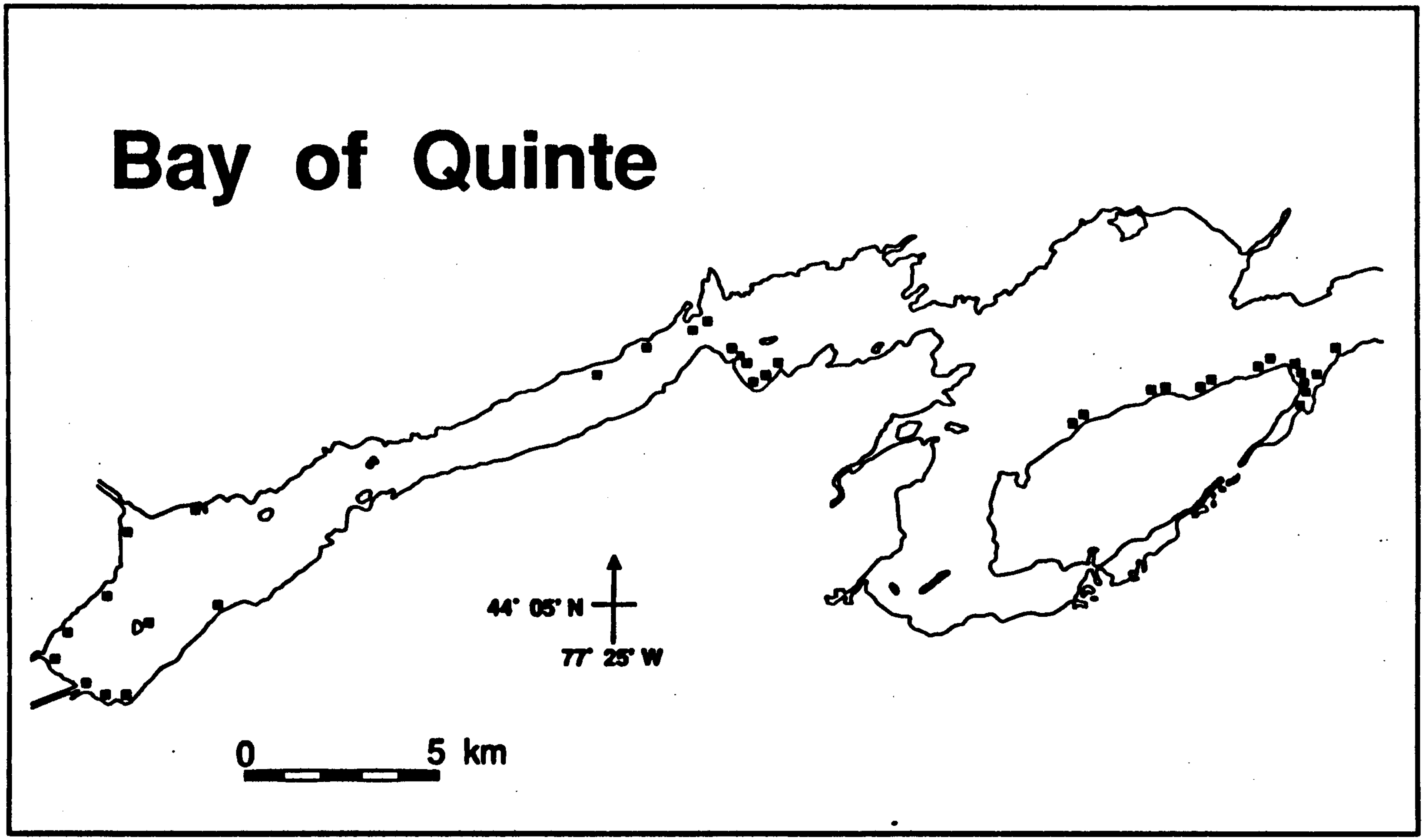

Figure 3. Map showing the location of thirty-three 100 m transects surveyed by electrofishing in upper Bay of Quinte.

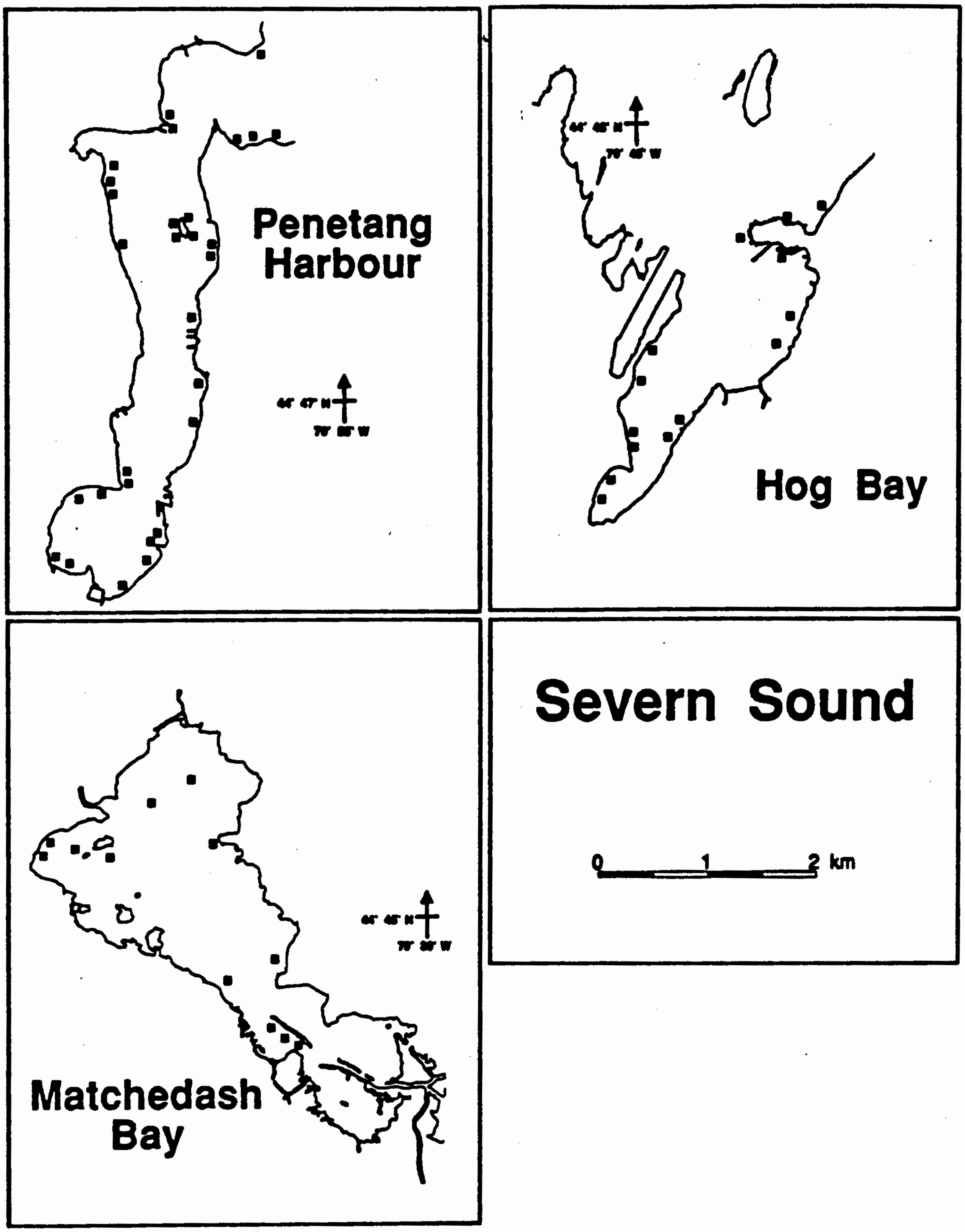

Figure 4 a) Map showing the location of twenty-nine 100 m transects surveyed by electrofishing in Penetang Bay. b) location of 14 transects in Hog Bay. c) location of 12 transects in Matchedash Bay.

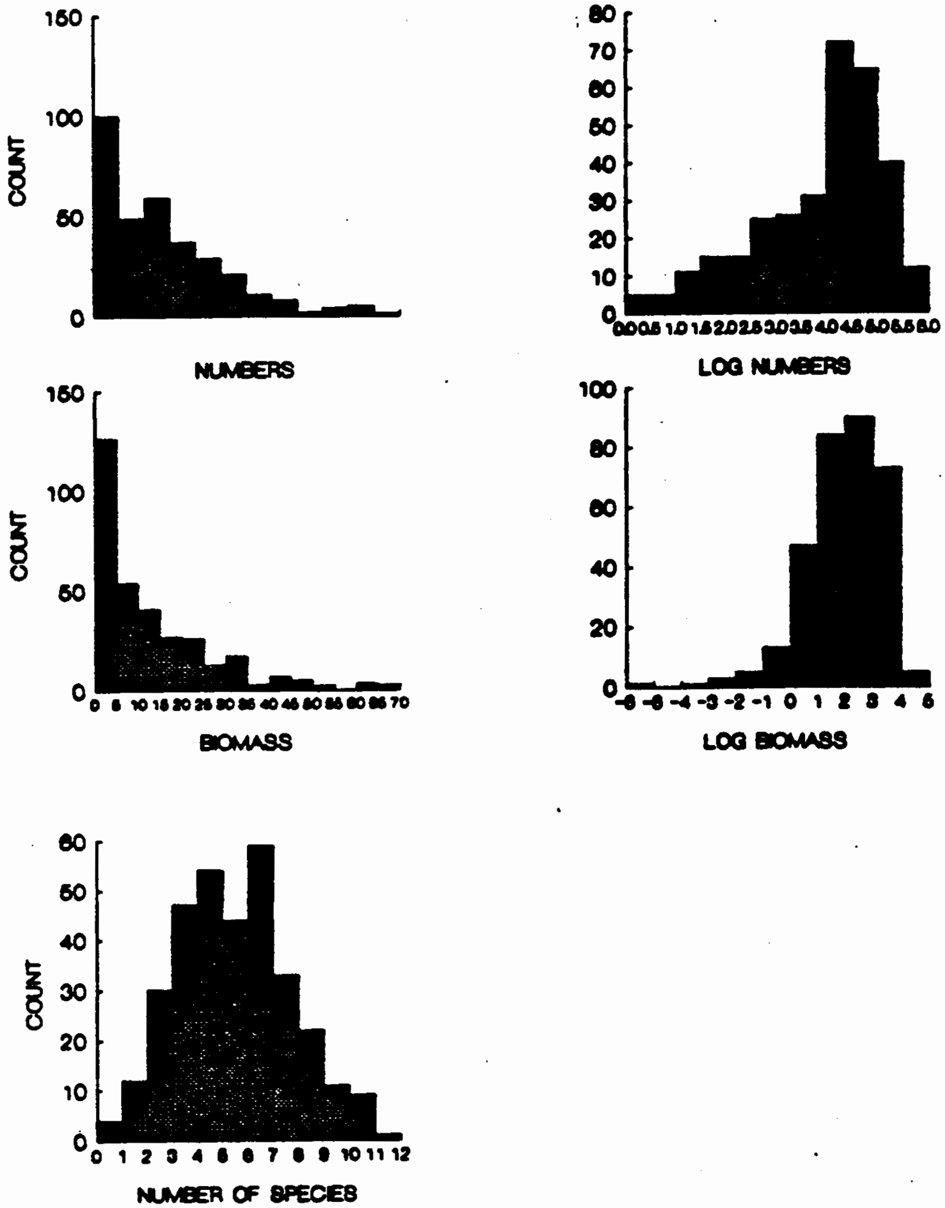

Figure 5. Frequency histograms of the numbers, biomass, and numbers of species per transect at 326 transects surveyed in Hamilton Harbour during 1988. The two figures at the right show the frequency histograms of numbers and biomass after the data were log transformed.

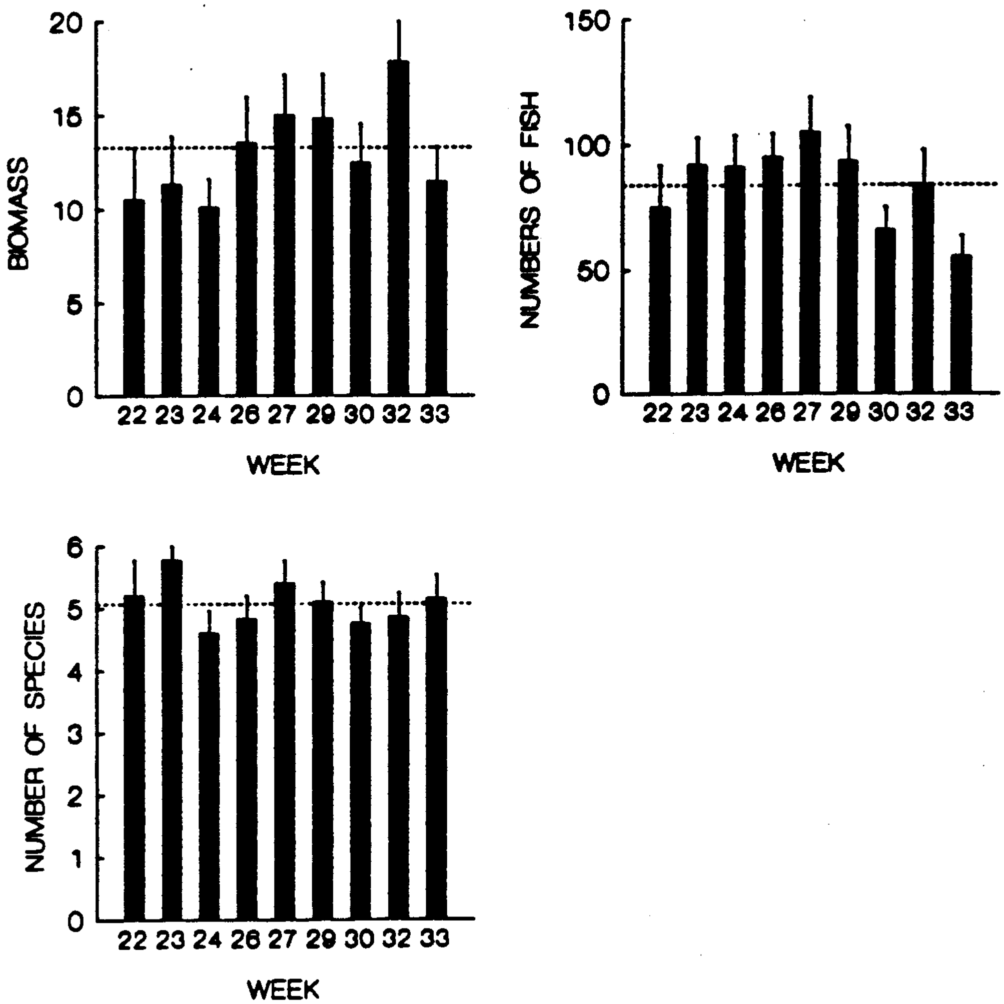

Figure 6. Mean biomass (kg transect^{-1}), numbers, and numbers of species of fish per transect in Hamilton Harbour for 10 separate weekly periods during 1988. Sample sizes and dates for each week are identified in Table 3. Horizontal dashed lines indicate overall seasonal averages.

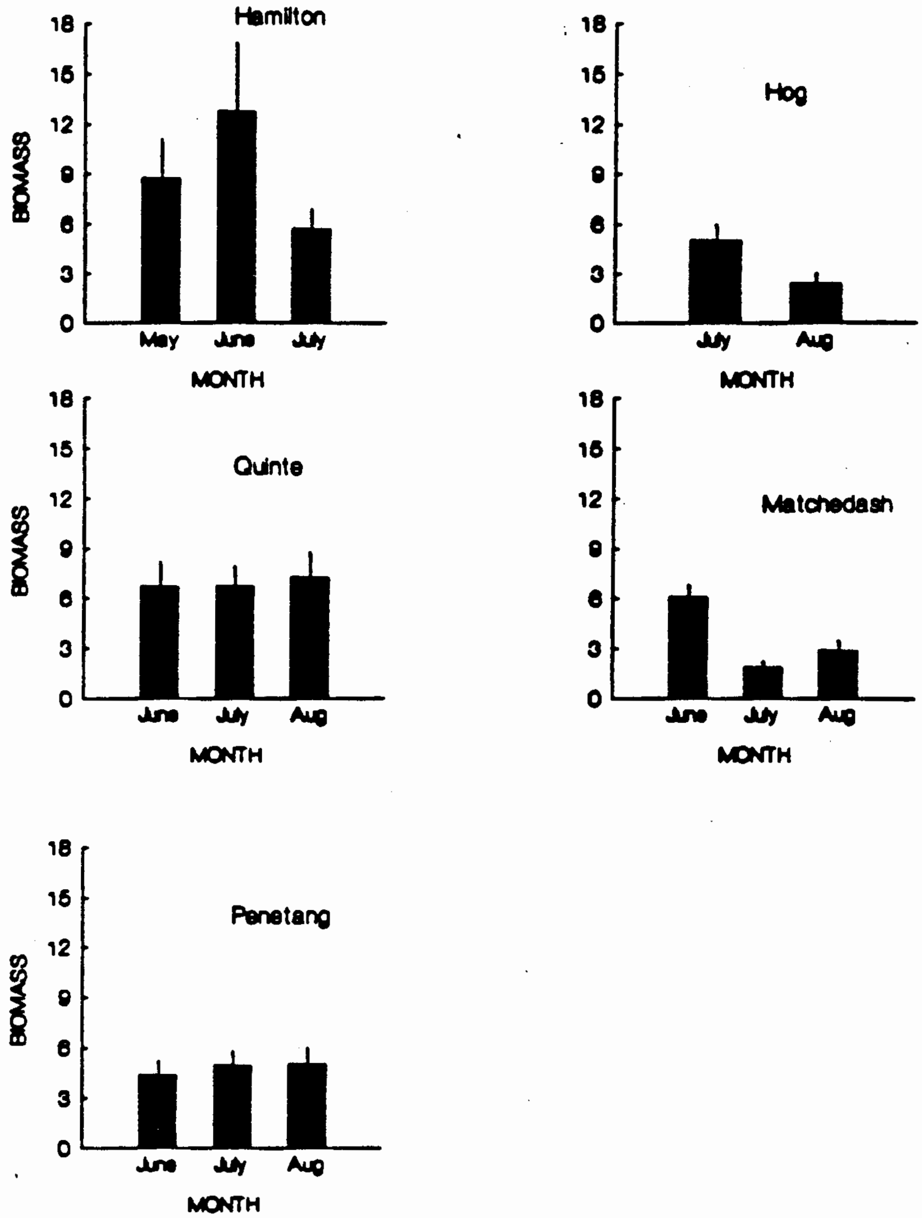

Figure 7. Mean biomass (kg transect^{-1}) of fish by month at the five study areas sampled in 1990. Vertical bars represent 1 SE. (ANOVA indicated significant differences among months for Hogs and Matchedash bays.)

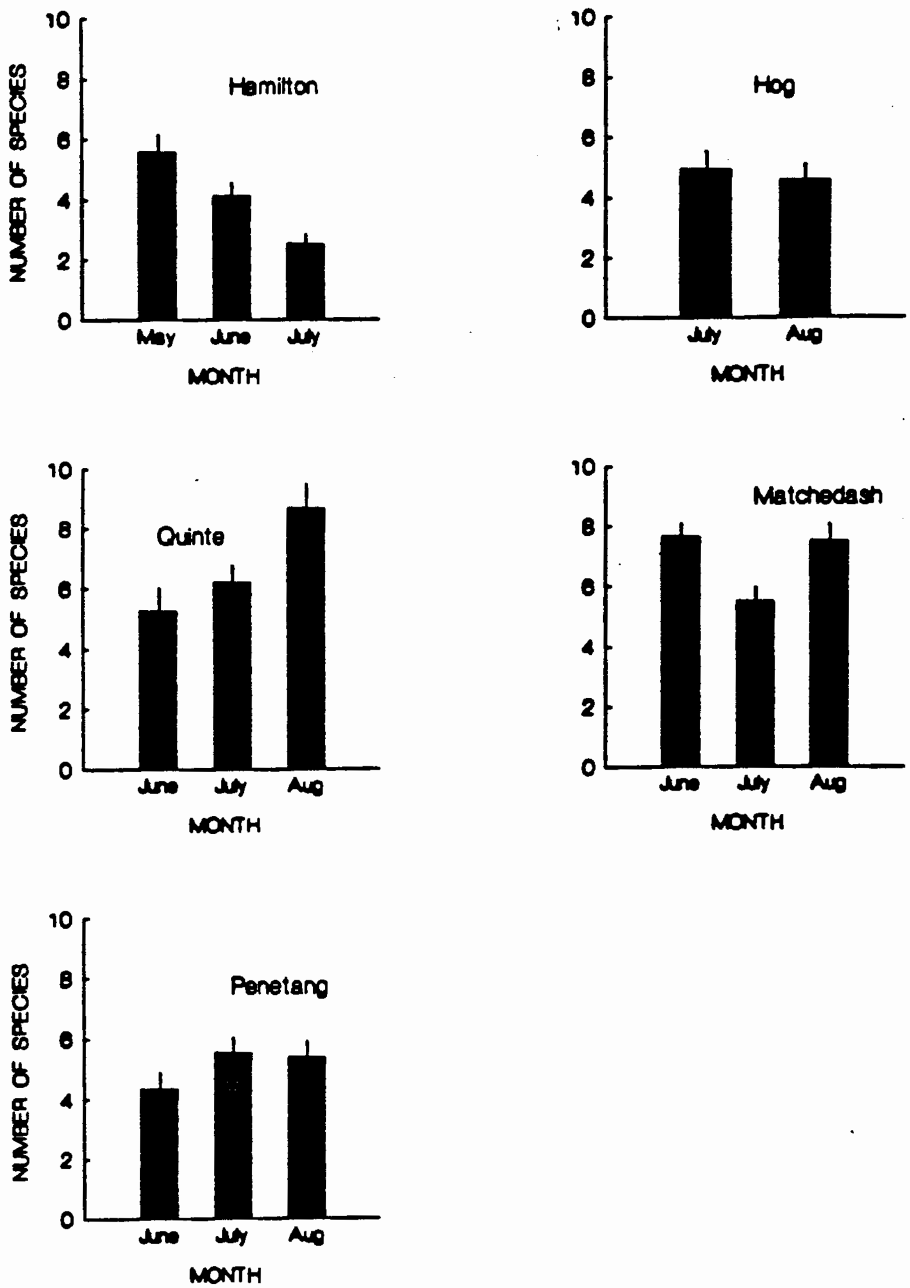

Figure 8. Mean number of species (no. transect^{-1}) of fish by month at the five study areas sampled in 1990. Vertical bars represent 1 SE. (ANOVA indicated significant differences among months for Hamilton, Quinte and Matchedash bays.)

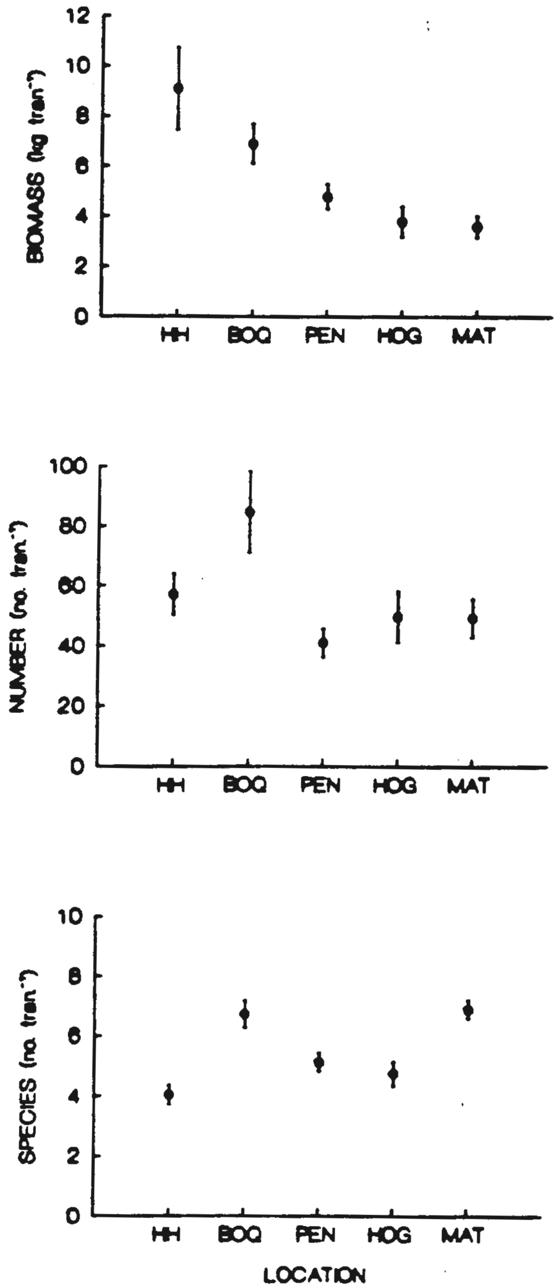

Figure 9. Comparison among study bays of the mean number of species (upper), mean numbers of fish (middle), and mean biomass (kg) per transect during 1990. Vertical bars represent 1 SE.

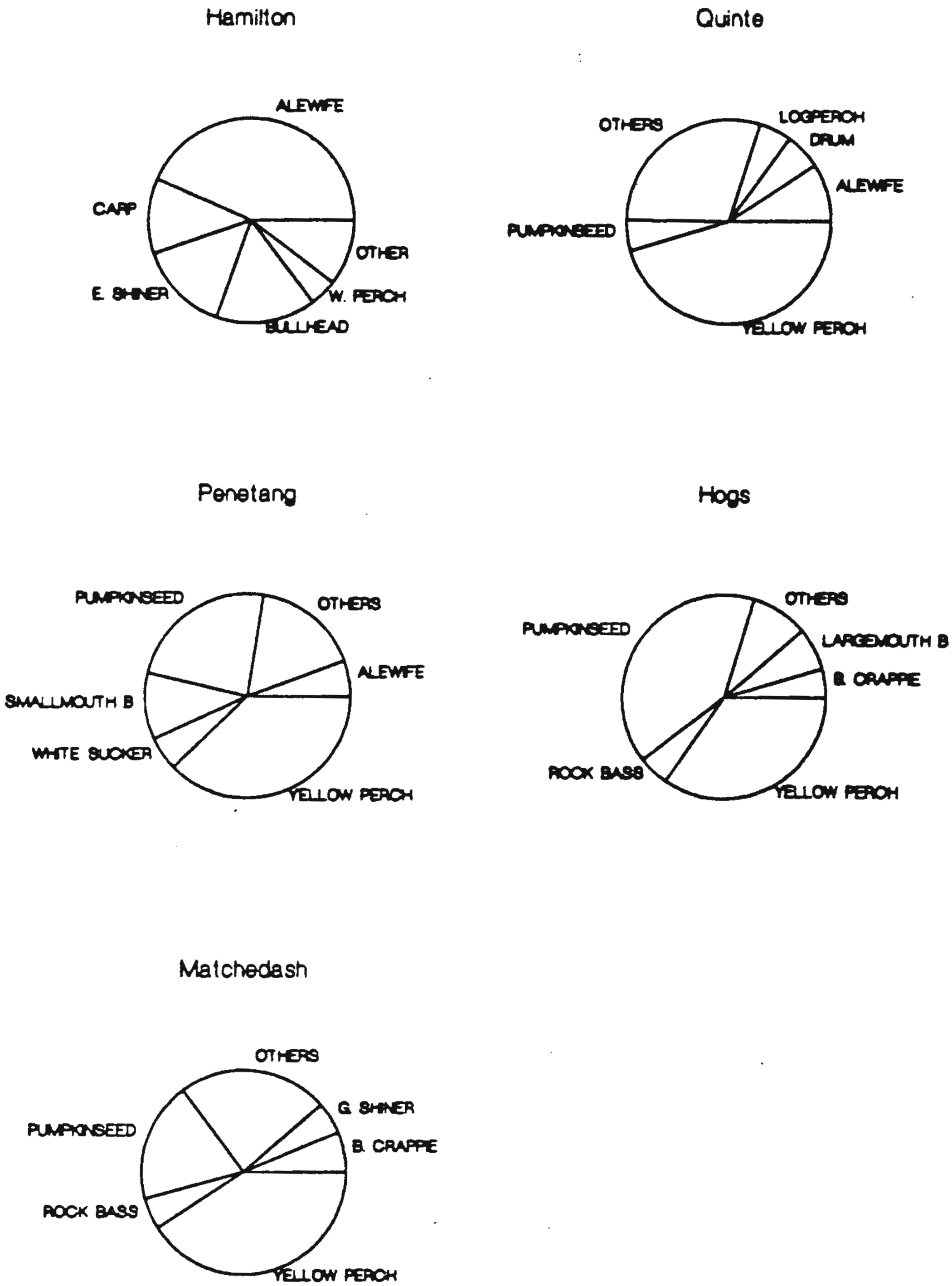

Figure 10. Pie diagrams to show the proportion by number of the 5 most abundant fish species in each study area during 1990.

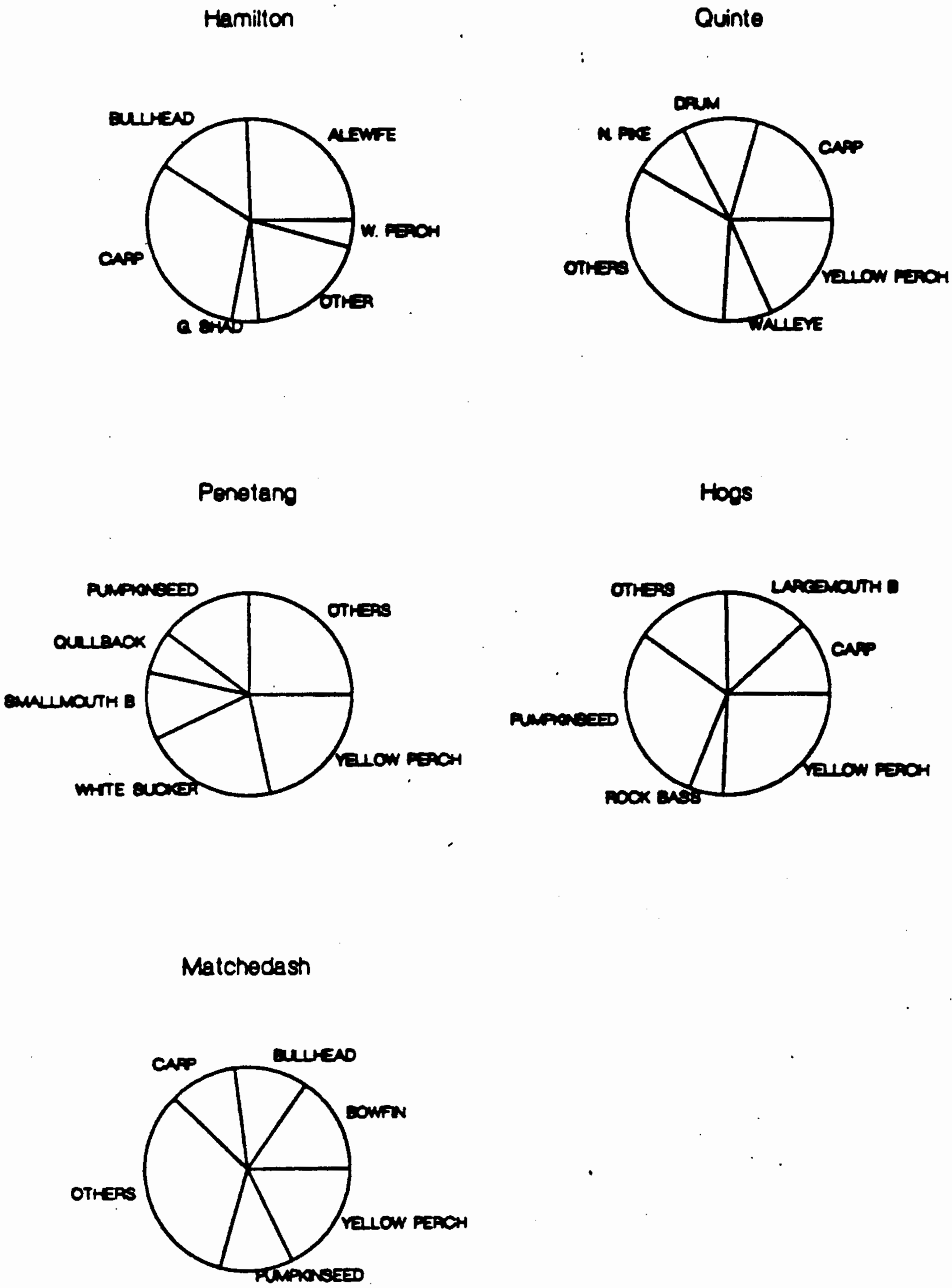

Figure 11. Pie diagrams to show the proportion by biomass of the 5 dominant fish species in each study area during 1990.

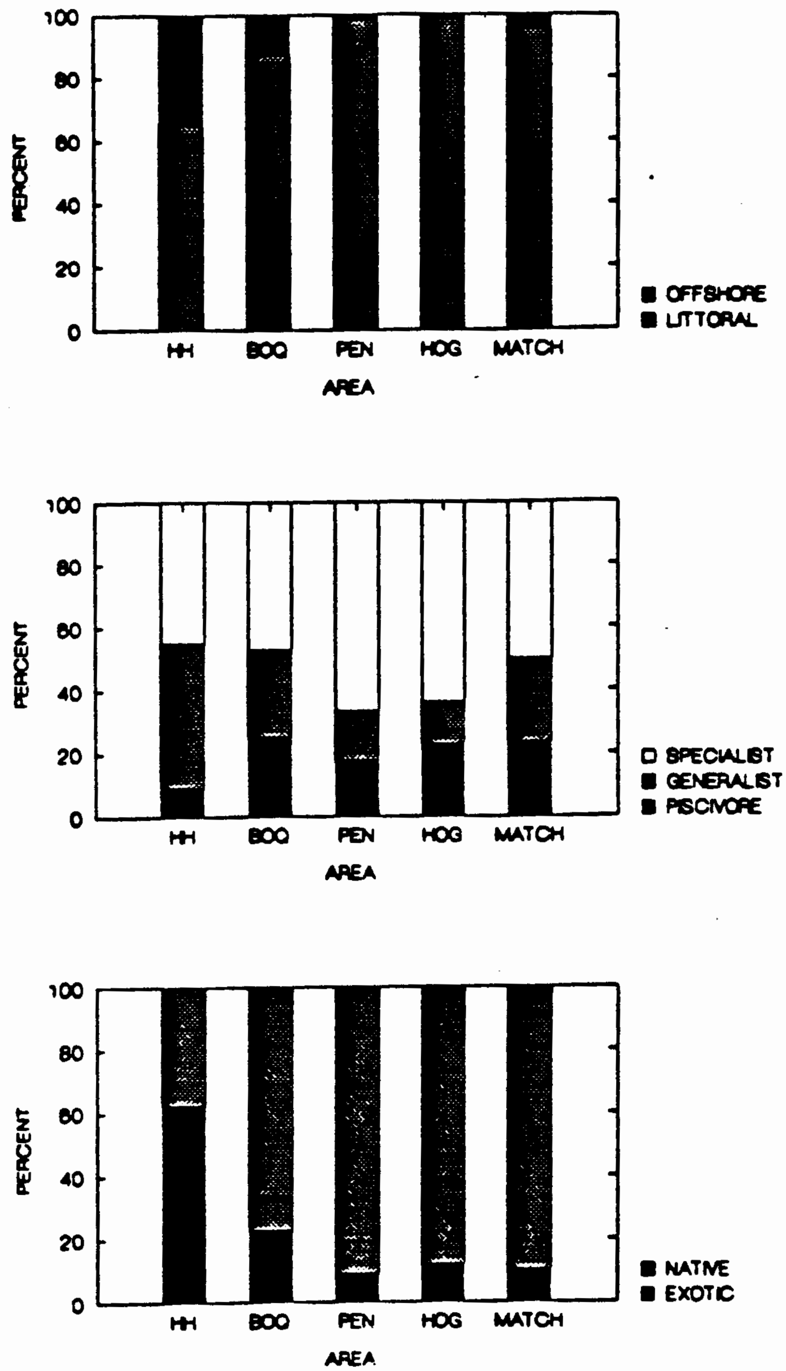

Figure 12. Histograms to show the proportion of total fish biomass which was: (upper) offshore versus littoral species, (middle) biomass by trophic groups, (lower) native versus exotic species of fish. Definitions for each category are given in the text.

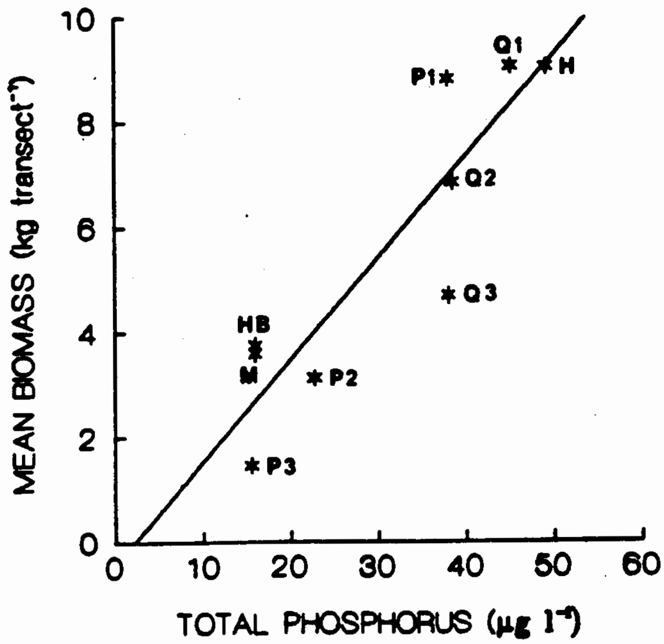

Figure 13. Correlation between phosphorus concentration and mean fish biomass among and within the five study areas. Survey areas included: Hamilton (H), Bay of Quinte (Q1 - Trenton, Q2 - Bellville and Q3 -Napanee), Penetang Bay (P1 - South Basin, P2 - mid bay, and P3 - outer bay), Hog Bay (HB) and Matchedash Bay (M). Regression equation was: Biomass = -0.42 + 0.20 (TP) (R^2 = 0.81; F = 30.0; P = 0.001).

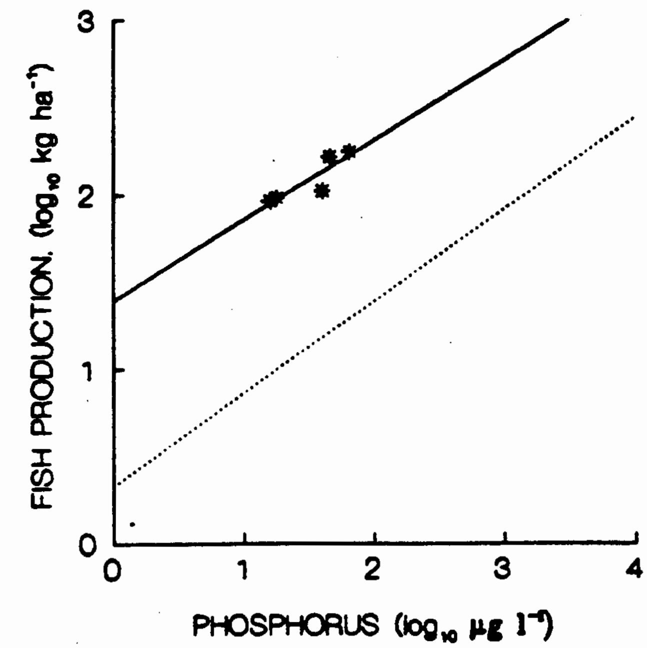

Figure 14. Correlation between mean fish production in the five study areas of the Great Lakes and phosphorus concentrations (solid line, asterisks). Fish production in the littoral habitats is compared to production in whole lakes (dashed regression line; data from Downing et al. 1990). Slopes of the two regression lines were not different, but intercepts were significantly different ($P < 0.05$).

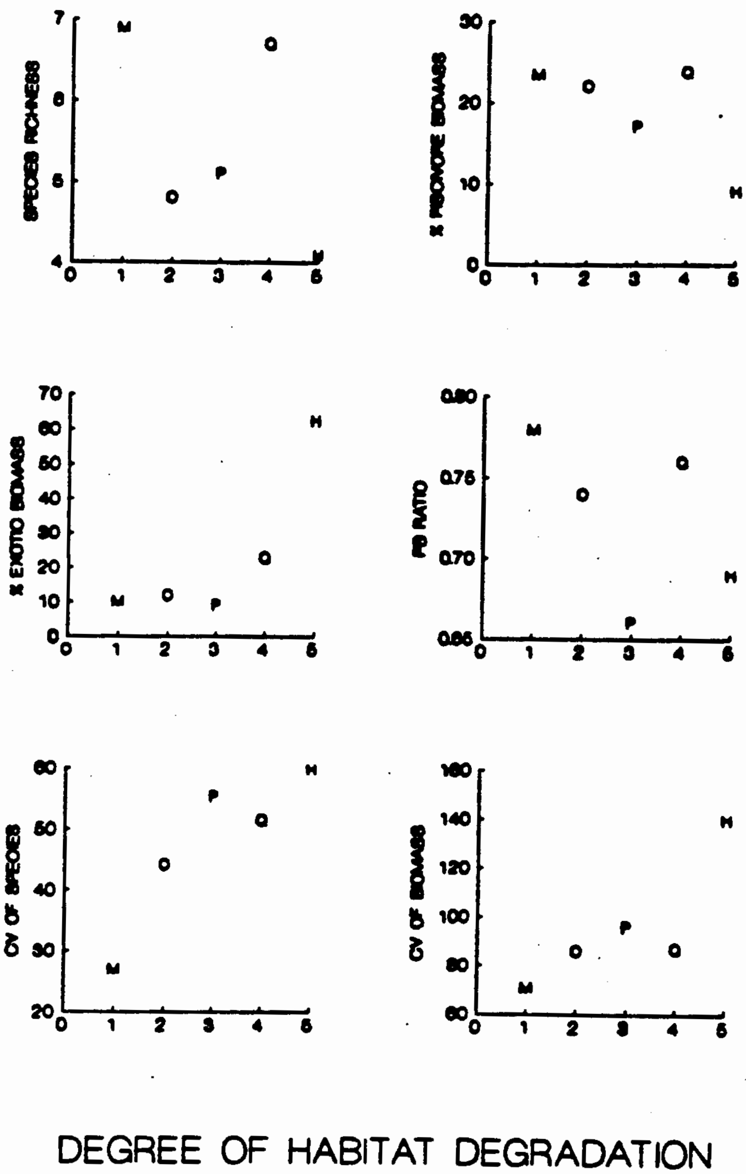

Figure 15. Summary of relationships between aspects of the fish data (vertical axes) and ranking of the study areas by degree of habitat degradation. Study areas are identified as: M - Matchedash Bay; O - Hog Bay; P - Penetang Bay; Q - Bay of Quinte; and H - Hamilton Harbour. Fish variables are species richness, % of biomass which was piscivores, % of biomass which was exotic species, P/B ratio (production to biomass), and coefficient of variation (CV) of species richness and biomass among transects.