Effect of fish species, life history, and fish size on catch probability during boat electrofishing in nearshore areas of the Great Lakes

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ABSTRACT

Randall, R.G., Minns, C.K, DeBruyn, E.R, Valere, B.G., and Boston, C.M. 2022. Effect of fish species, life history, and fish size on catch probability during boat electrofishing in nearshore areas of the Great Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 3552: vii + 28 p.

Catch probability for boat electrofishing was estimated using 500 m^2 enclosures in Hamilton Harbour. Results are described from nine experiments at locations with variable habitat and time of day. Species for marking (M) and recapture (R) were captured outside the enclosures and then released inside; these species included Alewife (pelagic), White Perch (midwater), and Brown Bullhead (benthic). Catch probability of marked fish, calculated as R/M, averaged 0.3 (range 0.11 to 0.52), and was species dependent. Capture probability of unmarked fish from depletion removals averaged 0.22 (range 0.15 to 0.29). Capture probability in the enclosures was usually high enough to show reduced catches during six successive removal passes. Removal estimates were proportional to the known number of released fish. Catch curves generated from other Lake Ontario embayments suggested catch rates during electrofishing were lower for small fishes (< age 2; < 60 g). Because catch probability depended on species, fish size, and water conditions, the assumption of a constant adjustment to estimate density (g m^{-2}) is approximate by applying a static measure to an inherently dynamic capture probability. Future electrofishing work could be conducted in other areas to confirm the effects of fish species, size and habitat on catch, and to test models to estimate catch probability based on the composition of individual catches.

RÉSUMÉ

Randall, R.G., Minns, C.K, DeBruyn, E.R, Valere, B.G., and Boston, C.M. 2022. Effect of fish species, life history, and fish size on catch probability during boat electrofishing in nearshore areas of the Great Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 3552: vii + 28 p.

On a estimé la probabilité de capture pour la pêche à l'électricité à bord d'embarcations au moyen d'enceintes de 500 m^2 du port de Hamilton, au lac Ontario. Les résultats sont décrits en fonction de neuf expériences réalisées dans des endroits où l'habitat et les périodes d'échantillonnage varient. On a choisi trois espèces représentant des poissons pélagiques, semi-pélagiques et benthiques pour le marquage (M) et la recapture (R); on a d'abord capturé les poissons dans des trappes en filet à l'extérieur des enceintes, avant de les relâcher à l'intérieur. La probabilité de capture des poissons marqués, établie selon le calcul R/M, était en moyenne de 0,3 (fourchette de 0,11 à 0,52) et dépendait des espèces. La probabilité de capture des poissons non marqués, calculée au moyen d'un échantillonnage par prélèvements successifs, était en moyenne de 0,22 (fourchette de 0,15 à 0,29). La probabilité de capture dans les enceintes était généralement suffisamment élevée pour montrer une diminution des captures au cours de six passes de prélèvement. Les estimations des prélèvements étaient proportionnelles au nombre connu de poissons remis à l'eau. Les données découlant des courbes de capture obtenues ailleurs dans les Grands Lacs montrent que les taux de capture pour la pêche à l'électricité sont plus faibles pour les petits poissons (< âge 2; < 60 g). Étant donné que la probabilité de capture dépendait de l'espèce, de la taille des poissons et des conditions de l'habitat, l'hypothèse d'un ajustement constant pour estimer la densité (g m^{-2}) est approximativement établie en appliquant une mesure statique à une probabilité de capture intrinsèquement dynamique. On pourrait réaliser des travaux de pêche à l'électricité dans le futur à d'autres endroits afin de confirmer les effets des espèces et de la taille des poissons, ainsi que de l'habitat, sur la probabilité de capture en se basant sur la composition des prises individuelles.

INTRODUCTION

Boat electrofishing is a valuable tool for measuring fish abundance, species richness and community composition, and for investigating fish-habitat associations in nearshore areas of the Great Lakes. This study documents, in retrospect, observations from experiments in 1991[1] on the fish catch probability of boat electrofishing to support earlier publications that cited an assumed catch probability of 0.3 (e.g., Randall et al. 1993; Randall and M[1]inns 2002). Limitations of this assumption are identified.

Experience with stream surveys with backpack electrofishing was used to design the experiments. In New Brunswick, stream surveys were used to determine the production rate and status of juvenile Atlantic Salmon (*Salmo salar*) for population [Fisheries and Oceans Canada (DFO) 2012] and species [Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2010] assessments. Abundance of juvenile salmon during summer was determined using barrier nets, repeated catches within the enclosed section of stream, and catch depletion, or mark-recapture data. Catch probability (defined as total catch at site after four or five removals/depletion population estimate) fluvial habitat was high for juvenile salmon (usually > 0.3; Randall and Chadwick 1986; Randall 1990). Fish movements in the index sections were bounded by the upstream-downstream placement of barrier nets, allowing estimates of density assuming closed populations during the surveys.

This barrier approach was transferred to the Great Lakes for a study to investigate fish catchability during boat electrofishing surveys in nearshore shallow habitats. Initial surveys in Hamilton Harbour were conducted to test the utility of using enclosures in littoral areas. Objectives of the experiments were to: (1) assess feasibility of using fish removal and mark-recapture methods to determine fish abundance in experimental enclosures, (2) determine if catch probability was species dependent, and (3) make preliminary observations on factors that potentially affect catch probability. The penultimate objective was to determine if CPUE catches (e.g., g unit effort^{-1}) from a defined area of habitat can be converted to absolute indices of abundance (g m^{-2}).

After the field experiments in Hamilton Harbour, age and growth studies of two species of fishes in Bay of Quinte, eastern Lake Ontario, indicated size-dependent catchability with the electrofishing boat. Although conducted for a different reason, the results and implications of fish size differences in fish catches are also discussed and incorporated as a factor possibly affecting capture probability.

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[1] Preliminary results from the 1991 experiments indicated that although further work elsewhere was needed (see discussion), this was not done at the time because of the costs and other research priorities (RGR). The preliminary results provided an informed catch probability.

This report documents, in retrospect, the results of the field experiments, subsequent observations, and lessons for future work using enclosures in littoral areas of lakes. The 1991 experiments were done primarily for the purpose of calculating a catch probability to allow estimation of areal density and biomass for comparison among other freshwater ecosystem contexts.

METHODS

Prior to the experiments, a standardized 100 m line transect, at 1.5 m depth, was used to survey fish in nearshore areas of the Great Lakes (Minns et al. 1994). This one pass line transect protocol was used as a basis for the experiments conducted in Hamilton Harbour. Results are presented in the context of a one pass survey design at transects.

Experiments were conducted in Hamilton Harbour. The proximity to the Canada Centre for Inland Waters aided in staging and the logistics of the work.

ELECTROFISHING BOAT

A Smith-Root electrofishing boat was used to capture fishes (Burow 1991; Valere 1996). The boat moved along shallow shoreline areas (with or without aquatic vegetation) at a pace of about 0.6 s^{-1} m^{-1}. The boat was about 6.1 m long, with an aluminum hull (acting as cathode), and was configured with pulsed DC output at 120 pulses per second, 340 volts, and 12 – 14 amps (a standardized protocol of 8 amps was later used for 100 m transect fish-habitat surveys, Valere 1996). Two anodes at the bow with cable danglers (dipped just below the water surface) were each positioned, to the left and right, at an angle from the midpoint of the boat. While fishing, the generator was operating continuously while collecting fish. Three to four crew members participated, one boat operator, two to capture stunned fish with dipnets at the bow, and the additional crew member, if available, helped empty the dip nets into the live well. All crew members had dead-man foot switches, wore rubber gloves, and flotation vests for safety. Portt et al. (2006) showed a photograph of the Smith-Root boat.

BARRIER NET

The enclosure net used for the field experiments was 50 m long, 10 m wide (i.e., surface area of 500 m^2) and 2.4 m deep (see Appendix 1 for full enclosure specifications). There was no physical bottom in the net; it was held in place and maintained as a rectangle by anchors, lead lines and buoys. Previously, survey data at various sites prior to the mark-recapture work, were collected by DFO using 100 m line transects, running parallel to shore at the 1.5 m depth contour in different areas (Randall et al. 1993; Minns et al. 1994; Valere 1996). To either side of the boat, fish were observed to respond to the electric current for approximately 5 m (not measured).

Therefore, the enclosure nets were custom made using a seine mesh for a dimension of 10 m width and 50 m length. The 10-m width was judged to be the minimum width required to operate the electrofishing boat with the anodes extended. A length of 100 m was judged to be too long for the field experiments and would have required too much seine material to deploy for individual day experiments. Individual enclosures had an area of 500 m^2, and catch probability was estimated for this survey width, length and area.

The custom-made barrier net was buoyed with two braided nylon float lines tied to the top of the net and with additional floats tied to one of the lines at 30 cm intervals. The bottom edge of the net was weighted with two heavy lead lines. A system of lanyards and trip lines were used to keep the net bunched up while the net was being towed into position. Four trip lines were used, one on each side of the rectangular enclosure. After choosing a study site and positioning, the corners of the floating net were anchored in the water, to achieve the 50 m by 10 m rectangular shape. The mid-line of the net was set at approximately 1.5 m water depth. After a waiting period to allow fish to re-establish residency (assuming they had moved because of our boat activity), the net was tripped, released and allowed to drop to the bottom to completely enclose the experimental survey area. Net deployment trapped fish. The anchor line was checked visually to ensure closure, to the extent possible. The water clarity during experiments was limited; Secchi depth was often less than 1.5 m.

FIELD PROCEDURE

Preliminary exploratory electrofishing at the west end of Hamilton Harbour indicated three species were abundant. Based these observations, the initial objective was to mark 100 Alewife (*Alosa pseudoharengus*), 100 White Perch (*Morone americana*) and 30 Brown Bullhead (*Ameiurus nebulosus*) for each experiment. Life histories of the three varied; Alewife are schooling and pelagic, Brown Bullhead are bottom dwellers, and White Perch are midwater.

During the evening prior to electrofishing, one or two trap nets (2.5 cm mesh) were set the evening before in the vicinity of the proposed enclosure site. After the enclosure was set in place, the trap nets were fished. Target species were fin-clipped (upper or lower caudal fin; we assumed that fin clipping did the affect the behaviour of the fish), their fork lengths were measured (nearest mm), and the fish were held in the boat's aerated live-well until time of release. Sampling mortality was recorded. Later, if needed for analyses, weight (W, g) was estimated from fork length (FL) mm from the generic length-weight relationship, assuming isometric growth, as $W = 0.0001FL^3$.

Trap nets and net placement were done using two additional vessels, a small skiff (Boston Whaler, used to set net), and an 8 m long vessel (P-class; used to carry nets). For the experiments, multiple locations within the Hamilton Harbour were surveyed on nine dates, four times at locations without vegetation and five times with submerged aquatic vegetation (SAV) habitat sites (Table 1). Both habitat types were surveyed during light (4) and dark (5) conditions. After the enclosure was positioned, set and the net stabilized, the marked fish were released into the enclosure and allowed time to distribute (about 1 h) to the new area. After moving the boat into the enclosure, the generator was engaged, and the boat was moved slowly while fishing along the 50 m transect midline, for 4 – 5 min, before reaching the end of the barrier. The captured fish were measured, checked for fin-clips, and then released outside the enclosure. After waiting for least one hour, the area was sampled again. Six removal events were completed in total. For most of the work, the fish mortality was low (< 5%) during the experiments, but long-term mortality was not assessed. Records of the capture removals by removal effort (i.e., pass) were kept separately.

Each survey took about eight hours to complete, owing to the time required to complete six replicate fishing events and to process each captured individual. Data were collected on other dates but were not used due to weather and mechanical problems.

CATCH PROBABILITY

For marked fish, catch probability was defined as the proportion of marked fish captured after one pass with the electrofishing boat. [in this report, the terms catch probability and capture probability are used, interchangeably]. Catch probability was estimated as R1/M, where R1 was the number of recaptures from the first removal from a known number of marked fish (M), which were released into an experimental enclosure. The number of recaptures for each subsequent removal event was also recorded.

For unmarked fish, catch probability was estimated by the removal method of estimating abundance (described below) and the catch depletion data. For the removal method, catch probability was estimated as the number of unmarked fish captured in the first removal pass divided by the abundance estimate of unmarked fish.

Zalewski and Cowx (1990) differentiated between catch probability and catch efficiency. Catch probability is the proportion of fish caught during each sweep (= removal) of the survey area. Catch efficiency is estimated as the catch of recaptures from the first removal as a proportion of the known abundance when the survey is complete. Efficiency can only be truly estimated if the true number of fish available to capture is known. Our estimate from R1/M and removal was for catch probability of the marked or unmarked fish for the first removal.

REMOVAL ABUNDANCE

Abundance of fishes by species was estimated by catch depletion (Zippin 1956; White et al. 1982; Pollock and Otto 1983) To be reliable, removal estimates of abundance should be based on catch probability of at least 0.2 and for consistently reliable results a catch probability > 0.4 (Bohlin et al. 1990; Schnute 1983; Seber 1982). The number of fish being estimated should be at least 40. Among experiments, Alewife and sometimes White Perch met this criterion, but the abundance of Brown Bullhead was less. Precision of the removal method depends on the number of removals and the capture probability (Bohlin et al. 1990) which was not known at the outset. Therefore, six removals were used to maximize precision. Capture probability and abundance were also calculated using the removal estimates (Pollock and Otto 1983) after six removals. The Pollock and Otto method is robust and allows for moderate heterogeneity in capture probability between removals.

Both R/M data and catch depletion data were compared with the one-to-one relationships and to each other. Likelihood chi square analysis was used to compare the capture probability among species, and between catches during day and night and present or absence of aquatic vegetation. Analysis of Variance (ANOVA) was also used to test for evidence that fish size was dependent on removal event (size selectivity). Did average of fish size (g) differ for different removal events, for individual species or for all marked fish combined?

Catch curves of two fish species from nearshore areas elsewhere in Lake Ontario (Randall et al. 2006; Randall et al. 2012) were also used to demonstrate the reduced catch probability of small fish compared to the predicted relationship of Dolan and Miranda (2003). Dolan and Miranda determined immobilization threshold by experiment in the lab using different fish species and size.

PHYSICAL CONDITIONS AT ENCLOSURE SITES

In addition to fish species and size, Zalewski and Cowx (1990) summarized many additional factors that potentially affect catch probability, including environmental and technical factors, as well as biological factors. At the sites within the experimental enclosures, we recorded water temperature, conductivity, aquatic vegetation, time of day, weather, effort and community species richness and fish density (abundance estimate/area). Associations between capture probability and physical conditions were compared among experiments using simple linear correlation.

Water at the sites was turbid, with decreasing visibility at depth, making it difficult to verify the lead line and enclosure were securely on the substrate.

RESULTS

Results are presented for mark-recapture, removal estimates (both marked and unmarked fish), size dependent catches, and possible physical factors affecting catch probability (Table 1).

MARK - RECAPTURE

A total of nine enclosure experiments were conducted in June and July of 1991. A total of 1,466 fish were marked and released in the enclosure, and 491 fish were recaptured after one removal (Table 2). We were not able to achieve our target number of marked fish for the White Perch and Brown Bullhead. The numbers of fish marked and recaptured varied by species, with good catches of Alewife, intermediate catches of White Perch, and low catches of Brown Bullhead. Surprisingly, no Brown Bullhead were recaptured in the first removal pass in experiment seven despite reasonable numbers of marked fish (39). Bullheads were sometimes slow to 'float up' after being immobilized by the electric current, and were observed floating behind the boat (B.G. Valere, personal observation).

Catch probability, all experiments combined, was 0.43 for Alewife, 0.17 for White Perch, 0.05 for Brown Bullhead, and 0.33 overall (Table 2). Relative capture probability among species, remained similar for all experiments, with highest for Alewife and lowest for Brown Bullhead. Likelihood chi square analysis, for the first removal recaptures, indicated the catch probability was significantly dependent on species (χ^2= 140.9, 2 df, $p<0.01$).

When all three species were combined, the total number of marked fish captured in the enclosure area after one removal was significantly related to the number of marked and released fish (. 1; F ratio = 10.2, DF 8, $P<0.05$, R^2 = 0.59). Catch after one removal divided by the catch probability of 0.3 was proportional to the actual number of released fish and approximated the 1:1 line for marked fish; Figure 1).

REMOVAL ESTIMATES

The number of marked fish and catch probability were high enough to observe a significant decline in catches with the six successive removals for seven of the nine experiments and for at least one of the three marked species (Table 3). Removal estimates of marked fish were possible for two of the three species (Alewife and White Perch) and were significantly correlated to the known number of marked and released fish (Table 2 and Figure 2). Surprisingly, no Brown Bullhead were recaptured after six removal passes in experiment seven.

The number of untagged fish for the first removal ranged from 0 to 106 fish. These untagged fish were trapped in the enclosure area when the net was set. After six removals, the capture number ranged from 10 to 286 fish. Catch depletion estimates were significant for five of the eight experiments (Table 4). Capture probability for the five experiments (first removal/removal abundance estimate), ranged from 0.15 to 0.30 and averaged 0.22. Total unmarked numbers within the enclosure ranged between 20 and 482 fish (Table 6). The number of untagged fish was higher for the later experiments. The strong correspondence between the first removal and total estimated unmarked fish is illustrated in Figure 3, although the first removal catches, even after adjustment for catch probability, underestimated abundance.

FISH SIZE

Evidence of possible size-dependent electrofishing, for the fish marked in this study, was mixed. For Alewife in all experiments combined, there was no significant difference in the mean fork length of fish captured between the first and second removals (F=0.02, p=0.89; ANOVA). The sample sizes for Alewife were high enough to compare means for six removals, which showed a significant difference in fork length among removals (F=0.19.8; P<0.001). The fork length was larger (144.4 mm) for sweep 5 than for the others (132.1 mm), suggesting larger Alewife were avoiding being captured in early removal events.

For the other marked species, there was no difference in length of White Perch and Brown Bullhead captured in the first and second removals (F=0.06 and 0.21; p>0.05, respectively), or in the remaining removals. Sample sizes for these species were small. Finally, there was no correlation between average fish size (mm) and capture probability among species or within species among experiments.

For Bay of Quinte, linear regression of catch at age for Yellow Perch (*Perca flavescens*) and Pumpkinseed (*Lepomis gibbosus*) > age 1 (Figure 4), extrapolated to ages 0 and 1, indicated reduced catch rates (observed/expected) for Pumpkinseed (0.01, 0.17), and Yellow Perch (0.05, 0.22) for fish less than age 2, respectively (Table 7). Assuming these young fish are in the vicinity, observed electrofishing catches underestimated abundance, suggesting low detection probability.

Estimates of catch probability for small fish, using the above regression, suggested lower values than those predicted by the Dolan and Miranda relationship (Figure 5), and a smaller threshold than 60 g (~ 85 mm). Note that all marked fish in the experiments (previous section) were > 85 mm.

The strong regression (Figure 4) of catch at age versus fish weight for fish > age 2 for both species is consistent with the assumption that catch probability is relatively constant for fishes greater than a certain size.

Physical Conditions:

Physical conditions in enclosures during experiments were summarized in Table 1. Conductivity in Hamilton Harbour was high, about 600 µS cm^{-1}.

A box plot illustrated that the median catch probability was variable at both day and night, and in areas with or without SAV (Figure 6). For the pooled data, all species and all experiments, catch probability was similar (0.32) at sites with SAV and without SAV

(Table 2). Capture probability was significantly higher during night surveys (0.37) than during day surveys (0.28) (likelihood x^2 = 4.79, df 1, p < 0.03). However, caution is needed in interpreting these data in detail. Table 1 shows the differences between day/night and SAV/no SAV samples. Conductivity seemed higher and fish density lower during the day than night. It is possible that these differences (rather than day/night) were driving this pattern. Density was also higher on average for SAV locations.

Capture probability showed a negative slope with conductivity and temperature, but positive slope with effort, fish density, and % Alewife (Figure 7). The number of experiments was limited (n=9) and interpretation because of these confounding covariates affecting catch was difficult. Catch probability was only significantly related to % Alewife (P<0.05).

Water at the sites was turbid, with decreasing visibility at depth and often <1.5 m, making it difficult to verify the lead line and enclosure was securely on the substrate.

DISCUSSION

It was feasible to use both mark-recapture and removal methods to determine fish abundance with experimental enclosures in shallow areas of a Great Lakes' embayment with an electrofishing boat. Reasonable recaptures of marked fish and mark-recapture ratios provided estimates of catch (i.e. capture) probability and abundance. We assumed that the marking technique (fin clipping) did not affect the recapture ratios. The removal method was validated by comparing estimates to known numbers of marked fish and was useful for providing a method of estimating catch probability of unmarked fish. The enclosure estimates of catch probability were achieved in one day of field work, but required four crew members, three vessels, strong logistical support (close to Canada Centre for Inland Waters), and ideal working conditions.

Results were applicable to the 500 m^2 enclosure with a width of 10m and length of 50 m. A different enclosure width would result in a different catch probability. The 0.3 adjustment applies to a 10 m survey width, and survey transect length of 50 m. For extrapolation to a 100 m transect (2X length), as been assumed in past works, but with the same effective width, the assumed catch rate of 0.3 is probably still reasonable. Although fish may be pushed ahead until blocked, the fish can only move laterally for the same width.

Among experiments, Alewife and White Perch abundance met the criteria of at least 40 fish for estimating abundance by depletion, but abundances of Brown Bullhead were insufficient. As noted above, estimates of abundance from mark-recapture and removals were highly correlated, but the x and y axes of these correlations were not independent. For these experiments, both axes were based on the same data.

Nevertheless, the correlations confirmed that the assumed catch probability of 0.3 reflected the abundance of fish in the enclosures.

For comparison with stream surveys, with long-term data and large spatial samples, removal estimates among years indicated higher catch probability of juvenile salmon, highly variable among sites, averaging 0.4 for fry (4.0 – 5.5 cm) and 0.5 for parr (6.5 – 13.0 cm) (Randall 1990). For the stream surveys, capture probability was determined using the algorithms of Zippin (1956). Capture probability was related to fish size, but the additional high variability could not be attributed to changes in physical conditions recorded during the surveys (Randall 1990). Elsewhere, for both streams and lakes, fish species and size typically affect catch probability (Zalewski and Cowx 1991; Reid et al. 2009). Other studies also suggested catch probability depended on species, size and lotic vs lentic conditions (Eloranta 1990; Casselman and Grant 1998). Because of the influence of location and species on electrofishing catch, catch probability is dynamic, and assuming a constant value for catch data is approximate.

Results for objective two for our study, to determine if catch probability was species dependent, was also clear. Catch probability was variable among the nine experiments, based on mark-recapture ratios, but was clearly dependent on species, varying among from 0.43 (range 0.16 – 0.69) for Alewife to 0.05 (range 0.0 – 0.25) for Brown Bullhead. For all marked fish combined, the catch probability was 0.3. Unfortunately, the initial number marked was not equal among the three species because the trap catches for marking differed for the different locations and experiments. Different catch probability in the enclosures may have been related to the life history of the species as well; Alewife are pelagic, and were sometimes observed to be driven ahead of the boat, whereas Brown Bullhead are benthic. Catch probability was positively related to the proportion of Alewife in the experiments.

The later growth study at Bay of Quinte, Lake Ontario, indicated that catch at age for young fishes were less than expected, assuming the small fish were located within the electrofishing path (they may have been in shallow water). The strong regression of catch at age versus fish weight for fish > age 2 of two species is consistent with the assumption that catch probability may be relatively constant for adult fishes greater than a certain size (Dolan and Miranda 2003). Adjustments of electrofishing catch data for small fish can be made, with implications to estimates of production indices (Minns et al. 2023).

Evidence from this study indicated that fish size of a few larger pelagic fish as well affected catch, as did the presence of the barrier net. For Alewife, a few larger (stronger) individuals were able to evade the boat and were captured in the later removal sweeps. These individuals would not be detected with one pass. The barrier net may have increased herding for some species. The estimates of catch probability may be biased high because of the use of the barrier net. On the other hand, no recaptures of Brown Bullhead despite reasonable numbers of marked fish resulted in uncertainty of escapement of these benthic fish or avoidance. The effect of the barrier net, fish size, and fish life history on electrofishing catch probability needs further investigation.

In addition to fish species and size, physical factors may have affected catches, including effort, time of day, macrophyte abundance, and water characteristics (e.g., conductivity). Our observations on physical factors effects were exploratory. Differences in capture probability were found between day and night electrofishing, but no difference was found between sites with and without aquatic vegetation. However, macrophyte diversity and extent of bottom cover was less in Hamilton Harbour than elsewhere in Lake Ontario. For the day-night comparison, results were also influenced by the variable proportion of Alewife used for the marking experiments. Physical factors were often confounded. Further work is needed to investigate the influence of physical factors during boat electrofishing surveys. For future day-night comparisons, careful differentiation between changes in fish abundance, species composition, and species catch probability will be important.

The average of 0.3 was a first order estimate of catch probability after one removal event from our experiments, and this catch probability has been used as an ‘informed’ assumption in density (Randall et al.1993) and productivity (Randall and Minns 2002) estimates for 100 m electrofishing survey transects in the Great Lakes. The 0.3 capture probability should be interpreted with caution. The diversity and composition of fish catches and catch rates would likely be different in ‘healthier littoral habitat of the Great Lakes” (Minns et al. 1994), where centrarchids and Yellow Perch are commonly abundant in nearshore areas. Extrapolation of average catch rates from Hamilton Harbour, with high conductivity and a high proportion of offshore species (Minns et al. 1994), to different areas may be biased. Also, if fish marking affected behaviour (not investigated in this study), this may bias estimates as well.

Nevertheless, our results with enclosures were consistent with the assumption that electrofishing surveys using a standardized protocol provide a meaningful index of fish abundance for habitat management in the Great Lakes. Electrofishing continues to be a valuable, active gear for detecting fish assemblages in a variety of habitats (Portt et al. 2006).

A final objective of this work was to develop an adjustment factor to estimate and convert the number of fish per unit of effort for 100 m transects to absolute estimates of numbers per m^2. This was achieved, at least tentatively (Model 1 presented below). Based on this conversion, a Habitat Productivity Index (HPI) was developed, where HPI was calculated as average transect biomass density (g m^{-2}) times a production to biomass (P/B) ratio.[2] P/B requires estimates of biomass density, i.e., it is a spatial estimate. Since P/B can be estimated roughly from fish size, adjustment for fish size could be made (Randall and Minns 2002). Productivity of fish in different habitats could be inferred from the electrofishing data, with community fish biomass, adjusted for fish size, to identify habitat value. Catches were adjusted for fish size on a transect basis, to become a dynamic measure. Absolute estimates of abundance and HPI can be used to compare habitats, regions and ecosystem types (Randall 2015).

Electrofishing catches from future surveys could be adjusted and tested by comparing one of three models:

Model 1 (catch/0.3) assumes a constant adjustment factor, as has been used previously in publications;

Model 2 adjusts for lower catchability of small fish: for fishes < 60 g first use the Dolan and Miranda adjustment (appendix 2) then use adjusted catch/0.3; and

Model 3 adjust for small fish first as in Model 2, then for the life history of fishes in the catch (if pelagic species, use 0.4; if benthic species, use 0.1; all else use 0.3). [The observation for high catch probability of all pelagic species like Alewife and low catchability for all benthic species needs to be confirmed.]

All models could be compared and tested for efficacy using benchmarks (e.g., Metabolic Theory of Ecology).

Future experiments with enclosures in the Great Lakes might consider conducting the work in areas with less degraded habitat, lower conductivity, and with typical resident nearshore fish communities. Experiment procedure would be strengthened if effort, duration, boat settings, number of marked fish, and fish density were more standardized. Obviously, verification of proper study site closure is paramount for measures based on ratio estimators.

Future approaches might consider more advanced statistics such as Bayesian models that look at both absolute catchability and relative size selectivity, and other independent methods of counting fishes such as scuba transects, side-scan acoustics, underwater video, and others. The further use of enclosures promises to be a constructive approach for quantifying electrofishing catch data from the Great Lakes.

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[2] In retrospect, the term Habitat Productivity Index was a misnomer: productivity is a biological measure, not a habitat trait *per se* (Randall 2003). The fish catches were intended to provide an index fish productivity for the habitat area where the survey was done. Fish community productivity index (FCPI) may be a better term.

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The order of coauthors reflected their chronology of input to RGR regarding survey procedure, operation and interpretation of catch data from boat electrofishing.

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TABLES AND FIGURES

Table 1. Physical and biological factors at sites during nine enclosure experiments in 1991. Fish density was for all fish; abundance estimates of marked fish from mark/recapture, and abundance estimates of untagged fish from removal estimates.

Experiment	Date	Capture probability (all marked species)	Water Temp (°C)	Conductivity (μ S cm-1) mid-depth	Effort (secs, rem1)	SAV Present	Time of day	Fish density (m^{-2})	Number of species	% Alewife
	June									
1	6	0.40	17.5	610	210	yes	day	0.48	4	67
2	13	0.37	22.5	650	185	no	day	0.55	2	55
3	19	0.11	24.0	640	120	no	day	0.32	3	40
4	20	0.18	24.5	630	205	yes	day	0.54	7	68
5	24	0.39	21.0	540	250	no	night	0.73	5	80
6	26	0.22	21.0	560	225	yes	night	0.47	7	46
7	27	0.19	21.3	590	287	yes	night	1.02	8	50
	July									
8	2	0.35	22.0	570	285	no	night	0.63	4	96
9	3	0.54	22.5	560	310	yes	night	1.21	9	83

Location general vicinity: experiment 1 Willow Point; 2 hydro island, east harbour; 3 hydro east harbour; 4 Willow Point; 5 breakwall east harbour; 6 breakwall east harbour; 7 Willow Point; 8 CCIW adjacent to wastewater lab; 9 breakwall north of CCIW

Table 2**.** Mark-recapture results from boat electrofishing experiments. Numbers of fishes marked (M) and recaptured (R) after one removal indicated a capture probability (Prob) that, although variable among species, averaged 0.3 (rounded) overall (bold). Also shown are the combined totals of marked and recaptured fish for SAV (yes/no) and time of day (day/night).

			Alewife			**White Perch**			**Bullhead**			**All**		
Experiment	**SAV**	**Time**	**M**	**R**	**Prob.**	**M**	**R**	**Prob.**	**M**	**R**	**Prob.**	**M**	**R**	**Prob.**
One removal														
1	yes	day	142	98	0.69	37	9	0.24	36	2	0.06	215	109	0.40
2	no	day	141	63	0.44	104	32	0.31	11	0		256	95	0.37
3	no	day	6`4	10	0.16	95	7	0.07	0			159	17	0.11
4	yes	day	130	29	0.22	51	3	0.06	12	3	0.25	193	35	0.18
5	no	night	163	78	0.48	28	1	0.04	12	1	0.08	203	80	0.39
6	yes	night	21	6	0.29	9	3	0.33	16	1	0.06	46	10	0.22
7	yes	night	46	18	0.39	8	0		39	0		93	18	0.19
8	no	night	180	66	0.36	8	0		0	0		188	66	0.35
9	yes	night	93	58	0.62	4	3	0.75	16	0		113	61	0.54
Total			**980**	**426**	**0.43**	**344**	**58**	**0.17**	**142**	**7**	**0.05**	**1466**	**491**	**0.33**
SAV	yes											660	210	0.32
SAV	no											806	258	0.32
Time		day										823	233	0.28
Time		night										643	235	0.37

Table 3. Number of marked fish recaptured during each of six removals inside the enclosure by Experiment; M is total number marked. Removal estimates of marked fish with 95% confidence limits in parenthesis; NS is not significant (Pollock and Otto 1983).

Experiment	Species	R1	R2	R3	R4	R5	R6	Total R	M	Removal estimates of M	Density (m^{-2})
1	Alewife	75	5	6	10	16	1	113	142	NS	
2	Alewife	63	14	15	3	1	3	94	141	100 (96-119)	0.2
3	Alewife	10	10	14	14	4	0	52	64	52 (52-52)	0.104
4	Alewife	29	60	15	6	6	1	117	130	122 (117-145)	0.244
5	Alewife	78	22	25	11	7	0	143	163	171 (155-204)	0.342
6	Alewife							21	21	NS	
7	Alewife	18	8	6	0	3	1	35	46	NS	
8	Alewife	66	38	22	0	0	0	126	180	170 (152-193)	0.340
9	Alewife	58	15	10	0	0	0	83	93	NS	
1	White Perch	9	4	7	4	1	2	27	37	37 (29-65)	0.074
2	White Perch	32	14	22	8	1	2	79	104	89 (81-117)	0.178
3	White Perch	7	0	3	13	13	1	37	95	NS	
4	White Perch	3	12	15	5	4	2	41	51	51 (43-79)	0.102
1	Brown Bullhead	2	7	2	0	2	0	13	36	NS	
7	Brown Bullhead	0	0	2	2	0	0	4	39	NS	

Table 4. Removal estimates if significant (with 95% CL; Pollock and Otto 1983) of untagged fish after six removals.

Experiment	SAV	Light	Catch	Removal estimates of untagged fish	Density of untagged fish (m^{-2})	Number of species
1	yes	day	14	24 (16-52)	0.048	7
2	no	day	10	20 (12-48)	0.08	7
3	no	day	16			3
4	yes	day	58	78 (65-112)	0.156	9
5	no	night	106			5
6	yes	night	150	190 (169–233)	0.380	10
7	yes	night	251			9
8	no	night	78	128 (109-158)	0.256	6
9	yes	night	286			6

Table 5. Number of marked fish released, number recaptured from one removal (Rem1), estimated catch probability, and total density (marked and unmarked) of fish in the enclosure. Estimated abundance (all species) assuming a catch probability of 0.3 is also given. Results are also illustrated in Figure 1 (X axis, column 2 and Y axes columns 3 and 5).

Experiment	Marked	Rem1	Catch probability	Estimated abundance	Abundance unmarked	Total abundance	Density m^{-2}
1	2	3	4	5	6	7	8
1	215	109	0.507	363.3	24	239	0.478
2	256	95	0.371	316.7	20	276	0.552
3	159	17	0.107	56.7	53	216	0.432
4	193	35	0.181	116.7	78	271	0.542
5	203	80	0.394	266.7	162	365	0.730
6	46	10	0.217	33.3	190	236	0.472
7	93	18	0.194	60.0	417	510	1.020
8	188	66	0.351	220.0	128	316	0.632
9	113	61	0.540	203.3	491	604	1.208

Calculations for columns (col) 1 – 8: col1 - experiment number; col 2 - number marked and released; col 3 - marked recaptures after 1 removal; col 4 - catch probability [col 3/col 2]; col 5 - estimated abundance after adjustment for catch efficiency [col 3/0.3]; col 6 - total estimated number of unmarked fish from table 6, col 7 - total abundance of all fish [col 2+col 6), and col 8 - density is col 7/500 m^2.

Table 6. Unmarked fish, total capture after six removals (Rem6), after one removal (Rem1), capture probability, and abundance estimated assuming a catch probability of 0.3 after one removal. Results are also illustrated in Figure 3.

Experiment	Rem6	Rem1	Estimated removal when significant	Capture probability	Total unmarked	Estimated abundance
1	2	3	4	5	6	7
1	14	4	24	0.167	24	13.3
2	10	3	20	0.150	20	10.0
3	16	0			53	0.0
4	58	17	78	0.218	78	56.7
5	106	35			162	116.7
6	150	56	190	0.295	190	186.7
7	251	90			409	300.0
8	78	32	128	0.250	128	106.7
9	286	106			482	353.3
Average				0.220		

Calculations for columns (col) 1 – 7: col 1 – experiment #; col 2 - recaptures after 6 removals; col 3 - recaptures after 1 removal; col 4 - estimated population if significant after 6 removals (from Table 4); col 5 - capture probability col 3/col 2; col 6 is col 4 if significant or col 3 times 4.55 [1/0.22]; col 7 - col 3/0.3. No unmarked fish were captured in the first removal event, but total unmarked was estimated as 16/0.3 for that experiment.

Table 7. Weight and observed catch-at-age for Pumpkinseed (*Lepomis gibbosus*) and Yellow Perch (*Perca flavescens)* captured at Bay of Quinte. Expected values are based on weights and regression (see text) or Appendix 2 of Dolan and Miranda (2003).

Species	Age	Weight at age (g)	Expected, regression (E)	Expected, D&M	Observed (O)	Ratio(O/E)
Pumpkinseed	0	2.1	6075	111	72	0.012
	1	8.8	2453	1471	415	0.169
	2	21.4				
Yellow Perch	0	3.5	14087	1412	681	0.048
	1	11.6	4915	4451	1069	0.217
	2	26.2				

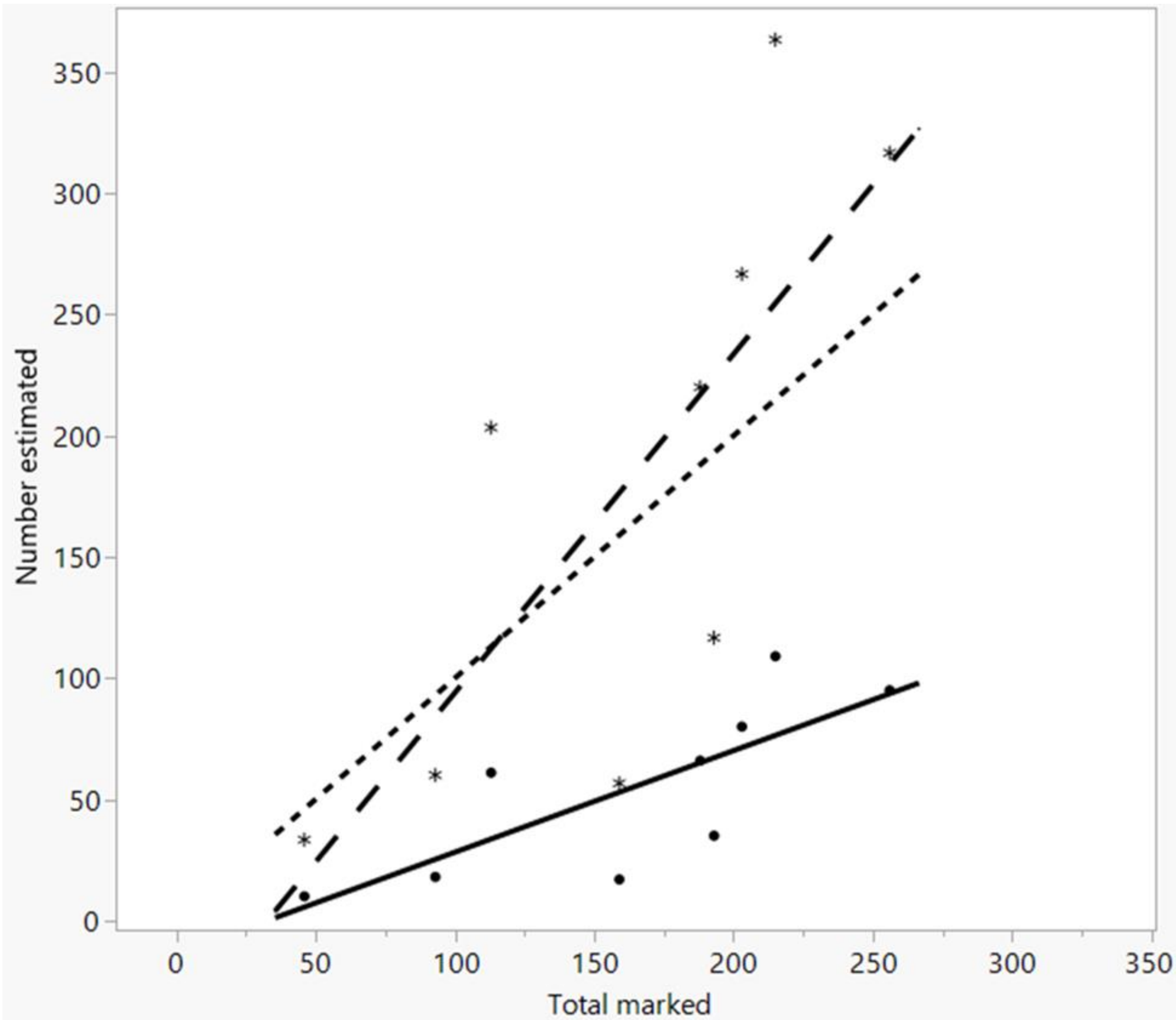

Figure 1. Correlation between total marked fish (x axis) and the number of fish from the first removal (solid line), the number in the enclosure estimated as catch from the first removal divided by 0.3 (long dashed line), and the 1:1 line for the independent x axis (short-dashed line). See Table 5, columns 3 and 5, for the underlying data.

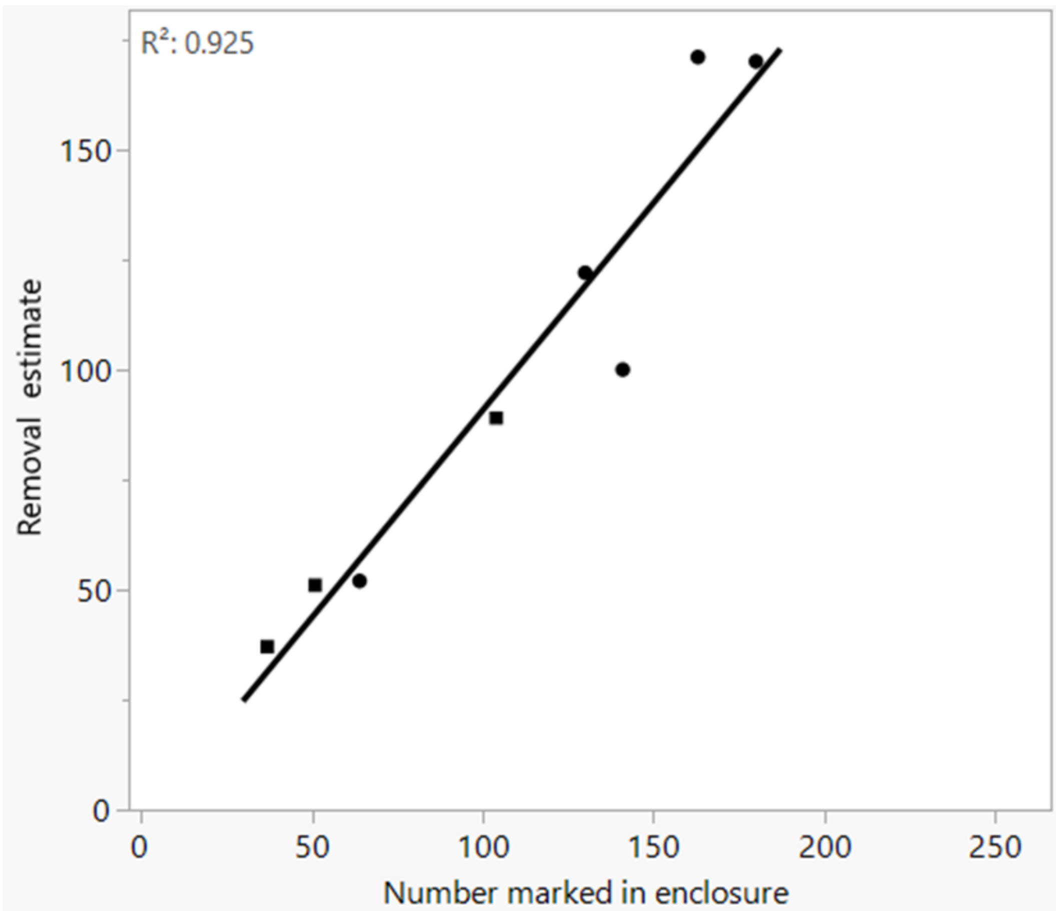

Figure 2. Comparison of number of marked fish released into the enclosure and number of marked fish estimated after six removals. Underlying data are presented in Table 3. Symbols are ● Alewife, ■ White Perch.

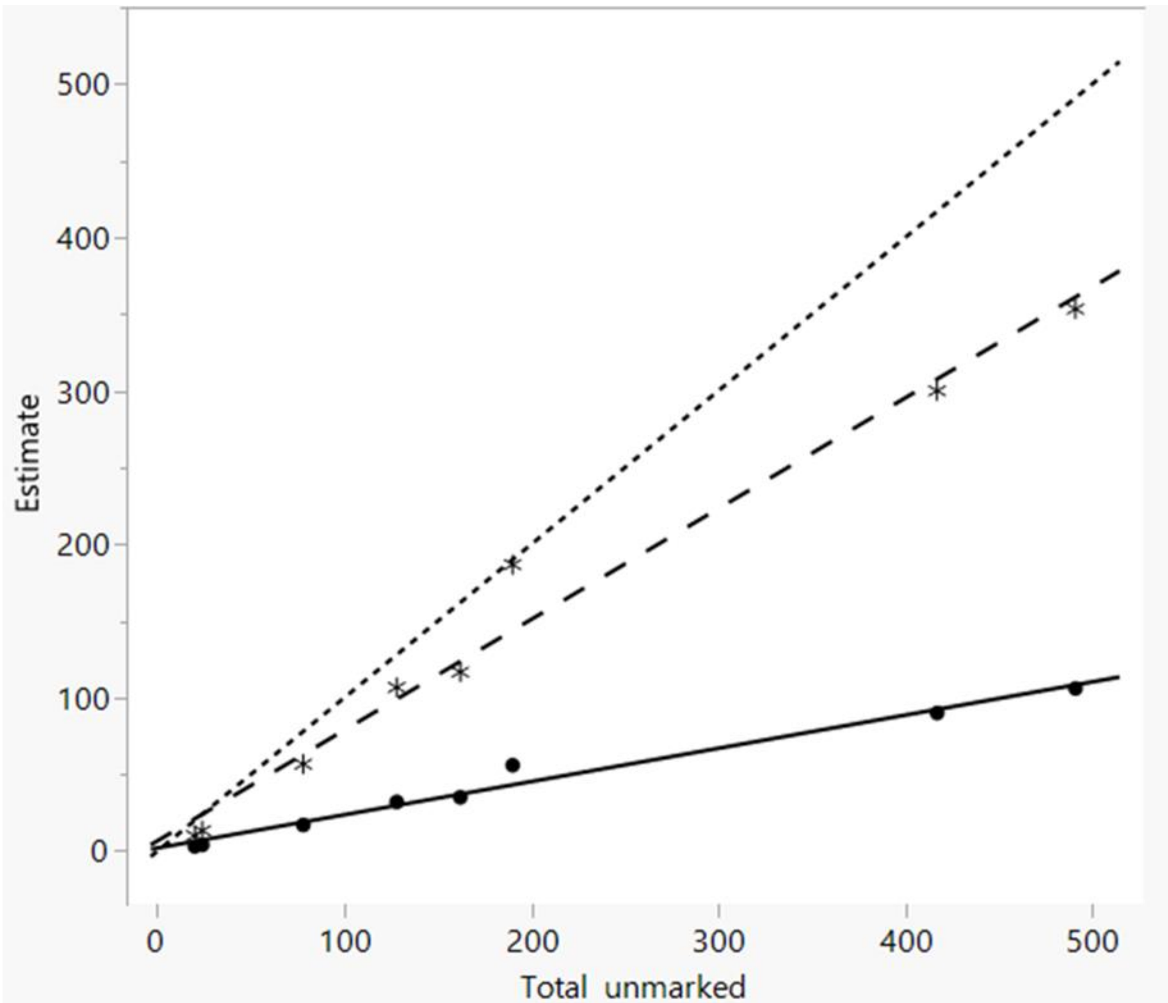

Figure 3. Correlation between total unmarked fish (all species), and catch from first removal (solid line), first removal estimate divided by 0.3 (long dashed line), and the 1:1 line for the x axis (short dashed line). Underlying data are in Table 6 (columns 3 and 6).

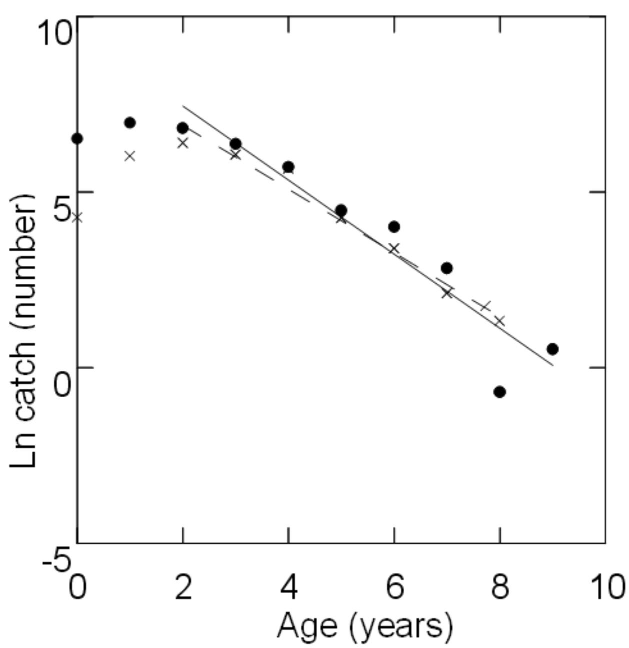

Figure 4. The catch curve data from Bay of Quinte indicated reduced catchability of Pumpkinseed (*Lepomis gibbosus*) (x) and Yellow Perch (*Perca flavescens*) (●) less than age 2. Average weight of age 2 fish was 21.4 g for Pumpkinseed and 26.2 g for Yellow Perch. Linear regressions for species were: Pumpkinseed: Ln catch = 8.712 – 0.906 age n=7, R^2=0.97, SE 0.37 and Yellow Perch: Ln catch =9.553 – 1.053 age n=8, R^2=0.89, SE 0.924.

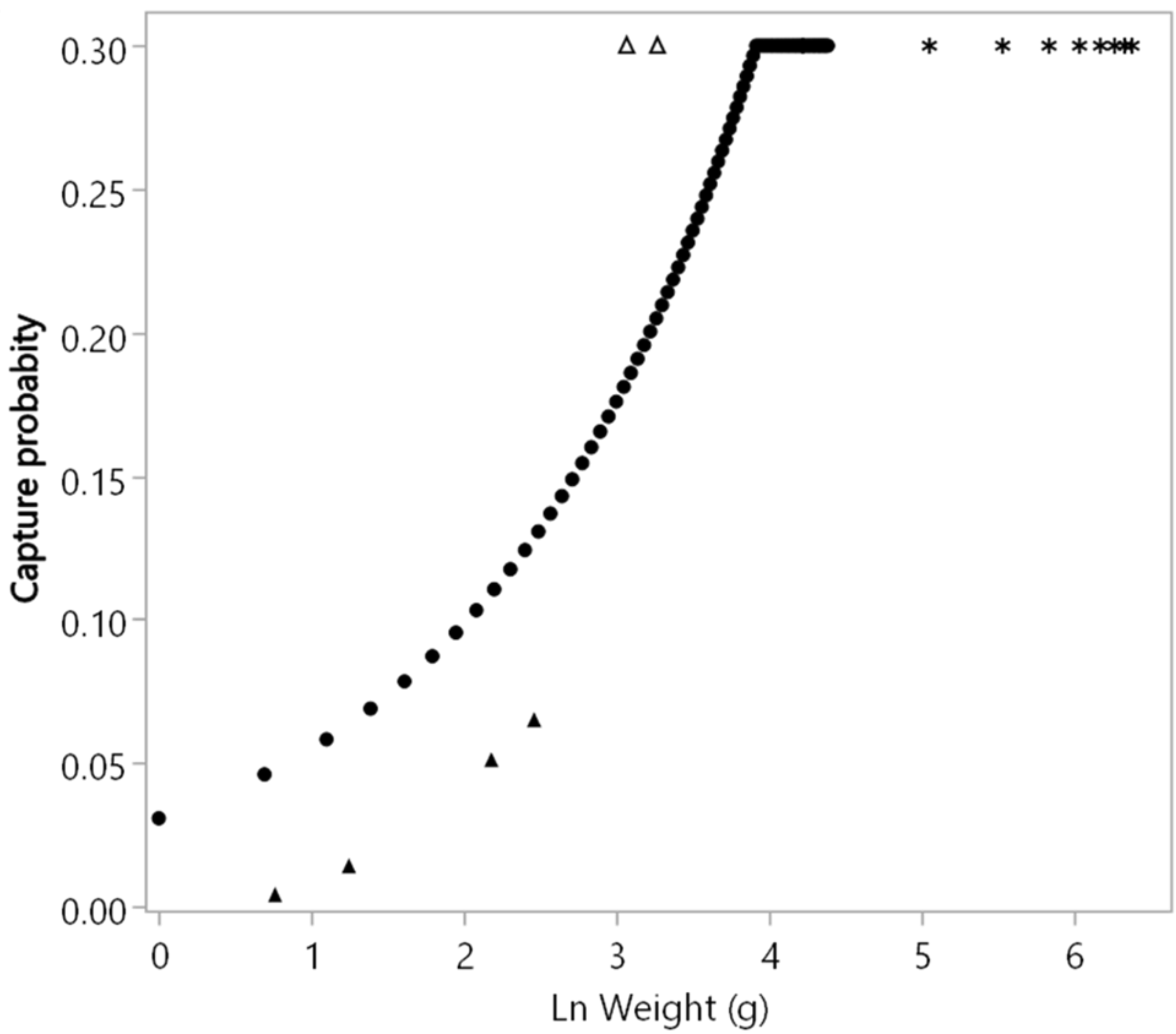

Figure 5. Relationships between fish size and capture probability using the Dolan and Miranda method and the Bay of Quinte catch at age data. A cut-point of 60 g and an assumed 0.3 catch probability for fish > 60 g is used. Catch probability of age 0 and age 1 Yellow Perch and Pumpkinseed are shown with solid triangles; data in Table 7. Open triangles are perch and sunfish at age 2. Asterisks are weight at age for Yellow Perch ≥ age 2, with assumed constant catch probability of 0.3, shown as an example species.

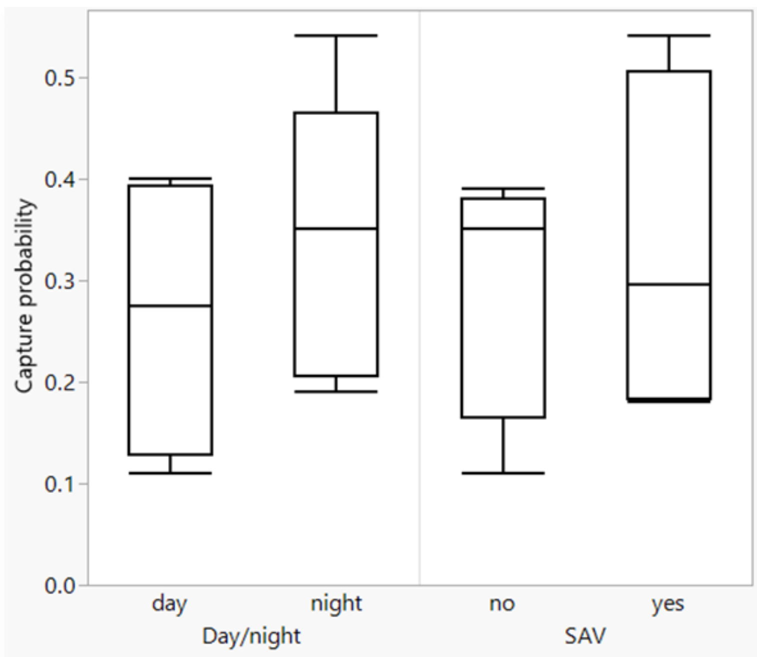

Figure 6. Box plot comparison of capture probability at sites with and without submerged aquatic vegetation (SAV) and for day versus night surveys. Chi-square analyses indicated that capture probability was significantly higher at night than during day, but there was no significance difference in capture probability with presence or absence of SAV. See text for qualifications.

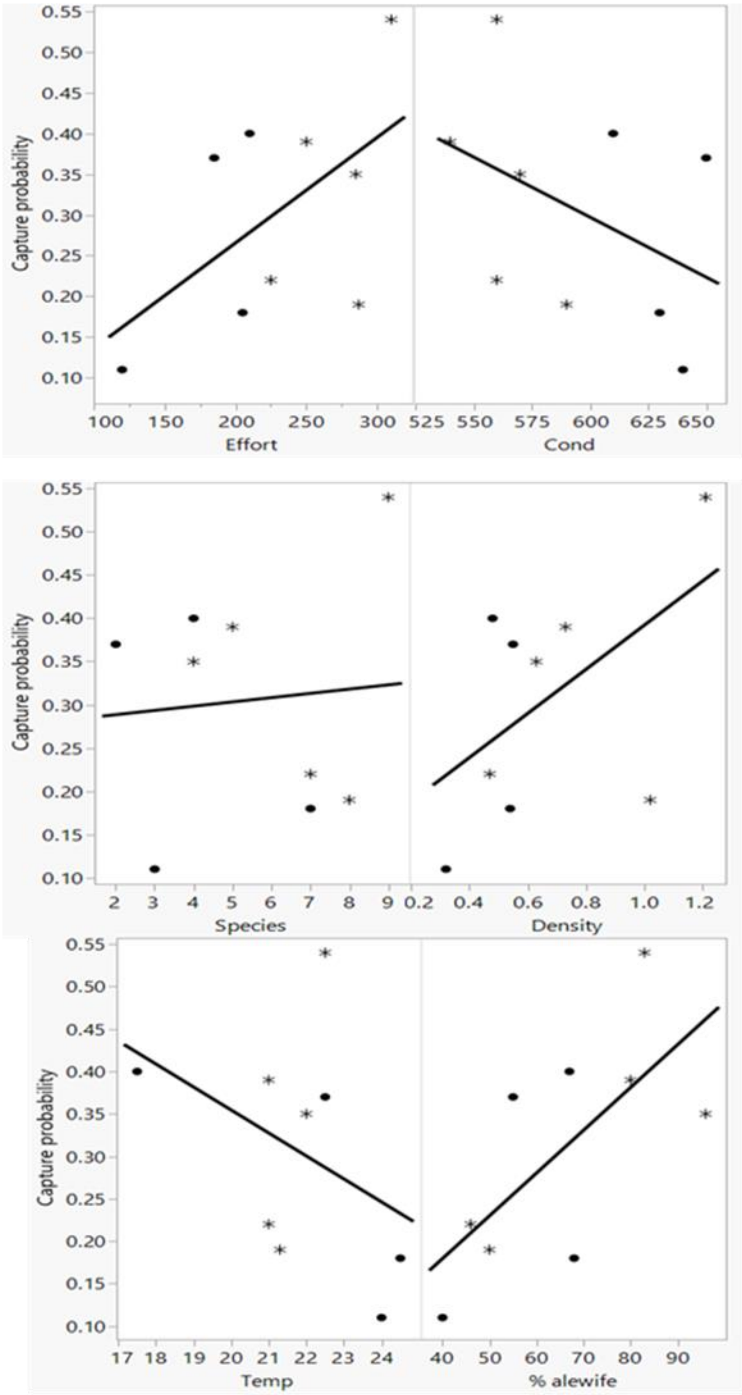

Figure 7. Comparison of capture probability among the nine experimental sites with different conductivity, effort (seconds, first removal), density (all species, number m^2), number of species, % Alewife, and water temperature (°C). Trend lines are shown. Linear regression indicated that only % Alewife was significant (n=9; P<0.05). Asterisks are night experiments. See text for qualifications.

APPENDIX A

DETAILS OF THE ELECTROFISHING ENCLOSURE

Dimension

- 50 m by 10 m by 2.4 m
- Set at 1.5 depth contour

Mesh

- ‘minnow’ seine
- Ace Oval, 7 mm aperture

Floats

- 4 large corner floats
- 2 float lines (½ inch) sewn to top of net
- Small (#250) floats sewn to top line about every 30 cm

Weights

- 2 lead lines (50) sewn to bottom of net

Tripping mechanism

- Lanyards and trip lines

Problems

- Mesh balloons in any current or wind
- Hard to maintain complete closure at bottom of net and difficult to confirm visually from surface.
- The generator was started outside the enclosure and activated after the boat was carefully moved inside. Boat control was difficult inside enclosure when wind was present.
- Originally, pickets (stakes, steel T-bars) were driven into the substrate to help stabilize the net. Pickets would have allowed us to secure the lead line to the substrate and ensure closure. However, driving the pickets was too time consuming (securely anchoring skiff, and driving stakes from boat). We then adopted the floating barrier net set-up.

APPPENDIX B

CATCH SIZE CORRECTION FOR SMALL FISH

Minns et al. (2023) worked with a dataset from Severn Sound, and using various factors and models and the Dolan and Miranda (2003) method, to establish a breakpoint of about 60 g, and the Dolan and Miranda method, to establish an adjustment factor:

$$X = \exp [-0.582*(\ln WI - \ln WTH)]$$

where WTH is the threshold weight (60 g); with an exponential slope of -0.582, each individual with a weight (WI) less than WTH is counted X-times in compiling total catches whereas the contribution of fish weighing WTH or more remains 1.

Thus a 1 g fish produces a ratio of about 12 and then the values decrease logarithmically to 1 at 60 g.

APPENDIX C

ANIMAL CARE CONSIDERATIONS

The experiments to determine catch probability using enclosures was stressful to the fish. For Alewife, trap capture and repeated depletion electrofishing caused scale loss (R.G. Randall, personal observation). Mortality was observed during the work but was usually < 5%. Long-term mortality was likely greater. For Brown Bullhead and White Perch, behavior response was potentially a factor that contributing to their low capture rates (conjecture).

Future work with enclosures would require animal care protocols and assessment of the procedure. To reduce stress, the number of removals should be as low as possible without compromising the experimental objectives. Areas with sensitive species (e.g., Species at Risk) should be avoided. A marking technique that does not affect the swimming performance of the fishes (i.e. not fin-clips) should be used. Determine minimum sample size requirements *a priori*.

At the time of the work (1991) the Great Lakes Laboratory for Fisheries and Aquatic Sciences had not yet created an animal care committee that follows guidelines of the Canadian Council for Animal Care (CCAC). Guidelines and protocols are now required for research studies. The CCAC ‘category of invasiveness’ for electrofishing in enclosures would be rated more stressful than single exposure surveys (e.g., spot checking).