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Using electrofishing data to determine regional benchmarks of habitat productive capacity

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

Electrofishing and habitat survey and monitoring data from stream sites can be used to determine region-specific benchmarks of habitat productive capacity[1]. Stream electrofishing data from three regions, Bay of Fundy (NS), Miramichi (NB) and Toronto region (ON), were used as a pilot to illustrate this method. Regression and covariance analyses were used to tentatively quantify the survey area-production (area-P) relationships for each region. Region-specific habitat productivity indices (HPI), measured as fish biomass times the P/B ratio (summed for all cohabiting species), were determined by differences in elevation of the ANCOVA model. Similar data on fish biomass from a number of regions could be obtaining in future from science-based monitoring programs or from existing survey data (e.g., salmon population assessment). The use of region-specific benchmarks of HPI to calibrate estimates of weighted suitable area to determine absolute rather than relative indices of productivity is demonstrated.

Utilisation de données de la pêche à l'électricité pour déterminer les points de référence régionaux de la capacité de production de l'habitat

RÉSUMÉ

Les données des relevés de l'habitat et de la pêche à l'électricité ainsi que les données de surveillance des sites fluviaux peuvent servir à déterminer les points de référence régionaux de la capacité de production de l'habitat. Les données de la pêche à l'électricité menée dans des cours d'eau dans trois régions, soit la baie de Fundy (N.-É.), Miramichi (N.-B.) et la région de Toronto (Ont.), ont servi de données pilotes pour illustrer cette méthode. Des analyses de la régression et de la covariance ont été utilisées pour tenter de quantifier le lien entre la production et la zone du relevé (zone-P) pour chaque région. Les indices de la productivité de l'habitat propres à chaque région, mesurés (IPH), mesurés comme la biomasse du poisson selon le ratio productivité-biomasse (la somme de toutes les espèces qui cohabitent), ont été déterminés en fonction des différents sommets dans le modèle d'analyse de la covariance. On pourrait obtenir des données similaires sur la biomasse du poisson dans de nombreuses régions au moyen de programmes de surveillance scientifiques ou de données tirées de relevés déjà menés (p. ex., évaluation de la population de saumon). On a démontré que l'on pouvait utiliser des points de référence de l'IPH propres aux régions dans le but d'étalonner les estimations de la superficie propice pondérée afin de déterminer des données absolues plutôt que des indices relatifs de la productivité.

INTRODUCTION

Compensation for loss of fish habitat is defined by the Habitat Management Program as 'replacement of natural habitat, increase in productivity of existing habitat, or maintenance of fish production by artificial means' (DFO 1986)[1]. Compensation is considered as a management option only if proposed activities affecting habitat cannot be avoided by redesign, relocation, or by mitigating potential damages. Pre- and post-project monitoring of effectiveness of compensation actions is important. Science-based monitoring to assess effectiveness of compensation requires clear data collection standards, and guidance on survey design and appropriate metrics.

The objective of effectiveness monitoring is to demonstrate by field measurement that there is no net loss of productive capacity of fish habitat. No net loss can be effectively assessed by using either habitat-based or biological-based metrics or approaches (Minns et al. 2011). Examples of biological approaches are provided by Jones and Tonn (2004) and Jones et al. (2003; 2008) for the Canadian Arctic, and Clarke and Scruton (2002) for Newfoundland. Minns (1997; 2006) and Minns and Moore (2003) provide examples of compensation assessment using a habitat-based approach. These examples utilized case study data and science expertise, either university or government.

The goal of this study is to demonstrate the potential use of empirical field data to determine region-specific benchmarks for measuring compensation effectiveness. Data on habitat area, fish abundance and body size, collected by government and university scientists, are used to develop region-based area-production (area-P) relationships. If science-based protocols were developed, similar data could be collected in future by proponents as part of a standardized monitoring program. The potential application of regional benchmarks for assessing net change with biomass or production units of productivity is discussed.

METHODS

DATA SOURCES

Electrofishing survey data from three regions were used to illustrate the use of area-P relationships for determining region-specific benchmarks. The three regions were: inner Bay of Fundy (several rivers from NS and NB), Miramichi (one tributary in NB), and Toronto region (several tributaries in vicinity of Toronto, Ontario) (Table 1). The survey data from these regions were originally analyzed to determine inter-regional differences in fish size-abundance relationships (Randall, *pers. obs.*).

For population assessment, fish abundance data from 43 rivers in the upper Bay of Fundy (NS and NB) were determined by stream electrofishing (Gibson et al. 2003). For this study, a subset of 11 rivers was chosen: Stewiacke (15 sites), Portapique (2 sites) and Upper Salmon, Black River, Reservoir Brook, Economy River, Folly River, Great Village, North River, Peticodiac and

[1] This Research Document was written to support a DFO Science Advisory process which took place prior to June 2012 amendments to the *Fisheries Act*. Prior to 2012, the habitat management provisions addressed concepts such a productive capacity and habitat compensation. Rather than compensation, recent revisions to the *Fisheries Act* refer to the term 'offset serious harm', which focuses on offsetting losses to the productivity of commercial, recreational or Aboriginal fisheries. However, the region-benchmark method outlined in this report would be equally applicable to the measurement of productivity metrics. New policy support to the 2012 legislative amendments is expected in the near term.

Point Wolf (one site at each). Although the primary target species was Atlantic Salmon (*Salmo salar*), the occurrence and relative abundance of all co-habiting fish species were recorded as well. Because information on fish weight was not available for a number of sites, two criteria were used to select samples to be included in this study: 1) only tributaries and sites with information on weights of species with the highest biomass density were included, and 2) only tributaries with at least 30 records of body size (L, W) were included, so that remaining missing weights could be determined by L-W regression for these tributaries. Based on these criteria, the 11 rivers and 26 sites were included in this analysis (Table 1); i.e., the Fundy sites were filtered for inclusion based on the available data. Although the Fundy data were collected to determine population density (Gibson et al. 2003), only total fish number captured by site, unadjusted for catch efficiency, were used for this study. For certain tributaries, catches were averaged across sites and years. Electrofishing data were collected between 2000 and 2003; stocking of Atlantic salmon from hatcheries occurred at some of the rivers during or in previous years (Gibson et al. 2003 and *pers. comm*.).

Catamaran Brook, a 3rd order tributary of the Little Southwest Miramichi River, New Brunswick was selected as an index watershed in 1990 to monitor the effects of forestry operations on stream ecology (Cunjak et al. 1993). Electrofishing survey data collected from eight sites in the lower reaches of Catamaran Brook from 2002 to 2004 were used for this study (Table 1). Catch data were used as an indication of population abundance; i.e., total catch for each fish species during three successive removals (passes), without adjustment for catch efficiency. For a small number of sites (n = 4), catches of salmon fry which were recorded as batch numbers and were excluded from this pilot study.

In Ontario, electrofishing data were collected at thirty-eight sites during September and October 2005 and 2006. Sites were located in Rouge River (12), Lynde Creek (9), Humber River (6), 14 Mile Creek (4), Duffins Creek (2), Morningside Creek (2), Silver Creek (2) and Sixteen Mile Creek (1). Surveys were conducted in September and October, during low water, to determine the distribution, status and habitat of Redside Dace (*Clinostomus elongatus*), a threatened species in Ontario (Reid et al. 2008). In the original study, population estimates were made based on the removal method or single-pass electrofishing (see Reid et al. 2008 for details), but for this study, total catch, without adjustment for catch efficiency, was used as an indicator of abundance.

The fish abundance and biomass data were used in this study as a pilot to demonstrate the feasibility of region-specific electrofishing catches to measure habitat productivity. For this study, region is defined as a geographic area with roughly similar drivers of productivity (latitude, water chemistry), which can be measured with empirical data on fish biomass as the metric of productivity, averaged for a number of sites. Different field methods were used in each of the three regions to determine fish abundance. Note that the field effort was not standardized among regions, and that different factors affected fish abundance in each region (urbanization, fishing, sea survival of salmon and stocking; Table 2). Key field measures in each region included area of fish survey (m^2), total catch (number and biomass) of all fish species, body size (length and weight), and survey effort.

MODEL AND ANALYSIS

Fish catch-area relationships were analyzed using ANCOVA models. Fish catch (response variable) was expressed as total numbers of fish captured per area, total biomass (g), and a calculated Habitat Production Index (HPI; Randall and Minns 2000). HPI was calculated as $\sum B_i(P/B)_i$), where HPI is the product of the biomass of species *i* (B_i) with the ratio of production over biomass for species *i* $(P/B)_i$, summed for each species in the assemblage (g yr^{-1} for the survey area). The species P/B ratio (1/y) was calculated as $P/B = 2.64W^{-0.35}$ (Randall and Minns

2000), where W was the average weight (g) of each species captured at each site. Total biomass (B, g) for each area of survey was used rather than biomass density (e.g., biomass per unit area) to avoid statistical errors associated with ratios (Jackson et al. 1990). Response variables were tested as functions of region (treatment category) and survey area (covariate). The abundance of salmonid species has been related to stream width and area using linear models in other studies (Bradford et al. 1997; Cote 2007; Cote et al. 2011). Initially, homogeneity of slopes were tested using an interaction term in the regression model (area*region). If the interaction term was not significant, it was removed from the regression. As an example, the ANCOVA model for fish biomass was : *Ln* B (g) = intercept + *ln* area (m^2) + region (category) + error. Differences in intercepts among regions were interpreted as being differences in habitat productive capacity. Coefficients were determined to be significant at $\alpha \leq 0.05$. The fish response variable and survey area were transformed (natural log) to normalize their distributions. All analyses were conducted using SAS (2012) software.

RESULTS

The average area of stream survey was 126 m^2 (range 67-194) at the Miramichi (157 m^2 (50-340) at Ontario sites, and 672 m^2 (125-1462) at the Fundy sites (Table 2). Total numbers of fish species captured were lowest at the Miramichi tributary (Catamaran; 11), intermediate at the Fundy sites (18) and highest at Toronto region (34 species) (Table 3).

For fish abundance, analysis of covariance showed that the numbers of fish at sites was a function of both region (treatment) and survey area (covariate) (Fig. 1). Initial analysis confirmed that a common slope model was plausible, as the interaction term was not significant (P=0.82); slopes of the regression lines of fish number and survey area were not significantly different among the regions. For the common slope model, both region and area were significant factors (ANCOVA; P<0.001), and fish abundance depended on region after correcting for the differences in survey area. Fish catch in numbers of fish was significantly higher at Lake Ontario than at Fundy or Catamaran (LS Means differences Tukey HSD; P<0.05). The ANCOVA model was highly significant (n=88, R^2=0.48, $F_{3,87}$=27.28, P<0.0001).

Average fish weight (g) was significantly different among regions (ANOVA $F_{2,87}$=82.8, P<0.001). Average weight was highest at Fundy sites (mean 13.38 g), intermediate at Ontario (9.68 g), and least at Catamaran (2.79 g) (Tukey-Kramer HSD, P<0.05).

Slopes of fish biomass versus survey area were not significantly different among regions (P=0.31) and, as with fish number, biomass was region-dependent after adjusting for the differences in survey area (Fig. 2). Fish biomass was significantly lower at Catamaran than at Fundy and Lake Ontario (LS Mean differences Tukey HSD; P<0.05). The R^2 coefficient for the biomass ANCOVA model was higher than the model for fish number (n=88, R^2=0.77, $F_{3,87}$=98.5, P<0.0001), in part because biomass is a product of body size and abundance and fish size, shown previously, was region-dependent.

As anticipated (by calculation), HPI trends among regions were similar to trends in fish biomass. For the initial analysis, the interaction term (area*region) was not significant (P=0.58), and therefore a common slope model was adopted. For the ANCOVA model, both the area and region factors were significant (P<0.0001). The ANCOVA model was highly significant (n=88, R^2=0.72, $F_{3,87}$=76.15, P<0.0001). The HPI was region-dependent, and was significantly lower at Catamaran than at Fundy or Ontario (LS Means differences Tukey HSD; P<0.05).

Significant differences in regression elevation of HPI among regions indicated differences in habitat productive capacity. Median fish biomass density for Catamaran, Fundy and Ontario was 1.8, 9.6 and 20.9 g m^{-2}, respectively, and the overall median biomass was 10.01 g m^{-2}. The

median values for HPI for Catamaran, Fundy and Ontario were higher (3.3, 10.4 and 22.6 g m^{-2} yr^{-1}). The overall median HPI value was 10.79 g m^{-2} yr^{-1} (n=88), indicating an average P/B of about 1.1.

The average abundance, biomass and HPI values were preliminary as fishing effort was not standardized among the three regions.

DISCUSSION

Fish community abundance, biomass, average body size, and production indices varied significantly among the Fundy, Miramichi and Toronto regions. This conclusion is tentative, as the fishing effort was not standardized among regions, and in some cases factors other than habitat capacity affected the fish catches (Table 2). After further revision and adjustment however, elevations of the ANCOVA models may change, but the general model structure will likely be similar: that is, biomass increasing with area of survey, common slopes, and with elevations defining regional productivity and population carrying capacity. Despite the preliminary nature of this analysis, these pilot results can be used to demonstrate the potential of using area-P relationships to determine region-specific benchmarks of productivity.

Total fish biomass is the key field metric in the area-P approach. It is assumed that the sum of biomass of all co-habiting fish species in the survey area is a first-order estimate of current productive capacity. The rationale is that although the abundance of an individual population may be reduced at the time of survey because of a non-habitat factor (e.g., exploitation), it is likely that the summed wet biomass of the fish community will reflect habitat capacity, if sufficient data are used for the assessment. Biomass by itself is a static measure, in units of wet weight for a defined habitat area (e.g., kg ha^{-1}). By calculation, the production index (HPI), the product of biomass and annual P/B, provides a dynamic measure of biomass turnover rate (units of kg ha^{-1} yr^{-1}), which better measures productive capacity as a rate (index of production). Limitations of using allometry with fish weight to estimate P/B from fish catch data were discussed by Randall and Minns (2000).

Assignment of productive capacity on a regional basis rather than at a site level is consistent with an area-based and ecosystem approach to resource management. With sufficient data, isopleths of productive capacity could be established for different geographic regions. Region is defined broadly as a geographic area with similar fish assemblages, climate and water nutrients (e.g., watershed, coastal management area). Regional drivers of productivity, such as surface area, climate regime, nutrients and habitat structure, have been shown to be key determinants of fish production (recent examples: Cote et al. 2011; Jonsson et al. 2011; and Kim and Lapointe 2011). After confirmation of differences in productive capacity observed in this study, potential regional drivers will be investigated in future. For application at site scales, habitat suitability indices (e.g., Table 4) need to be identified with known levels of certainty. Partitioning of B and P by habitat type for site assessments infers a direct link between habitat type, suitability assignment and fish biomass.

For estimating habitat quantity and quality, Weighted Suitable Area (WSA_i) is often calculated as the product of habitat area (a_i) times a Suitability Index (s_i) for each habitat category *i* (Table 4). WSA is often expressed as a relative index. Determination of region-specific benchmarks would allow productive capacity for specific habitat categories to be expressed in absolute units of biomass or production (Table 4). That is, if productive capacity for a defined area can be determined with reasonable confidence (e.g., Fig. 3), and science-based suitability indices are available, gains or losses in productive capacity by habitat category can be expressed in units of fish biomass or production, rather than as relative units. After reviewing past approaches and metrics for measuring productive capacity, Minns et al. (2011) emphasized the need in future to

‘communicate the link between habitat suitability and absolute units of fish production’. A region-dependent measure of productive capacity provides the basis for quantifying this link.

Data to measure region-specific productive capacity could be obtained in future from a combination of existing databases and from a structured monitoring program. Existing databases could include both DFO (e.g., salmon population assessment, species-at-risk and other) and provincial (e.g., OMNR; Stanfield et. al. 1997) fish survey data. For a structured monitoring program, a prerequisite would be to develop science-based guidelines for data collection, for both habitat measures (footprint of activity, direct and indirect areas impacted, habitat category, other factors) and fishes (ID, measurement, fish sampling, permits, training (electrofishing), effort standards, survey design and data quality control). Field data collection could be geo-referenced and secured (i.e., Program Activity Tracking for Habitat; Fig. 4) using a GIS framework (Bakelaar, C. 2013. *pers. comm.*). Whereas existing and continuing electrofishing data collection would help define productive capacity for regions where population assessment programs apply, a monitoring program could be used to fill data gaps, in regions where projects potentially impacting fish habitat are ongoing (Fig. 4).

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PERSONAL COMMUNICATIONS

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TABLES AND FIGURES

Table 1. Region, data source, survey objectives and sampling effort in terms of the number of rivers, sites, samples and total area surveyed.

Region	Data source[1]	Objective	Survey Effort			
			Rivers	Sites	Samples	Area (ha)
Fundy	DFO	Population assessment	11	26	26	1.7
Miramichi	UNB	Research	1	8	24	0.3
Toronto	OMNR	Species at risk	8	38	38	0.6
		Total	20	72	88	2.6

[1] DFO, Fisheries and Oceans Canada; UNB, University of New Brunswick; OMNR, Ontario Ministry of Natural Resources

Table 2. Range in survey areas (m2), method used to determine fish abundance, total number of species captured, and target species of interest and habitat status in each of the three regions.

Region	Average area, m^2 (range)	Method[1]	Species	Target species	Habitat status
Fundy	672 (125-1462)	Catch, Mark-recapture	18	*Salmo salar*	Salmon populations at risk but abundance is related to low sea survival of adults (and historically habitat fragmentation)
Miramichi	126 (67-194)	Catch, Removal	11	*Salmo salar*	Healthy habitat but possibly low sea survival of adults
Toronto	157 (50-340)	Catch, Removal	34	*Clinostomus elongatus*	Surveys were conducted across a gradient of rural to heavily urbanized sub-watersheds

[1] Method includes the data used for this study (total catch) and, as background, the method used by the researchers to determine fish abundance. Effort and catches among regions can be standardized and adjusted for catch efficiency

Table 3. List of fish species captured in each region during the surveys included in this study. Note that fishing effort (area of survey and electrofishing time) differed in each region.

Species	Fundy	Miramichi	Toronto
Atlantic Salmon	√	√	
Brook Trout	√	√	√
Blacknose Dace	√	√	√
White Sucker	√	√	√
American Eel	√	√	
Slimy Sculpin		√	√
Mottled Sculpin			√
Creek Chub	√	√	√
3-spine Stickleback	√	√	
Brook Stickleback			√
Sea Lamprey	√	√	√
Lake Chub	√	√	
Common Shiner	√	√	√
UI Cyprinidae	√	√	√
Northern Redbelly Dace	√		√
Redside Dace			√
Rainbow Trout	√		√
Atlantic Tomcod	√		
Pearl Dace	√		√
Brown Trout	√		√
Yellow Perch	√		
Brown Bullhead	√		√
Golden Shiner	√		
Bluntnose Minnow			√
Fantail Darter			√
Rainbow Darter			√
Johnny Darter			√
Fathead Minnow			√
Largemouth Bass			√
Smallmouth Bass			√
Rock Bass			√
Pumpkinseed			√
Green Sunfish			√
Common Carp			√
American Brook Lamprey			√
Longnose Dace			√
Central Mudminnow			√
Northern Hogsucker			√
Hornyhead Chub			√
Northern Hognose Sucker			√
Lampetra			√
Central Stoneroller			√
Stonecat			√
Total	18	11	34

Table 4. Hypothetical example of assigning relative (WSA) and absolute (b_i and p_i) units of productive capacity to different habitat types for a total area of 1000 m^2. Total biomass and production for the 1000 m^2 area for this example was assumed to be 10.01 kg and 10.79 kg yr^{-1}, respectively (i.e., the medial values for the three regions of this study, n=88).

Habitat type	a_i (m^2)	s_i	WSA_i	b_i (g)	p_i (g yr^{-1})
1	400	0.3	120	2355	2539
2	500	0.7	350	6870	7405
3	100	0.4	40	785	846
Total	A = 1000		WSA = 510	B = 10010.0	P = 10790.0

Symbols and calculations: a_i = area of habitat by type; A (total area) = $\sum a_i$; s_i = habitat suitability index; WSA_i (weighted suitable area) = s_i X a_i; WSA = $\sum WSA_i$; b_i = (WSA_i/WSA) X B; p_i = (WSA_i/WSA) X HPI.

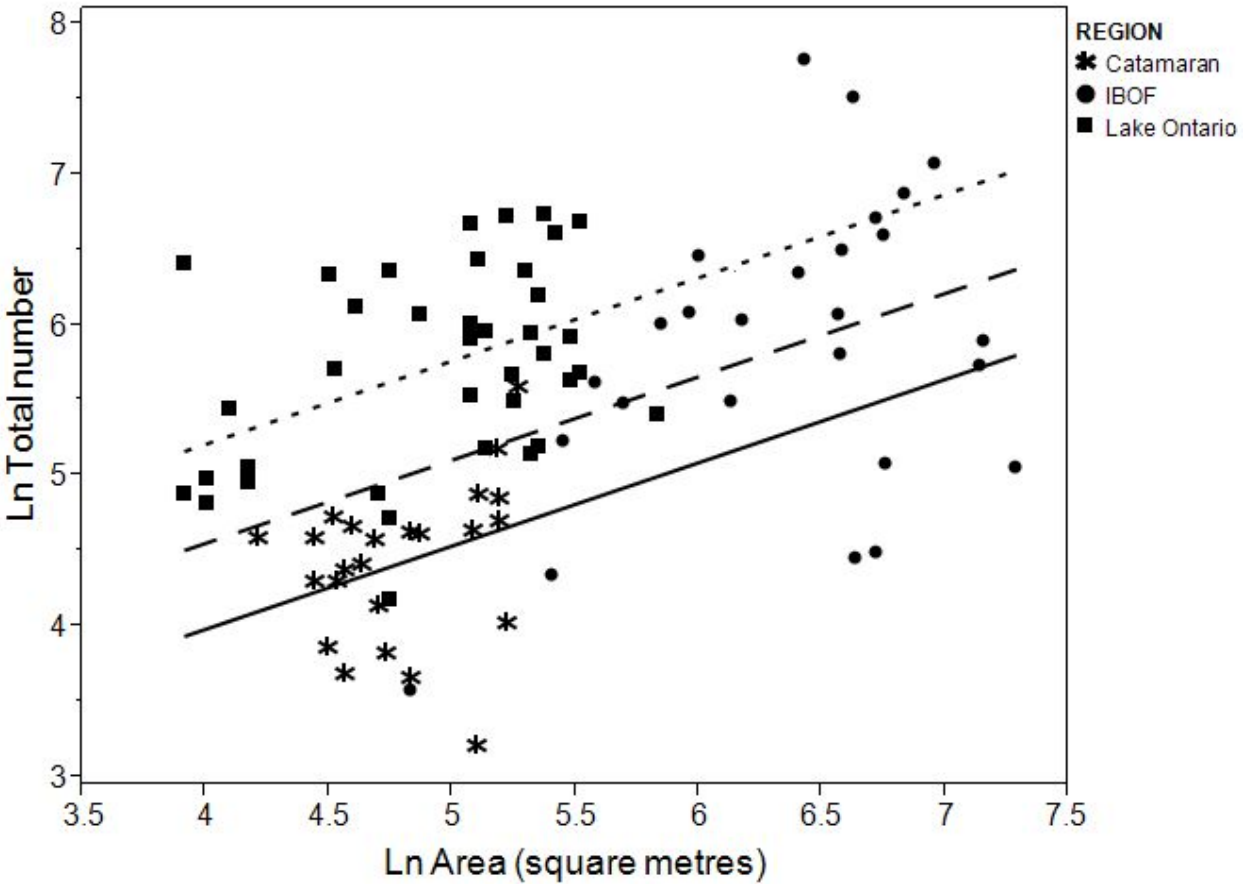

Figure 1. Relationship between the total catch (numbers of fish) and survey area in the three regions. Regression lines assume a common slope among regions (see text). The ANCOVA model was significant ($n=88$, $R^2=0.48$, $F_{3,87}=27.28$, $P<0.0001$), and indicated fish density, adjusted for area, was region-dependent.

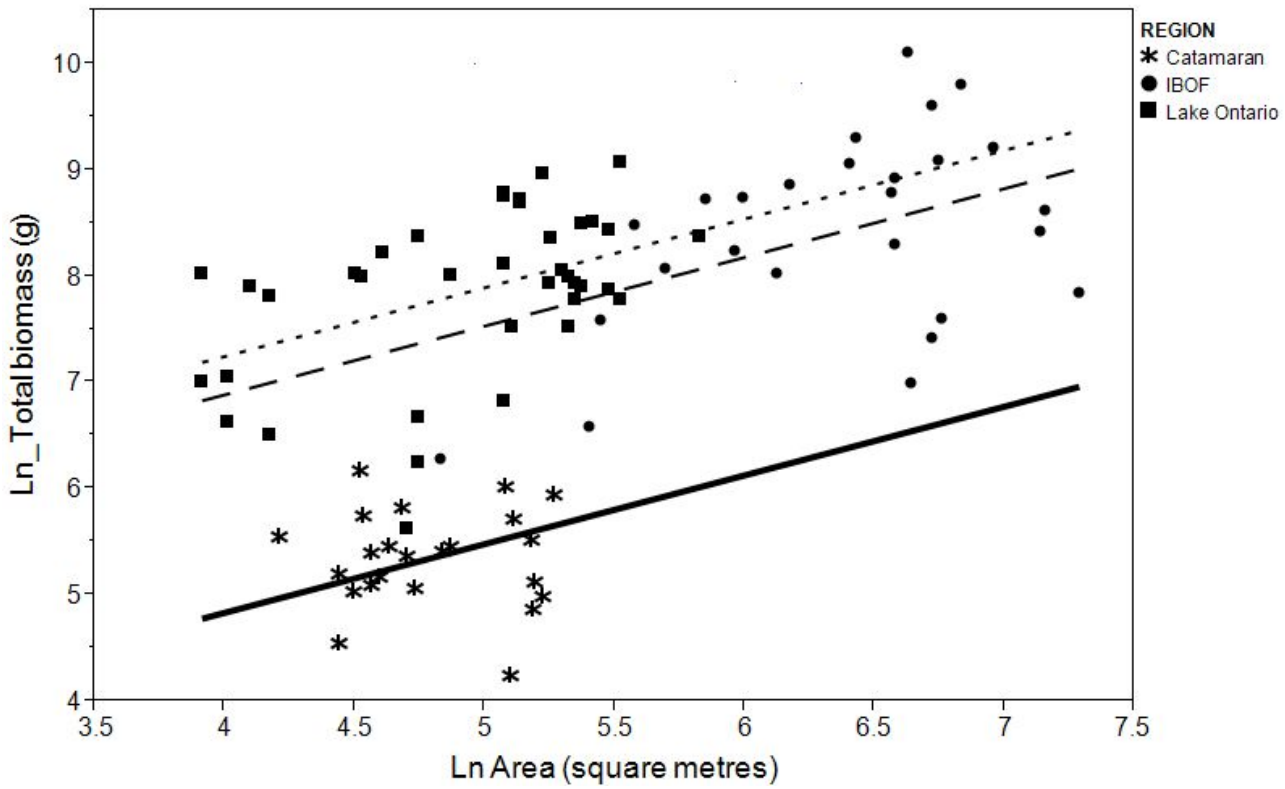

Figure 2. Relationship between the total catch (biomass, g) and survey area in the three regions. Regression lines assume a common slope among regions (see text). The ANCOVA model was significant (n=88, R2=0.77, F3,87=98.5, P<0.0001), and indicated fish biomass, adjusted for area, was region-dependent.

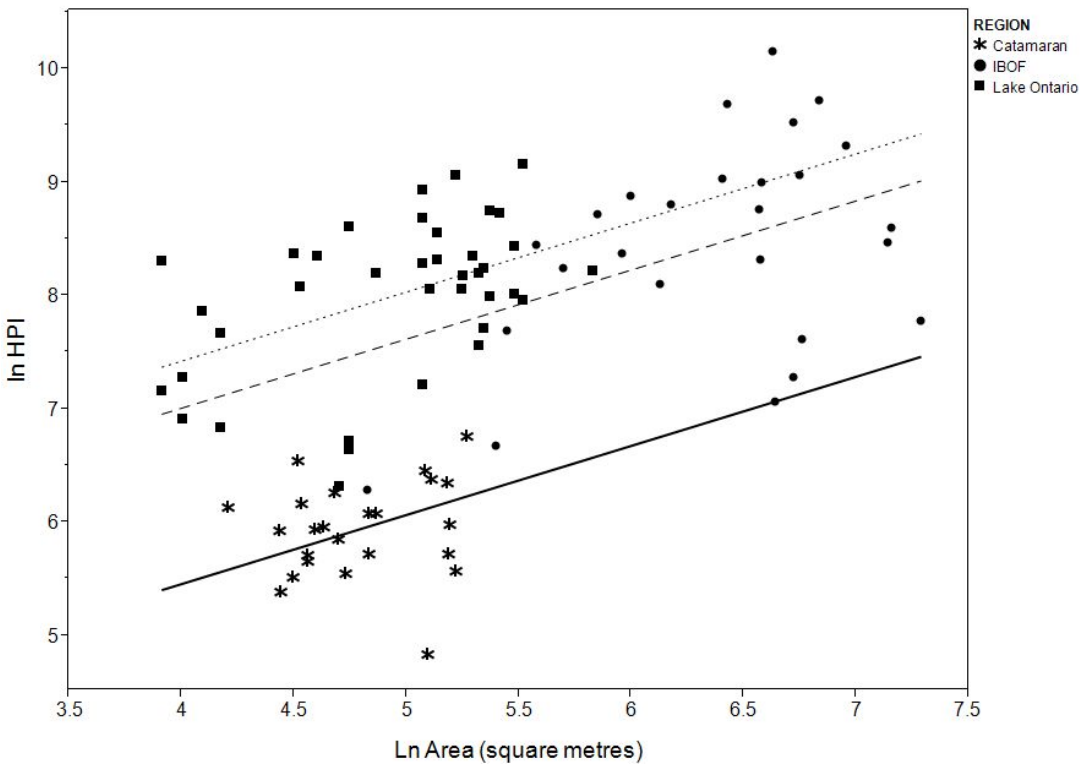

Figure 3. Relationship between the production index (ln HPI, g yr-1) and survey area in the three regions. Regression lines assume a common slope among regions (see text). The ANCOVA model was significant (n=88, R2=0.72, F3,87=76.2, P<0.0001), and indicated fish biomass, adjusted for area, was region-dependent.

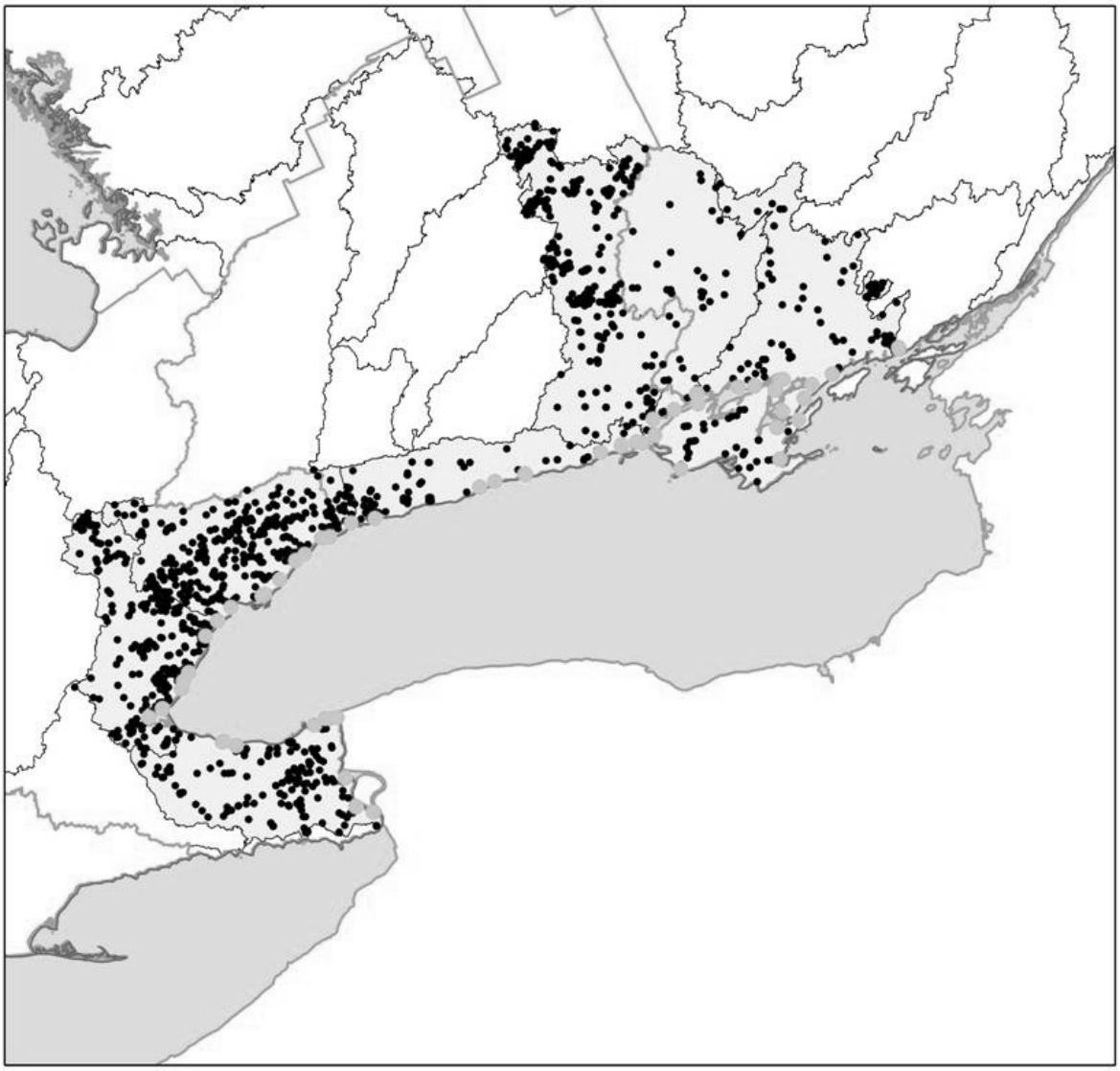

Figure 4. Map showing the number of in-water habitat projects (black dots, project referrals to DFO) within 1 km of the Lake Ontario shoreline, 1989 to 2009, to show the spatial extent of potential monitoring data. From: Program Activity Tracking for Habitat (PATH), Habitat Management Program, Ontario-Great Lakes Area (Carolyn Bakelaar, pers. comm.).