Field Measurement of the Productive Capacity of Fish Habitat – Proceedings of the Second Project Workshop, November 2000.

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Summary

The second workshop for the project ‘Field measurement of the productive capacity of fish habitat’ was held at the Bayfield Institute, Fisheries and Oceans Canada, Burlington, Ontario in November 2000. The objective of the workshop was to provide a summary of the fieldwork completed during the 2000 field season in support of the project objectives. The Productive Capacity project, initiated in 1999, was funded by the Environmental Sciences Strategic Research Fund (ESSRF), Fisheries and Oceans Canada, for a three year period. The objectives of the project were fourfold: 1. Identify linkages between habitat classes and fish production; 2. Develop and document standardized field methods for measuring fish and habitat in lakes and rivers; 3. Develop a production index, to be used as a surrogate of fish production; and 4. Develop standardized methods for monitoring and evaluating habitat compensation projects. To achieve the objectives, the project included partners from Fisheries and Oceans Canada (scientists from St. John’s Newfoundland, Burlington and Sault Ste. Marie, Ontario, Winnipeg, Manitoba, and Cultus Lake, British Columbia) and from the Ontario Ministry of Natural Resources (scientists from Glenora and Peterborough).

Research on defining linkages between physical habitat and fish abundance is ongoing in the Great Lakes, in inland lakes, in streams and in large rivers. In the Great Lakes, habitat classes are being identified using field data from different habitats and a pattern recognition approach. For inland lakes, habitat classes were identified a priori by the investigator, and are being validated and refined with field data. In addition to investigating fish-habitat linkages, comparison of the efficacy of different fishing gears is a goal of two of the inland lake studies (Turkey Lakes in Ontario and Harrison Lake in British Columbia). The objective of research in lakes in insular Newfoundland is to evaluate a Defensible Methods (modified) approach of evaluating productive capacity, using a fish-habitat database prepared for that Region. A study in Algonquin Park, Ontario, is using changes in fish biomass density, as determined using a visual transect method, as a measure of productive capacity in different habitats. Fish-habitat models are the most developed for streams and standardized protocols for collecting field data are available for Newfoundland and Ontario. Research on large rivers in Ontario and Manitoba show consistency in the survey methods that are used, and show predictable differences in fish abundance in channel and shore habitats. A physical energy approach for predicting physical habitat in shallow waters (Erosion, Transport, and Deposition, ETD) was investigated in a large river and at inland lakes, with mixed but promising results. Most of the individual studies are addressing objectives 1-3 of the Productive Capacity project, and both differences and similarities in approaches to evaluating habitat productive capacity among regions are apparent. Progress to date on addressing the individual project objectives was summarized.

Validation of models for linking fish and habitat is critical and a pre-requisite to achieving standardization and transferability of methods for evaluating habitat productive capacity. In future, research is needed on linking the function of physical habitat at a localized site scale to fish population production at a larger geographic scale.

A proposal was made to present the results of the individual studies of this project at a fisheries conference in 2002. In addition, the lessons from this project for evaluating habitat productive capacity will be discussed at a Technology Transfer workshop, proposed for March 2002, involving DFO science and habitat managers.

Résumé

Le deuxième atelier dans le cadre du projet « Mesure sur le terrain de la capacité productive de l'habitat du poisson » a eu lieu à l'institut Bayfield, de Pêches et Océans Canada, à Burlington, en Ontario, en novembre 2000. Le but de l'atelier était de faire un compte rendu du travail accompli sur le terrain pendant la campagne 2000 en soutien des objectifs du projet. Le projet sur la capacité productive, lancé en 1999, a été financé par le Fonds de recherche stratégique en sciences environnementales (ESSRF), de Pêches et Océans Canada, pour une période de trois ans. Le projet poursuivait quatre objectifs : 1. Cerner les liens entre les classes d'habitat et la production de poisson, 2. Élaborer des méthodes normalisées d'évaluation sur le terrain du poisson et de son habitat dans les lacs et les rivières et rassembler de la documentation sur ces méthodes, 3. Mettre au point un index de production, devant servir de substitut à la production de poisson et 4. Élaborer des méthodes normalisées pour surveiller et évaluer des projets de compensation de l'habitat. Afin d'atteindre les objectifs, le projet regroupait des partenaires de Pêches et Océans Canada (des scientifiques de St-John's, Terre-Neuve, de Burlington et Sault Ste. Marie, Ontario, de Winnipeg, Manitoba, et de Cultus Lake, Colombie-Britannique) et du ministère des Richesses naturelles de l'Ontario (des scientifiques de Glenora et de Peterborough).

La recherche visant à cerner les liens entre l'habitat physique et l'abondance des poissons continue dans les Grands Lacs, les lacs intérieurs, les ruisseaux et les grandes rivières. Dans les Grands Lacs, on inventorie les classes d'habitat en utilisant les données de divers habitats et une méthode d'analyse typologique. Dans le cas des lacs intérieurs, les classes d'habitat sont d'abord déterminées par le chercheur et elles sont ensuite validées et précisées à l'aide des données recueillies sur le terrain. En plus des liens entre le poisson et l'habitat, la comparaison de l'efficacité de différents engins de pêche est un objectif de deux des études menées dans des lacs intérieurs (les lacs Turkey, en Ontario, et le lac Harrison, en Colombie-Britannique). L'objectif de la recherche effectuée dans des lacs de Terre-Neuve est d'évaluer les méthodes valables (modifiées) pour mesurer la capacité productive, en utilisant une base de données sur les poissons et l'habitat préparée pour cette région. Une étude menée au parc Algonquin, en Ontario, utilise les changements de la densité de la biomasse des poissons, déterminée à l'aide de la méthode des transects visuels, comme mesure de la capacité productive dans différents habitats. Les modèles servant à établir des liens entre le poisson et l'habitat sont plus approfondis dans le cas des ruisseaux et des méthodes normalisées de collecte des données sur le terrain existent pour Terre-Neuve et l'Ontario. Les recherches effectuées dans les grandes rivières en Ontario et au Manitoba montrent une uniformité dans les méthodes utilisées et des différences prévisibles de l'abondance du poisson dans les habitats riverains et les habitats situés dans le chenal principal. Une démarche axée sur l'énergie physique pour imaginer ce qu'est l'habitat physique en eau peu profonde (érosion-transport-dépôt) a été testée dans une grande rivière et dans des lacs intérieurs et a donné des résultats variables, mais prometteurs. La plupart des études individuelles se penchent sur les trois premiers objectifs du projet sur la capacité productive et on constate à la fois des différences et des similitudes parmi les régions dans les approches d'évaluation de la capacité productive de l'habitat. On a fait la synthèse des progrès réalisés jusqu'à maintenant en ce qui a trait aux objectifs des projets individuels.

La validation des modèles servant à établir des liens entre les poissons et l'habitat est essentielle et il s'agit d'un préalable pour réaliser la normalisation et la transférabilité des méthodes d'évaluation de la capacité productive de l'habitat. Dans l'avenir, il faudra mener des recherches pour lier la fonction de l'habitat physique en un point localisé à la production du poisson à une échelle géographique plus grande.

On a proposé de présenter les résultats des études individuelles du projet à une conférence sur les pêches en 2002. De plus, on discutera des leçons tirées au cours du projet en ce qui concerne l'évaluation de la capacité productive de l'habitat à l'occasion d'un atelier sur le transfert du savoir-faire, qui devrait avoir lieu en mars 2002, auquel participeront le Secteur des sciences du MPO et des gestionnaires de l'habitat.

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Part I: Field Measurement of Productive Capacity: Objectives, Synthesis and Future Goals (*B. Randall*)

Introduction

The second annual workshop for the project 'Field measurement of the productive capacity of fish habitat' was held at the Bayfield Institute, Fisheries and Oceans Canada, Burlington, Ontario on 17 and 18 November 2000. The objective of the workshop was to provide a summary of the field work completed during the 2000 field season in support of the project objectives (Appendix I). The workshop provided an opportunity for individual partners from different regions to interact, to compare methods, and to identify opportunities for collaborative and synthesis work. Nineteen participants from across Canada attended the second workshop (Appendix II).

The Productive Capacity project was initiated in 1999. The project was funded by the Environmental Sciences Strategic Research Fund (ESSRF), Fisheries and Oceans Canada, for a three year period (April 1999 to March 2002). The specific objectives of the project were fourfold: 1. to identify linkages between habitat classes and fish production; 2. develop and document standardized field methods for measuring fish and habitat in lakes and rivers; 3. develop a production index, to be used as a surrogate of fish production; and 4. develop standardized methods for monitoring and evaluating habitat compensation projects. Both science and habitat management products were identified for the project, as listed below (Progress on Project Deliverables). To achieve the objectives, the project included partners from Fisheries and Oceans Canada (scientists from St. John's Newfoundland, Burlington and Sault Ste. Marie, Ontario, Winnipeg, Manitoba, and Cultus Lake, British Columbia) and from the Ontario Ministry of Natural Resources (scientists from Glenora, Peterborough and Thunder Bay). The intent was to hold annual workshops to co-ordinate the activities of the multi-partner project. This report is a summary and proceedings of the second workshop. Proceedings from the first workshop for this project are available (Randall et al. 1999).

This report is divided into two parts. Part I provides a synthesis discussion of the individual reports presented by the partners, a report on the status of products and deliverables for the project; and finally, a discussion of future work in the final year of the project. The workshop agenda, a list of the participants, and a list of the workshop handouts are provided in Appendices 1 to 3, respectively, at the end of Part I. In Part 2, detailed reports by individual partners are provided. The individual reports were presented at the November 2000 workshop.

Individual Reports: a Synopsis

Habitat classes are sometimes used as physical surrogates of productive capacity in the scientific literature. At a mesohabitat scale, these surrogates provide only a coarse quantification of fish habitat. For determining surrogates, the power of resolution (number of classes that are distinguishable) and proper validation are two important issues (Randall, Report 1). Each of these two issues will be used as a focus for comparing the individual projects in a synthesis framework in this section. This focus is relevant to all four objectives of the project, as validation requires that a clear linkage between fish and habitat be demonstrated, habitat classes provide a standardized physical surrogate of productive capacity, and validated surrogates also provide a tool for monitoring and evaluating compensation. For each project, research on alternate fishing gears, survey protocols, and biotic indices of productive capacity are also discussed.

The validation of models linking fish and habitat can be considered at two levels. Level 1 validation is the testing of significant differences in fish density (or some other fish measure) among habitat classes, often followed by cross validation using new data sets. All of the individual projects include level 1 validation.

In contrast, Level 2 testing of habitat classes involves validation at a fish population level. Fish production is a population trait and it is the key measure of habitat capacity. For definitive validation, habitat classes should be evaluated at a large spatial scale (macrohabitat) which encompasses the entire population, but this has rarely been done. One example from a stream study was cited (see Randall, Report 1), where salmon densities by habitat classes, multiplied by habitat area, compared favourably with whole system estimates of salmon abundance. Although differences in growth and production rate among habitat classes was not studied, spatial differences in production was implied. Parasiewicz and Dunbar (2001) cite other examples where clear habitat-population linkages have been demonstrated.

Validation	Description
Level 1	Statistical difference in fish density among habitat classes and cross validation
Level 2	Habitat effect on population production

Modelling habitat suitability in streams has a longer history than in lakes, and often involves linking fish to habitat at a microhabitat scale using, for example, a Habitat Suitability Index (HSI) or Instream Flow Incremental Methodology (IFIM) approach and PHABSIM software. A recent review of fish-habitat models used in streams and rivers, in the context of altered river discharge, is provided by Parasiewicz and Dunbar (2001). Validation applies to these microscale models as well, with transferability from one system to another being the critical extension of Type I validation. Even with the longer history and more sophisticated models, transferability of suitability models in fluvial systems has often failed. Key confounding issues are univariate versus multivariate evaluations of habitat function, failure to consider non-physical factors affecting fish (exploitation, competition with cohabiting species), and habitat influences on distribution versus system effects on production. Recent approaches for developing habitat models are addressing all of these issues (Parasiewicz and Dunbar 2001). One area of research that shows promise is the development of mechanistic habitat models based on fish bioenergetics; these models are relevant because bioenergetics is closely tied to population production. Parasiewicz and Dunbar (2001) emphasized that these models may help overcome problems with the transfer of habitat suitability criteria between rivers. After reviewing the literature, Parasiewicz and Dunbar optimistically concluded that 'a range of new techniques are being developed which are able to model riverine physical habitat in a manner which can be more biologically relevant and easier to generalize'.

Investigation of linkages between habitat function and population production (i.e., Type II validation) could provide a useful common link between lake and river habitat science, ultimately leading to general and transferable habitat models for both types of freshwater systems. Type I validation was implied in the original objectives for this project. Type II validation was not an original objective, except in a larger context for three of the projects (Turkey and Algonquin lakes, Ontario, and Newfoundland). However, it is apparent (as a working hypothesis) that linking habitat suitability to population production is a necessary prerequisite in future to fully achieve standardization and transferability of habitat models in the different regions and habitats across Canada.

Progress of individual projects are summarized below for each of the four main habitat types: Great Lakes, inland lakes, streams and large rivers:

Great Lakes (1 project, lower Great Lakes; reports 1 and 7)

Habitat class resolution: In the lower Great Lakes, meso-scale habitat classes are being identified by analysing fish and habitat data, collected over a number of years, to identify patterns. Preliminary results (regression/discriminant analysis) indicate that the power of resolution is limited, but 3 or more classes based on site exposure, cover and substrate are discernible. Currently, data from the lower Great Lakes are being analysed using a regression tree approach. Maximum fetch distance is being used as the habitat predictor of fish abundance. Fetch is correlated with other physical habitat attributes, including substrate, cover and water temperature. Preliminary results confirm that a number of habitat classes are discernible in the Great Lakes.

Validation: Type I validation using ANOVA and cross validation was used. Fish abundance was significantly different among the regression tree nodes. In future, some Type II validation will be attempted using habitat-production linkages from the field and from the literature. Also, productivity will be determined for lower trophic levels (another project; EcoPath), providing corroborative evidence of habitat-productivity linkages.

Survey protocol: Field work in 2000 was directed at comparing line transect with point sampling techniques to measure the inshore fish community in the Great Lakes. Line transect surveys were used in the past to establish the database, while point sampling was tested for the first time. Results indicated that point sampling is feasible as a survey technique in the Great Lakes. Point sampling provided fish and habitat data from localized areas (i.e., high spatial resolution), making it possible to obtain a large number of replicate samples with specific habitat characteristics. Point and transect sampling provided similar measures of fish composition, abundance and richness, confirming that either method could be used to survey the nearshore areas. Point sampling showed that fish catches decreased with depth, and fish size increased. Whether or not point or transect sampling is used in the future will depend on the objective of the survey. Protocols for surveying nearshore habitat using standardized transect or point-sample methods will be prepared.

Gear: Boat electrofishing is the main fishing gear being used to survey the fish community at the littoral areas of the Great Lakes. In addition, preliminary observations were made on the use of a video camera to determine fish abundance.

During electrofishing surveys, the amount of power transferred to fish is a function of the applied power output, water conductivity and water temperature. Preliminary analyses have been made on the effect of transferred power on fish catches. To reduce variability in fish catches associated with catch efficiency, the electrofishing survey protocol may be standardized by using a constant transferred power target.

Indices: An Index of Biotic Integrity (IBI) and Habitat Productivity Index (HPI) are being compared as fish assemblage measures of productive capacity. Spatial variability in growth (and P/B) of two fish species that are ubiquitous in near shore habitats is being investigated to validate the Habitat Productivity Index.

Inland lakes (4 projects – Newfoundland, Turkey and Algonquin lakes in Ontario, and Harrison Lake in British Columbia; reports 2,3,4 and 9):

Habitat class resolution: Fish habitat classes were determined *a priori* for all of the lake projects. The habitat classes differed in number (4-6) and type, and were judged to be distinguishable and potentially important as predictors of fish distribution by each researcher:

Habitat classes used in inland lakes

Newfoundland[1]	Ontario – Turkey lakes	Ontario – Algonquin	British Columbia
	Coarse woody debris (CWD)	Woody (CWD)	
	Artificial woody debris[2]		
Coarse substrate	Rock	Rocky (rubble, boulder, rock)	Rubble
			Bedrock
Medium substrate		Inlet (delta)/outlet	Sand/gravel beaches
Fine substrate		Sill	Mudflats (some veg.)
Vegetated littoral	Natural vegetation	Cove (emergents)	
	Artificial vegetation[2]	Pipewort (submergents)	
Non-littoral	Open areas		Limnetic

[1] based on a modified Defensible Methods approach; [2] artificial habitat for experiments

Preliminary research on fish-habitat associations in the Turkey Lakes watershed revealed no clear or consistent association between fish and habitat classes. Research on fish-habitat linkages in this watershed is instructive because it is being conducted on an experimental basis (using habitat addition or removal), rather than via pattern recognition (as in the Great Lakes project, for example).

In contrast to the above, consistent patterns in habitat use were found at two small lakes in Algonquin Park. Floating-leaf macrophyte (cove) and inlet delta habitats were shown to be important for supporting fish biomass.

Fish-habitat surveys at Harrison Lake, British Columbia are providing information on the fish use of nearshore areas, which have traditionally not been surveyed extensively. The importance of the littoral zone to salmonid and non-salmonid fishes is largely unknown. As was found elsewhere, the variability in catch rates was high, and it was difficult to detect significant and consistent differences in fish abundance among habitat types.

In Newfoundland, research is proceeding to evaluate/validate fish-habitat associations in lakes using a modified Defensible Methods approach. The Newfoundland Region has recently developed a fish-habitat database for all life stages of fish species in Newfoundland and Labrador (Bradbury et al. 1999).

Validation: Three studies are using Type I validation: differences in abundance or biomass among classes were tested using ANOVA or log linear analysis. For the Turkey lakes study, as part of another ESSRF project, fish production for the entire lake is being measured. Level 2 validation testing will be possible in this study over the long term. In the Algonquin lakes study, change in fish biomass over time (July to August) was used as a measure of production.

Survey protocol: For three of the studies, a stratified random sampling design was used, with samples being collected randomly within each habitat class. In the Algonquin lakes, fish and biomass density was estimated using a visual line transect method. This survey method shows promise for measuring biomass density.

Gear: A variety of gear types are being used. These include: gill nets, small and large minnow traps, trawls, seines, fyke nets, a visual line-transect method, video camera and radio telemetry. Testing the efficacy of different fishing gears is one objective of two of the projects (Harrison Lake and Turkey Lakes). For the Turkey Lake study, minnow trap catches and video camera observations of fish are being compared. Estimates of fish abundance between the two gears were not correlated. In Harrison Lake, small and large minnow traps and gill nets are preferred over other gear types because they can be used in all habitat classes.

Indices: Fish CPUE or counts were used to measure habitat use in two studies. Absolute fish biomass density (g/m^2) during summer was used to measure the productive capacity of habitats in the Algonquin lakes.

Streams (2 projects; Ontario and Newfoundland; reports 2 and 5)

Habitat class resolution: Research in Newfoundland and Labrador on linkages between habitat and fish is broad in scope of activity and geographic area. Four habitat classes in streams that have been used by habitat managers for some time are currently being refined. A literature search of fish-habitat linkages in Labrador has been initiated, and research in a coastal fluvial system is proposed. Data on fish-habitat linkages from remote Labrador areas are unique and badly needed because of the large-scale developments in this region (Voisey Bay mining and hydro development in Labrador).

Stream habitat evaluation in Ontario is based on a Habitat Suitability Index approach.

Validation: In both Newfoundland and Ontario, level 1 validation of habitat classes is being done. In Newfoundland, some work on level 2 validation is also being done (e.g., trout production in the Copper Lake watershed). In addition, the ecosystem project in Newfoundland is directed at understanding how different habitat areas contribute to whole-system population production, and is clearly addressing level 2 validation.

Survey protocol: A protocol manual has been developed for measuring habitat and fish abundance in the streams of southern Ontario. The manual is currently being peer reviewed. Work in 2000 focused on further refinements for standardizing the field effort. Results suggested that the effort required to estimate abundance could be reduced to 5 seconds per square metre, although the abundance of benthic species and juveniles may be underestimated. Catches from past surveys can be standardized by adjusting effort (shock time), using a catch-effort equation which has been developed. There was no advantage in subsampling within study sites. Reference material from undisturbed sites are being collected, and standardized methods for monitoring are being taught in a stream survey training course.

The Newfoundland project also includes work on gear standardization, specifically, testing the efficacy of one-pass electrofishing. Methods for conducting standardized electrofishing surveys in Newfoundland have been documented (Scruton and Gibson 1995).

Gear: In streams, back-pack electrofishing is the only method used for collecting fish. Catch efficiency is high, making it possible to calculate numeric or biomass density using mark-recapture or catch depletion methods.

Indices: Estimates of numeric and biomass density (number or weight of fish per unit area) are used as indices of productive capacity. Fish production rate is occasionally measured directly (Newfoundland).

Large Rivers (2 projects; Trent/Grand in Ontario and Assiniboine in Manitoba; reports 6 and 8)

Habitat class resolution: Large rivers are defined as fluvial systems that are deep and wide such that non-wading techniques must be used to survey the fish and habitat. Quantitative fish-habitat data from large rivers are rare compared to streams or lakes. Identification of discreet habitat classes in large rivers is challenging. Based on a synthesis of the literature, Casselman et al. (1990) identified four general habitat classes in large rivers: channels – large open water regions associated with high flow; shoreline – inshore areas with cover; floodplains – areas of periodic inundation and flooding; and oxbows – landlocked backwater areas in meandering systems. For the two large river projects in this study, channel and shoreline habitat classes were surveyed.

In Ontario, two rivers are being compared, the Trent River and the Grand River, with an emphasis on the Trent. The Trent River has multiple barriers and reservoirs to stabilize the flow, while the Grand has few dams, although one dam/reservoir in an up-river area partially stabilizes the flow. Habitat fragmentation in both systems is a concern, particularly in the Trent. In the Trent, results to date indicate that species richness is a function of distance from the river mouth and proximity to lakes. To estimate species richness using cumulative species curves, more transects are needed in the channel than in shoreline areas. Species richness in the Grand was higher than in the Trent.

In the Assiniboine River study, consistent patterns in fish-habitat distributions were observed between years and sites. A difference in redhorse catches between years was attributed to habitat.

Results from both projects confirm that fish distribution and abundance differs in channel and shoreline areas. In addition, distance from the mouth and proximity to lakes is important in the Trent, and in the Assiniboine, catches are quantitatively linked to substrate and water velocity (Nelson and Franzin 2000).

Validation: Fish-habitat linkages in both large rivers are being evaluated by Level 1 validation.

Survey protocol: Both the Assiniboine and Ontario projects involve similar methods for surveying, line transects at different depths and distances from shore, and show promise for developing a tentative standardized protocol for surveying fish and habitat in large rivers.

Regional patterns in geology are currently being investigated as a predictive tool for determining depth, velocity and substrate characteristics, and the use of these habitats by fish. Results are being used to estimate/predict fish biomass by substrate category. Linkages to regional geology and the Erosion, Transport, Deposition (ETD) method show promise for determining reach-wide estimates of productive capacity.

Gear: Boat electrofishing is being used for surveying the large rivers (both projects).

Indices: Fish CPUE data, by species, is the measure of productive capacity being used in large rivers.

Erosion, Transport and Deposition (ETD) (Reports 10 and 11).

For the purpose of this report, Erosion, Transport, and Deposition (ETD) is defined as a map-based approach for identifying the substrate characteristics of fish habitat. ETD is driven by physical energy and hydraulic processes (water current, wind) and it provides an explanatory model for the habitat features we see in shallow water. The model can be used to inter-relate and inter-calibrate habitat classification schemes in different habitat areas. The ETD principle and methodology applies to streams, rivers, small and large lakes, and to coastal marine habitats.

An introduction and description of the ETD approach and linkages to fish habitat is provided by Franzin et al. (Report 10). The ETD concept is being applied to the Assiniboine River study in Manitoba. In inland lakes in Ontario, preliminary analysis of topological lake units and fish habitat classification demonstrated the methodology and application of the ETD approach. Research in Winnipeg and Ontario is ongoing. In future, the ETD concept has potential as a standardized operational framework that can be applied in different regions across Canada.

Project Deliverables – Progress to date

A list of the planned workshops and the products of the project (science and management) during the three-year time frame are summarized in Table 1 below. The current status of each product is indicated:

Table 1. Summary of the workshops and science and management deliverables for this ESSRF project. Status and progress to date is provided in ***bold italics***.

Workshops:

- Year 1. Detailed project scoping workshop with science and habitat management staff input. Documentation as a Technical Report. (Late summer 1999).

  Completed, November 1999. Proceedings are available: Randall, R.G. et al. 1999. Field measurement of the productive capacity of freshwater fish habitat - proceedings of a scoping workshop. Fisheries and Oceans Canada, Burlington, Ontario. Workshop report, 60 p.

- Year 2. Assessment/compensation monitoring design (protocol development) workshop. Proceedings documented as a Technical Report. (Autumn 2000)

  Completed, November 2000. The focus of this workshop was revised. Partners presented summaries of their research in 2000, and synthesis tasks were discussed. For work on assessment/compensation monitoring design, see the Management Products below. Workshop proceedings are presented in this report.

- Year 3. National technology transfer workshop, documented as a Technical Report (Winter 2002).

  A draft agenda and time frame for the National Technology Transfer Workshop was prepared at the November 2000 Workshop (see Future Work below).

Science Products:

- Year 1. Development and field-testing of a method of estimating productivity for fish from field sampling of abundance, size and growth estimation.

  This product addresses goal 3 of the project. A Habitat Productivity Index (HPI) was developed and published: Randall, R.G. and C.K. Minns. 2000. Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitats. Can. J. Fish. Aquat. Sci. 57:1657-1667. The preparation of a second paper on HPI is ongoing. In addition, the utility of using both HPI and an Index of Biotic Integrity (IBI) to evaluate the fish production and fish diversity aspects of productive capacity is being investigated (paper submitted).

- Year 1-3. Fish-habitat associations by habitat categories.

  This product addresses goal 1 of the project. Research is ongoing by all Project Team Members. Results will be published in the primary literature; most partners will prepare a paper on their project. A proposal to present the results at a special session of CCFFR in January 2002 was tabled at the November 2000 workshop.

- Year 1-2. Comparative testing of sampling methods for fish and fish habitat with emphasis on representativeness and reproducibility.

  This product addresses goal 2 of the project. Research is ongoing by several Project Team Members (Table 2). Results will be documented in the primary literature or as Technical Reports.

- Year 2-3. Description of 'common' habitat indicators of productive capacity across habitat classes.

  This is a synthesis task, which will be addressed in year 3 of the project.

Management Products:

- Year 1 (2). A computer-based standardized methodology for estimating fish productivity of habitats using field assessment data.

  The development and testing of the Habitat Productivity Index is relevant to this product. HPI still requires use/field testing by other partners. For this product, there is a cross-link to Defensible Methods, a computer-based method for determining habitat suitability and net change in productive capacity. Within the project, complimentary modelling is possible, allowing opportunities for comparison with DM. Opportunities for field testing of DM will also be sought.

- Year 2-3. Manual of standardized fish and habitat field assessment methods in freshwaters, including streams, rivers, large lakes (including Great Lakes), and inland lakes.

  An Erosion-Transport-Deposition (ETD) approach for identifying habitat classes using remote data was discussed at the November 2000 workshop, and this method shows promise (see section on ETD above). Current research at Winnipeg and Burlington was presented, and will be included in the Workshop proceedings. The ETD method has application in both lakes and rivers. Other aspects of this product are not yet well defined. A compendium of methods currently used in research (this project and literature) will be prepared, as well as advice/criteria for the selection of fish and habitat survey methods for baseline assessment .

- Year 3. A manual of recommended field fish and habitat assessment plans for use in preparing a project assessment and in designing the monitoring components of compensation agreements. [There would also be advice on how to assemble and use results from multiple compensation monitoring programs to test and assess compensation activities.]

  At the November 2000 Workshop, a proposal was made for Project Team Members to participate and contribution to the Design Standards Workshop, which is to take place in March, 2001. Dr. Carl is leading the planning of the Standards Workshop, and other Project Team Members are on the Steering Committee. Fish Habitat Management is providing funding for the workshop. Project Team Members will be encouraged to attend and contribute to the Workshop.

- Year 3. Joint science-management planning and technology transfer workshops.

  A Technology Transfer workshop is proposed for March, 2002. A tentative outline for the Transfer workshop was drafted at the November 2000 workshop (see section on Future Work below).

Future Work

It was proposed at the November 2000 workshop that a final project workshop be held in November 2001, and that a theme session on productive capacity be proposed at the Business Meeting of the Canadian Conference on Fisheries Research (CCFFR). If the theme session was approved, project members would have the opportunity of presenting the results of their research at CCFFR, January, 2002. It was also proposed that project members could have a brief meeting following CCFFR to discuss and plan the Technology Transfer Workshop. The Technology Transfer Workshop, a final deliverable of the project, would be held in February/March 2002.

A proposed outline for the Technology Transfer Workshop was discussed briefly:

Productive Capacity
- measurement
- linkage to habitat
- linkage to HADD (physical)

Erosion, Transport, Deposition (ETD)
- framework
- small streams, rivers, small lakes, large lakes

Methodological Issues

Management Implications

What's next?

Finally, a number of possible synthesis activities was discussed, including a comparison of fish-habitat survey methods in riverine and lacustrine habitats, an annotated literature search of fishing gear, with comments on limitations and advantages of their use in different habitats, a literature search of habitat survey protocols used in different regions, and a comparison of different fish indices of productive capacity (IBI, HPI and others). Opportunities for addressing some of these tasks will be investigated in the final year of the project.

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Table 2. Summary of the studies which are contributing to this ESSRP project. For each project, information on the habitat measures, fishing gear, fish species of interest, and the components of the ESSRF project which are being addressed are indicated. Table updated from Randall et al. (1999).

Province:	Newfoundland		Ontario					Manitoba	British Columbia
Location:			Several in Ontario south	Algonquin lakes	Turkey lakes	Lake Ontario	Trent	Assiniboine	Harrison
Ecosystem type:	Streams/rivers	Lakes	Streams	Inland lake	Inland lake	Great Lakes	Large River	Large River	Inland lake
Study:	1		2	3	4	5	6	7	8
Habitat Measures									
Depth	✓	✓	✓	✓	✓	✓	✓	✓	✓
Substrate	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cover	✓	✓	✓	✓	✓	✓		✓	✓
Velocity	✓		✓				✓	✓	
Other	Habitat category or type[1] Temperature Weather	Fetch Position Secchi Littoral/pelagic Temperature	Detailed habitat assessment, using a standardized protocol[2]	Use of habitat categories, including rocky, woody, cove, pipewort, inlet and outlet	Habitat categories: woody debris(WD), vegetation (V), open, artificial WD, artificial V	Position Fetch Temperature Conductivity Turbidity	Habitat categories: shoreline, mid-river, proximity to lakes or locks	Stratified sampling, based on substrate	Habitat categories: mud flats, sand/gravel beaches, rubble, bedrock, deep water
Fishing gear	Electrofishing – backpack	Fyke nets	Electrofishing –backpack	Visual	Minnow traps, video	Electrofishing boat	Electrofishing boat	Electrofishing boat	Small and larger minnow traps, trap net, gill nets, seine, trawl
Fish species of interest[3]	Atlantic salmon, brook trout, cohabiting species	Atlantic salmon, brook trout, and cohabiting species	Salmonids and cohabiting species	Nearshore community	Community	Nearshore Community	Community	Community	Sockeye salmon and cohabiting species in nearshore
ESSRF component[4]	1, 2,3	1,2,3	1,2,3,4	1,2,3	1,2	1, 2, 3	1,2	1,2,3	1,2

[1] Beak classification
[2] Stanfield et al. (1999)
[3] Species of economic interest (exploitation) that prompted the interest in habitat studies. Despite these target species of interest, all studies involved data collection at the fish community level
[4] The four ESSRF project components were: 1. Description of fish-habitat linkages; 2. Standardized methods for measuring fish and habitat; 3. Production indices; and 4. Compensation monitoring and evaluation.

Appendix I: Agenda for the Second Workshop –Field Measurement of Productive Capacity

Fisheries and Oceans Canada, Burlington, Ontario 17,18 November 2000

Productive Capacity Workshop (November 17 and 18, 2000)
Canada Centre for Inland Waters, North/South Seminar Room

Day 1: Friday, 17 November, 2000

0830 - 0900	Introduction and workshop logistics. Great Lakes: 1. Standardized electrofishing; 2. Habitat classes (B. Randall).
0900 - 0930	Newfoundland: comparison of fish-habitat assessment methods in rivers and lakes (D. Scruton, K. Clarke)
0930 - 1000	Ontario lakes: comparison of video and trap counts of fishes (K. Smokorowski)
1000 - 1030	**Coffee break**
1030 - 1100	Ontario lakes: repeatability of line transect estimates of density (M. Ridgway)
1100 - 1130	Ontario streams: standardized effort and repeatability (L. Stanfield)
1130 - 1200	Ontario rivers: application of line transect methods in the Trent (L. Carl)
1200 - 1330	**Lunch Break**
1330 - 1400	Great Lakes: Line vs. point sampling (C. Boston)
1400 - 1430	Manitoba: comparison of transect length on catch in the Assiniboine (B. Franzin)
1430 - 1500	British Columbia: Fish utilization of habitat types in Harrison Lake (J. Hume)
1500 - 1530	**Coffee break**
1530 - 1630	Group discussion of projects (Q & A); transferability of results to FHM

Day 2: Saturday, 18 November, 2000

0830 – 0840	Introduction: ETD goals (K. Minns)
0840 - 0930	ETD – Winnipeg study (B. Franzin, P. Cooley; P. Nelson)
0930 –1000	ETD – Ontario study (T. Frezza)
1000 - 1030	**Coffee**
1030 - 1200	Group discussion:use of ETD as a synthesis tool for identifying habitat classes in freshwaters
1200 - 1330	**Lunch**
1330 - 1500	Group discussion: protocols for fish habitat assessment – comparison of fishing gears, survey design and approach in different Regions. Is standardization possible?
1500 - 1530	**Coffee**
1530 - 1630	Synthesis tasks. Transferabililty of results to FHM. Discussion of science workshop in 2001, project deliverables, and an annual habitat science workshop (proposed).

Appendix II: List of Participants

Productive Capacity Workshop, Fisheries and Oceans Canada, Burlington, Ontario 17,18 November 2000

Mandi Clark	DFO, Burlington, Ont.	ClarkMG@DFO-MPO.GC.CA
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Francois Hazel	DFO, Mont-Joli, Quebec	HazelF@ DFO-MPO.GC.CA
Ken Minns	DFO, Burlington, Ont.	MinnsK@ DFO-MPO.GC.CA
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Bob Randall	DFO, Burlington, Ont.	RandallR@ DFO-MPO.GC.CA

Appendix III: List of handout and reference material.

Agenda for Productive Capacity Workshop (17,18 November 2000)

Agenda for Habitat Suitability Criteria Workshop (20,21 November 2000)

Protocols for Fish Habitat Assessment and Synthesis Tasks – Group discussion for Saturday afternoon

Randall, R.G. et al. 1999. Field measurement of the productive capacity of freshwater fish habitat – proceedings of a scoping workshop. Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Burlington, Ontario.

List of activities in the Toronto region for participants staying over the weekend.

Reprints and reference material:

Clarke, K.D. and D.A. Scruton. 1999. Brook trout production dynamics in the streams of a low fertility Newfooundland watershed. Trans. Amer. Fish. Soc. 128:1222-1229.

Nelson, P.A. and W.G. Franzin. 2000. Habitat availability and its utlization by 11 species of fish from the Assiniboine River, Manitoba, with special reference to habitat processes. Can. Tech. Rep. Fish. Aquat. Sci. No. 2313.

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Scruton, D.A. , S.C. Riley, B.A. Bennett, F.T. Bowdring and K.D. Clarke. 2000. A review of habitat suitability criteria applicable to four salmonid species in Newfoundand, Canada. Can. Man. Rep. Fish. Aquat. Sci. No. 2548.

Part II: Individual Projects – Research by project partners during the year 2000 field season

Report 1. Productive capacity of nearshore habitat in the lower Great Lakes: habitat classes, power of resolution and validation *(Randall)*

Dr. Robert G. Randall, Research Scientist, Fisheries and Oceans Canada, P.O. Box 5050, 867Lakeshore Road, Burlington, Ontario L7R 4A6

Introduction

The goal of the productive capacity project is to identify linkages between physical habitat and fish abundance in nearshore habitats of the lower Great Lakes. Because of the large scale, abiotic and biotic surrogates of productive capacity are often needed in the Great Lakes to evaluate the different habitats. A primary goal is to validate existing or to develop new surrogates of productive capacity. Field data collected using line transect and electrofishing methods for a number of years were used to establish a database. Linkages between fish and habitat are being examined using a pattern recognition approach (Minns 2000).

The objective of this report is to provide an update on ongoing research to define habitat classes in the lower Great Lakes. Specifically, observations are presented on methods for defining habitat classes, for identifying the power of resolution (number of discernible classes) and methods for validating the habitat surrogates of productive capacity.

Habitat Classes and Power of Resolution

Severn Sound, a Great Lakes' Area of Concern: Randall et al. (1998) used fish and habitat data collected in Severn Sound, Georgian Bay, to investigate linkages between the physical habitat at localized sites and fish catches. The fish and habitat data were collected in 1990, 1992 and 1995, and included 85 different transects, each surveyed from 2 to 5 times, to provide a total of 236 samples. Transects were 100 metres is length, fish samples were collected by electrofishing, and habitat features were recorded at the time of sampling (substrate, macrophyte abundance, temperature, water conductivity and site location). Exposure characteristics were measured from charts, as the average distance to shore in 16 compass directions. Valere (1996) and Randall et al. (1998) provide details of the methodology for collecting the fish and habitat data.

Randall et al. (1998) used the habitat variables of substrate, cover and exposure to discriminate between two or three fish abundance groups. Samples were divided into groups based on species richness (low, medium, and high), with an equal sample size (approximately) in each group. Habitat variables were used to discriminate the richness groups, and the percent of samples which were correctly classified into each group was determined (Table 1).

The analysis indicated that fish species richness at the nearshore sites depended on the habitat. Two or three groups, each with different habitat characteristics, could be classified with reasonable confidence (Table 1). High species richness was associated with nearshore habitat that was protected from the wind (low exposure) and had abundant macrophytes and fine substrate (silt and sand). Fish catches were lower at exposed sites that had little macrophyte cover. The data in Table 1 are based on fish species richness; similar results were obtained when other assemblage measures or the presence/absence of individual species were used (Randall et al. 1998). The variance in the fish catches was high, and the linkages between habitat and fish abundance, although discernible, was limited in terms of the degree of resolution.

Observations that fish-habitat linkages were discernible in the field were consistent with and supportive of a Defensible Methods approach for classifying fish habitat. Defensible Methods uses a literature database to compute suitability scores, based on the requirements for spawning, nursery and adult habitat (Minns et al. 1995). All species of fish that inhabit an area are used to derive composite habitat suitability values.

Using a GIS database, Minns et al. (1999) developed a habitat classification model for all littoral areas of Severn Sound (343 km of shoreline). Composite suitability index values were derived using habitat attributes and the Defensible Methods model (Minns et al. 1995). Information on rare habitat, wetlands and local expertise was also incorporated into the habitat model. Three habitat classes were identified, representing high, medium and low fish suitability, respectively. The habitat classes were validated by comparison with fish survey data. The fish habitat classification model is currently being used to update a Fish Habitat Management Plan for Severn Sound.

In the longer term, nearshore fish habitat will be classified in Hamilton Harbour and Bay of Quinte as well, two additional Areas of Concern in Ontario. Fish Habitat Management Plans will be developed for these two AOC's.

A similar approach to large-scale habitat mapping has been undertaken in a marine area. A Habitat Suitability Index model was developed for Casco and Sheepscot Bays in Maine (Brown et al. 2000). The model was used to develop habitat suitability maps for six fish and two invertebrate species. As is the case for Severn Sound, these Suitability maps for the coastal areas in Maine will be used to manage habitat conservation and restoration.

Lake Erie and Lake Ontario: During 1994, fish and habitat data were collected at coastal wetlands, harbours and exposed shoreline areas in Lake Erie and Lake Ontario. Details of the survey methods are given in Randall and Minns (2001). Fifty-one transects from this survey were used to investigate potential methods for identifying habitat classes in the lower Great Lakes. The following results are preliminary, and are presented to illustrate the proposed methodology only.

Certain habitat characteristics, including substrate, macrophyte cover and water temperature, were associated with wind exposure as measured by maximum fetch (Fig. 1). Following the methodology used by Minns et al. (1999), a regression tree approach was used to identify habitat classes. The Habitat Productivity Index and the Index of Biotic Integrity were used as dependent variables (in separate regression tree analysis), and maximum fetch was used as the independent (predictor) variable. Randall and Minns (2001) showed that HPI and IBI closely track community fish biomass and species richness, respectively. The TREES module of Systat (Wilkinson 1999) was used to develop the regression trees; least squares was used as the loss function, and the minimum number of cases in each node was set at 10.

Preliminary analyses indicated that maximum fetch was a useful predictor of fish abundance in the Great Lakes. Four nodes for HPI (Fig. 2) and two nodes for IBI (Fig. 3) were produced with fetch as the predictor in the regression tree. The Proportion Reduction in Error (statistic similar to R^2) of 71% and 68% for HPI and IBI, respectively. Fish catches were highest in areas with low exposure to wind, which corresponed to habitat areas with abundant cover, fine substrate and relatively high water temperature (Fig. 1).

It is feasible to identify a number of habitat classes in the lower Great Lakes, and to make inferrences about fish densities and species composition in each habitat with reasonable confidence. Habitat class surrogates of productive capacity will be useful to fisheries and habitat managers.

Validation

Level 1 validation: As noted above, habitat classes in the Great Lakes are being identified using field data to detect patterns in fish-habitat linkages (discriminant analysis, regression tree analysis). Habitat classes can also be decided *a priori* by the investigator (e.g., Ridway, Smokorowski, Hume, ESSRF). Either way, the biological significant of the habitat classes are confirmed by comparing fish abundance in the different classes, using routine statistical methods such as ANOVA (above), non-parametric tests, or by using regression models (e.g., Minns et al. 1999). For regression tree and other statistical procedures, cross-validation using reserved data (additional data not used to build the model) is important for confirming the predictive power of the model. Statistical comparison of fish catches among habitat classes and cross-validation are two important steps for level 1 validation of the habitat classes as surrogates of productive capacity.

Level 2 validation: Estimates of the productive capacity of habitat is an evaluation, either direct or implied, of the fish production rate that the habitat can sustain. Fish production is the best measure of the quantitive performance of a population in a habitat area. Production determines fish yield, and in stable populations, yield cannot exceed a certain proportion of production (Fig. 4). For definitive, level 2 validation, habitat indices of productive capacity should be linked to estimates of population production, but this has rarely been done because of the differences in scale (i.e., localized site biomass versus whole system production). Linking population production to habitat type provides the basis for determining a mechanistic or functional link between the habitat and the fish population.

Quantifative fish and habitat data are easier to obtain in streams than in lakes because of the smaller spatial scale (stream width), shallow water and efficient methods for estimating fish abundance (electrofishing). In particular, population densities and production of salmonids has been well studied in different stream habitats. After a detailed analysis, Caron and Talbot (1993) re-evaluated the habitat classification system which was used for *Salmo salar* in Quebec. The number of habitat classes was reduced from three to two: habitat features (rapids, runs, pools and % sand) could be used to distinquish between dense and sparsely populated areas in the experimental rivers that they investigated. In France, Baglinière et al. (1983) used two methods to estimate the total population size of juvenile salmon in a tributary – a habitat method and a trap method. The habitat method was based on estimates of population density for two habitat classes, multiplied by the area of each habitat class. The trap method was based on counts of migrating salmon at a trap, adjusted for trap efficiency and over-winter mortality (all salmon were anadromous, and exited the river as smolts). The two methods of estimating salmon abundance were highly correlated (Fig. 5). Although the authors were interested in investigating an alternate method of estimating the number of emigrant smolts for population assessment, the results were also useful for evaluating and validating the habitat classes. Validation was at the whole-system population level. Population production rate could also be used, and a study has been proposed for eastern Canada (Randall and Scruton, pers. obser.).

Future work

Studies in both lakes and streams are similar in that different habitat classes, supporting low or high fish densities, can be discerned, but the number of classes may be limited (low resolution). Level 2 validation, where habitat classes are linked to population abundance or production, are rare but feasible. Work to address this level of validation is proceeding in streams and lakes.

In the Great Lakes, a large database will be used to develop habitat classes for nearshore areas, using a regression tree approach (proposed). The efficacy of the model will be tested (level 1) by cross validation with additional data sets. Estimates of fish production have been initiated in bays in the Bay of Quinte, Lake Ontario. It will be possible to accomplish level 2 validation of the productive capacity of habitat types in inland lakes. Results will be relevant to the Great Lakes by extrapolation. In addition, Ecopath models (Froese and Pauly 1998) will be used to compare the productivity at lower trophic levels to fish production in different habitats (C.K. Minns, pers. comm.).

Research is proceeding on validating the use of P/B ratios and the Habitat Productivity Index in different freshwater habitats. Currently, P/B ratios are being compared temporally within populations and spatially among populations of the same species (Randall 2001). The goal is to further develop models for predicting P/B, based on biotic (fish mass) and abiotic (habitat productivity) predictors.

The need for both biotic (HPI) and abiotic (habitat class) surrogates of productive capacity is acknowledged, and the investigation of surrogates will remain a priority.

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Minns, C.K., J.D. Meisner, J.E. Moore, L.A. Greig, and R.G. Randall. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. 1. A prototype methodology for headlands and ffshore structures. Can. Man. Rept. Fish. Aquat. Sci. 2328, 65 p.

Minns, C.K., P. Brunette, M. Stoneman, K. Sherman, R. Craig, C. Portt, and R.G. Randall. 1999. Development of a fish habitat classification model for littoral areas of Severn Sound, Georgian Bay, a Great Lakes' Area of Concern. Can. Manuscript Rept. Fish. Aquat. Sci. No. 2490.

Randall, R.G. 2001. Using allometry with fish size to estimate production to biomass (P/B) ratios of salmonid populations. *Submitted*.

Randall, R.G., and C.K. Minns. 2001. Comparison of a Habitat Productivity Index (HPI) and an Index of Biotic Integrity (IBI) for measuring the productive capacity of fish habitat in nearshore areas of the Great Lakes. (Journal of Great Lakes Research, *submitted*)

Randall, R.G. and C.K. Minns. 2000. Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitats. Can. J. Fish. Aquat. Sci. 57:1657-1667.

Randall, R.G., C.K. Minns, V.W. Cairns, J.E. Moore, and B. Valere. 1998. Habitat predictors of fish species occurrence and abundance in nearshore areas of Severn Sound. Can. Manuscript Rept. Fish. Aquat. Sci. No. 2440.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. No. 191.

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Table 1. Discriminant function analysis with fish species richness as the dependent variable and the habitat predictors of substrate, macrophyte cover, and fetch. Fish species richness was divided into 2 or 3 groups of approximating equal sample sizes. The classification rate, Wilks lambda (significant at P<0.001), Kappa statistic (significant at P<0.05), and the results of a cross validation are shown. Data from Randall et al. (1998).

Species richness	Sample	Wilks lambda	Classification (%)	kappa (95% CL)	Cross validation (%)
2 groups	121,112	0.74	73 (66,80)	0.46 (0.34,0.58)	69 (54,85)
3 groups	58,98,77	0.61	59 (81,29,81	0.39 (0.29,0.49)	55 (64,34,70)

Table 2. Physical habitat characteristics and salmon density in the River Oir, France (from Baglinière et al. 1993).

Habitat	Depth	Velocity (cm/s)	Area (m2)	% of total area	Density[1] 0+	Density[1] 1+
Riffle	< 25	> 40	13,878	32.7	15.1	2.1
Fast run	< 40	30 < V < 40	13,043	30.7	3.2	0.3
Slow run	> 40	20 < V < 30	14,061	33.1		
Pool	> 60	< 20	1,483	3.5	very low	

[1] 1989 data

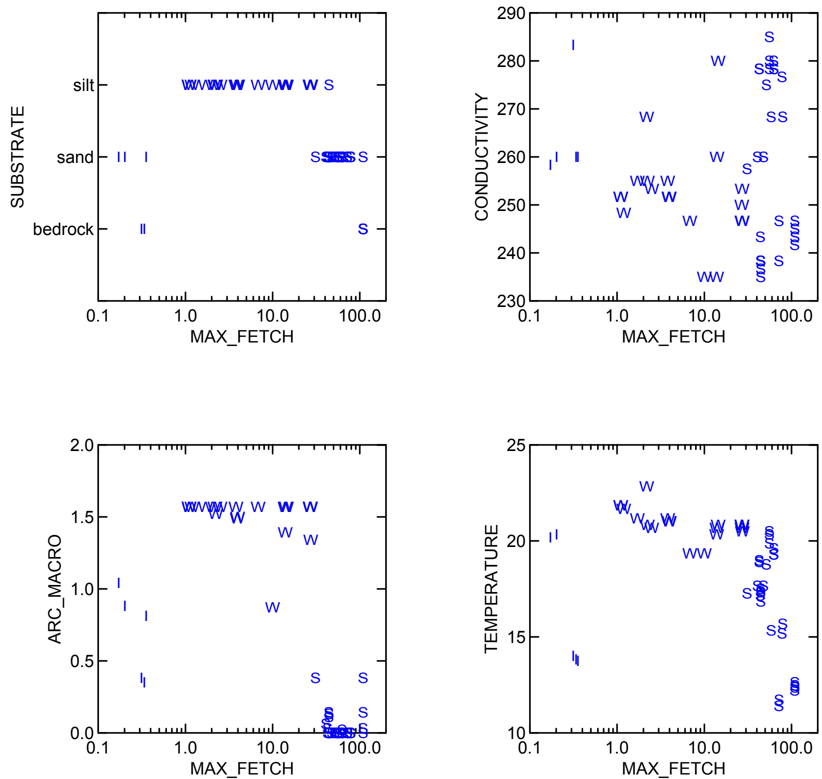

Figure 1. Scatterplots of maximum effective fetch (km) and substrate size, water conductivity, macrophyte density, and temperature at nearshore transects in Lake Erie and Lake Ontario, 1994. Symbols are: W – coastal wetlands; S – exposed shore; I – inside harbour breakwalls.

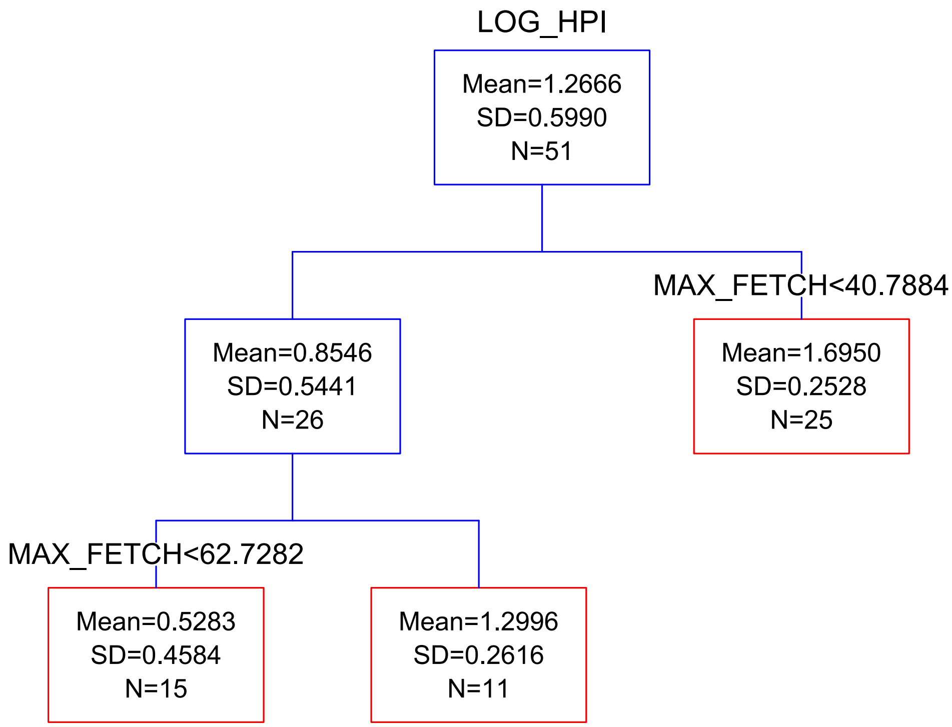

Figure 2. Example of a regression tree analysis, with the Habitat Productivity Index (HPI) as the dependent variable, and maximum effective fetch (km) as the predictor variable. A least squares loss function was used, with a minimum count of 10 at the nodes. PRE = 0.71.

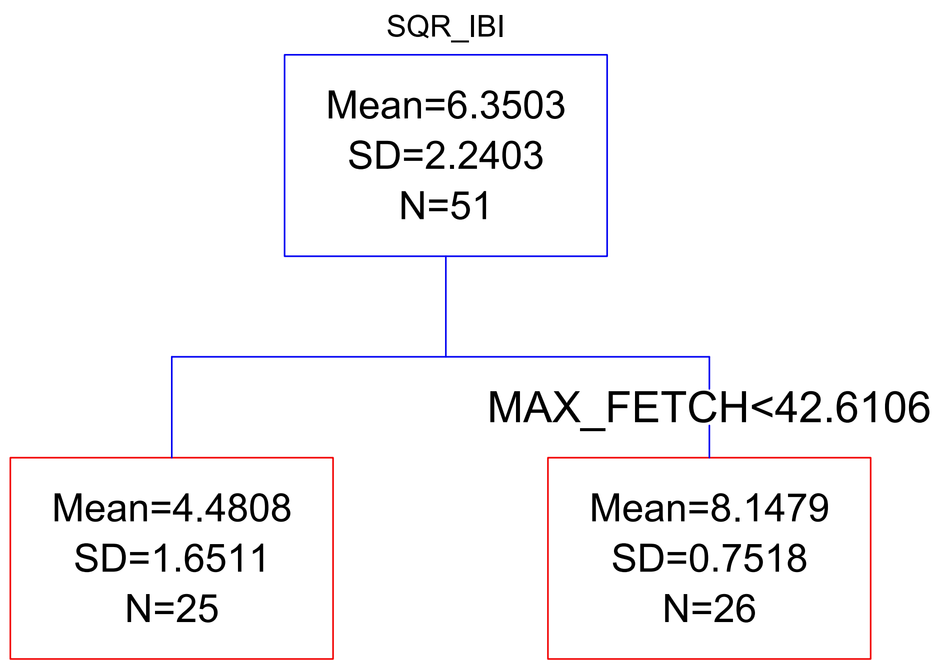

Figure 3. Example of a regression tree analysis, with the Index of Biotic Integrity (IBI) as the dependent variable, and maximum effective fetch (km) as the predictor variable. A least squares loss function was used, with a minimum count of 10 at the nodes. PRE = 0.68.

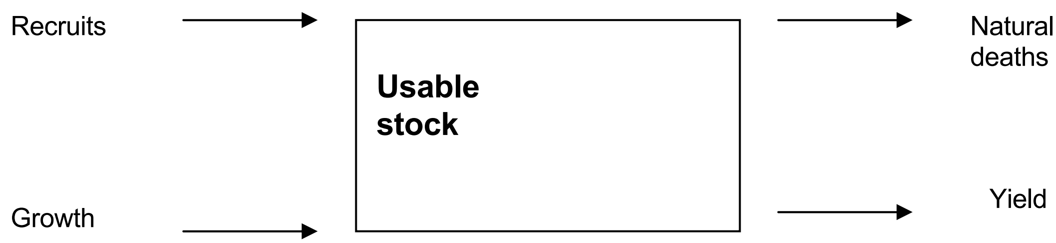

Figure 4. Diagram of the dynamics of a fish stock (from Ricker 1975). To be sustainable, natural and fishing mortality must be balanced by recruitment and growth.

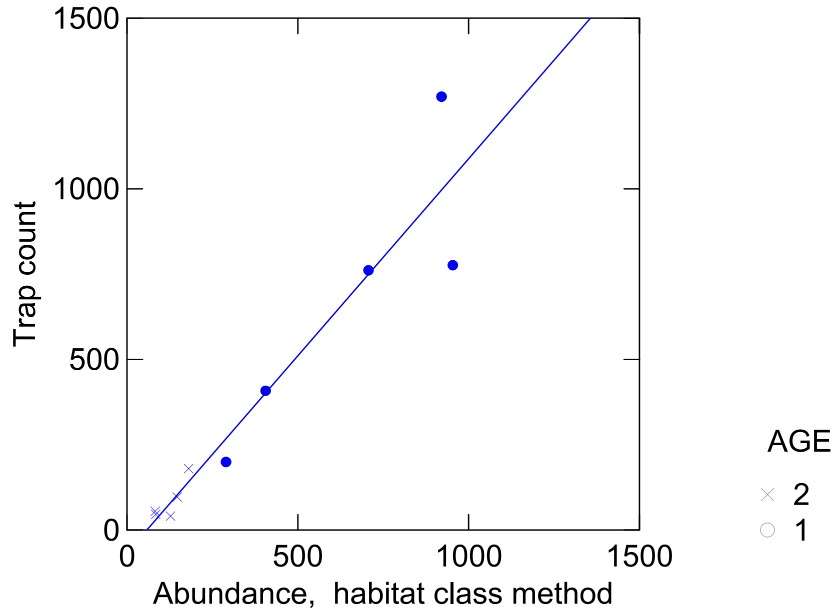

Figure 5. Comparison of the abundance of juvenile *Salmo salar* as estimated using a habitat method (density times area of habitat class) and trap counts over five years. Each data point is a separate year-class. Data from Table 5 of Baglinière et al. (1993).

Report 2. Productive capacity research in freshwater habitats of the Newfoundland Region
(Clarke and Scruton)

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Preface

Productive capacity research within the Newfoundland region has had a broad focus under the national project which for the purpose of this overview has been sub-divided into four major areas of research. These areas include research on: fluvial habitats; lacustrine habitats; an ecosystem study including the role of inter-habitat migration; and the study of productive capacity in Labrador. All of these research initiatives are related and complimentary.

Introduction:

Fluvial Habitats: Fluvial freshwater fish habitats within the Newfoundland region of DFO have been assessed and quantified using a classification system that was developed by Beak Consultants (1980) for the assessment of the Upper Salmon Hydroelectric Development (circa 1978-1980). This is essentially a macro-habitat classification system which delineates 4 major habitat types on the basis of flow (velocity, surface turbulence), depth, and substrate conditions (see Randall et al. 1999). This system was intended for very coarse quantification of Atlantic salmon habitat into units (100 m^2) from aerial surveys (helicopter) for mapping at the 1:50,000 scale. Recently the Beak classification system has been revisited with a view to redefining it on a meso-habitat scale in hopes of making it more robust (Gibson et al. 1987; Randall et al. 1999). The meso-habitat classification or 'Modified Beak' will still be based on 3 key physical habitat criteria (velocity, depth, substrate) but will also try to incorporate cover owing to the importance of that feature for some species (e.g. vegetation for northern pike). The approach is then to link the habitat types with key life stages of fish species which have been identified as: (i) spawning; (ii) YOY, young of the year (< 1 year of age); (iii) juveniles, greater than 1 year of age but not mature; and (iv) adults, mature fish but not in spawning condition. The modified Beak also allows for a more coarse classification, applicable to very large rivers (e.g. the Lower Churchill River), for which the traditional Beak has proven to be unsuitable. This coarse classification identifies habitats as slow, intermediate, or fast in terms of observable flow.

Lacustrine Habitats: Currently, the Marine Environment and Habitat Management Division is undertaking the development of an approach for quantification of lacustrine habitats. This system will be a modification of the 'defensible methods' approach developed by Minns (1997). Lakes will be initially separated into littoral and non-littoral zones (based on secchi depth), and within the non-littoral zone there will be delineation of the true pelagic habitat (open water areas with no association with the substrate). The area of each of 4 substrate/cover classes (coarse, medium, fine, vegetation) will then be quantified (m^2 or units [100 m^2]), separately for littoral and non-littoral zones. Composite habitat suitabilities, considering preferences for depth, substrate, and vegetation, are then calculated for each species/life stage present in the lake. Habitat preferences are contained in a recently completed compilation of habitat requirements for the various fish species, and 4 life stages (spawning, YOY, juveniles, adults; see above for definitions), inhabiting Newfoundland and Labrador (Bradbury et al. 1999). These composite habitat suitabilities, multiplied by the corresponding area of each habitat strata, are then summed to give Composite Equivalent Habitat Units (m^2 or units).

Ecosystem Project: Freshwater systems in insular Newfoundland are generally characterised by low production, simple species assemblages and a high degree of diadromy. These attributes coupled with the tendency of salmonids to use both fluvial and lacustrine habitats (and possibly estuarine) within the early part of their life-cycle in insular Newfoundland creates a myriad of problems when managers evaluate productive capacity within these systems. The relative importance of each habitat to the system or population as a whole is often brought into question. Further more recent studies have indicated that inter-habitat migration within and across seasons may occur more often than once estimated (Erkinaro and Gibson 1997; Hiscock et al.1999). Thus a new project was started in the Stoney Brook watershed (southern Avalon Peninsula, Figure 1) to investigate the relative importance of distinct meso-habitat types to the systems overall production while at the same time evaluating inter-habitat migration over the course of the year.

Labrador: Labrador systems, due to their species assemblages, more closely resemble those of other areas within the Canadian Shield (i.e. Ontario) than their insular Newfoundland counterparts. Thus, it may be possible to utilize and/or test some of the indices/models (SRP Goal 3) developed from the national project in Labrador during the third year of study (2001/2002). It should be noted that most Labrador systems are remote, making it a very expensive place to conduct field work and any field program would have to be piggybacked on other projects. With the onset of the Voisey Bay Mine Project, the pending Labrador Hydro Project and the Labrador Highway extensions these opportunities should become viable within the life of the productive capacity project.

Project Descriptions

Fluvial Habitat: Research within fluvial habitats of Newfoundland will investigate the linkages between physical habitat characteristics and productive capacity (SRP Goal 1) in streams as well as investigating simple methods of measuring productive capacity in the field (SRP Goal 2). This investigation will be conducted on a meso-habitat scale (i.e. pool, riffle, flat etc.) to remain consistent with efforts to modify the Beak classification. A combination of current field projects and historical data will be used to develop the habitat linkages.

The first analyses of historical data investigating habitat production linkages was recently published (Clarke and Scruton 1999). Production estimates were calculated for brook trout from four small headwater streams of the Copper Lake watershed. These estimates were then compared to both water quality parameters and physical habitat attributes. The study found that differences in production among the study streams were attributable to habitat characteristics within the range dictated by the water fertility (Clarke and Scruton 1999). In this specific example production estimates varied up to 6-fold between the study streams. The most important of the habitat attribute was food abundance with substrate composition and habitat complexity playing a secondary role in the most productive stream (Clarke and Scruton 1999). Milhous (1999) hypothesised that one of the determinates of benthic macroinvertebrate biomass (i.e. food abundnace) in Newfoundland is the amount of physical habitat (i.e. Weighted Useable Area).

Current projects include data collection on Northeast Trepassey Brook (1998) located on the Avalon Peninsula, Pinchgut Brook (1999) located on the west coast of the island and Indian Bay Brook (2000) located on the northeast coast of the island (Figure 1). Semi-quantitative electrofishing, snorkeling observations and detailed habitat data (depth, velocity, habitat type, cover and substrate) were collected in these streams throughout the open water period to supplement historical data on habitat-production linkages and to investigate simple methods of measuring the productive capacity.

A preliminary analysis of one pass electrofishing and snorkeling techniques has been conducted for 5 distinct meso-habitats for the Pinchgut Brook data. One pass electrofishing made reasonable estimates of both density and biomass in all sampled habitat types (Glide; Flat; Low Gradient Riffle; Pocket Water and Run) when compared to a historical 10 year average (Figure 2). Abundance estimates from snorkelling data was less reliable. Snorkelling numbers were only comparable to electrofishing estimates (and historical records) in the ‘lease complex habitats’ (i.e. Flat and Glide).

Lacustrine Habitat: A directed field study was conducted during the open water season of 2000 to evaluate the lacustrine guidelines being developed by habitat management staff and to refine the habitat requirements presented in Bradbury et al. (1999) which are largely based on literature values. The study was conducted within two lakes located on the southern Avalon Peninsula with detailed sampling being conducted in June and again in September, a quick 'spot check' fish sample was also conducted in one of the lakes during November. Fish were sampled in specific locations during these times via Fyke nets and seine nets with individuals being fin clipped to indicate position of first capture. Habitat data (depth, substrate, water temperature etc.) was also collected to help determine habitat usage and investigate habitat production linkages. Radio telemetry over the winter of 2000/2001 will also be conducted in one of the systems which will add to our understanding of lake habitat use for specific species (i.e. Atlantic salmon and brown trout). The majority of the analysis of this data is ongoing with a report to be forwarded to the Habitat Management Division by March 2001.

Other initiatives related to lacustrine productive capacity include historical data collected during the Copper Lake Buffer Zone study where both density and biomass estimates of brook trout were conducted on 3 small lakes. Detailed habitats attributes were also collected including bathymetry and substrate characteristics. This data set will allow a further evaluation of the lacustrine guidelines with a quantitative data set (including production). There has also been an investigation by the Newfoundland Department of Forest Resources and Agrifoods, Inland Fisheries and Wildlife Division (Mike van Zyll de Jong) namely the Fyke Littoral Index Netting Program (FLIN). The FLIN database includes detailed habitat and fisheries data on 43 lakes throughout insular NF which may be augmented with data from historical projects (i.e. Acid rain database). For more details regarding this ongoing analysis see Randall et al. (1999). Updating of the FLIN database has been delayed due to the pending move of the Inland Fisheries and Wildlife Division from St. John's to Corner Brook.

Ecosystem Project: One of the main objectives of this project is to develop habitat-production linkages within distinct meso-habitats (SRP Goal 1). This project, however, will expand into both the fluvial and lacustrine habitats within the ecosystem and to account for the temporal interplay between these habitats. This study has just been initiated, and it is ongoing. The first quantitative sampling was conducted in September 2000 and included density and biomass estimates in one small lake (Stoney Pond; see Figure 1) and eight fluvial habitats which included: four riffles; one small pool; two flats; and one large pool. Fish were sampled using the Schnabel mark-recapture technique (Knoechel and Ryan 1994) in the pond and by quantitative electrofishing in all the fluvial habitats (Scruton and Gibson 1995). Pools were surveyed by seining. The preliminary density estimates (Figure 3) were as expected, with the riffle habitats having the most fish followed by the flats, small pool and pond. Sampling in the large pools was not successful and an alternate sampling technique will be utilized in the future.

Inter-habitat use will be evaluated by marking a sub-sample of the population with small floy tags and by radio telemetry. The floy tags will be affixed during both quantitative and less intensive (CPUE) sampling periods. During the initial study, 68 salmonids and 29 American eels (yellow phase) were marked in the fluvial habitats, and 68 salmonid and 79 eels were marked in the pond in September 2000. The first of the CPUE sampling was conducted in early November; an additional 113 salmonids were marking in the pond. It was evident that there was a lakeward migration of post-spawning brook trout between September and November. The first radio telemetry trial was also conducted in early November: seven juvenile Atlantic salmon being tagged in the pond, 13 were tagged in fluvial habitats and 6 adult brown trout were tagged in the lake. Preliminary results indicated that a lakeward migration of juvenile Atlantic salmon was occurring as the water temperature decreased.

Labrador Systems: Currently, in conjunction with Habitat Management and the Area Habitat Biologist, we are conducting a literature review of fish-habitat related data in the Labrador region. The literature search is focused on three geographical areas within Labrador that are important from a habitat management perspective: 1) The Churchill River watershed; 2) the western plateau; 3) coastal systems. The information gathered from this literature search will be used to develop specific hypotheses to be tested in the field. We are also proposing to initiate habitat work in one coastal system next fiscal year (2001/2002). Habitat utilization would be evaluated for the life stages outlined in both the modified Beak classification and the lacustrine guidelines on a meso-habitat basis. This work would provide the baseline information needed to begin evaluating the productive capacity of a Labrador coastal systems.

Summary

Productive capacity research within the Newfoundland Region has focused on SRP goals 1 and 2, and to a less extent on evaluating production indices (SRP goal 3). The broad scope of the work stems from the fact that aquatic systems in insular Newfoundland have low species diversity which may allow salmonids to expand their habitat utilization (Gibson et al. 1993). Also, the low productivity of these systems may mean that all habitats are used by individuals throughout their life-cycle at different times throughout the year. Fish-habitat associations in Newfoundland may be unique because of the low fish diversity and low habitat productivity.

Our research is focused on the fish habitat management needs within our Region, and all projects involve the active participation of habitat management staff. The major objective is to develop usable habitat-production linkages in distinct meso-habitats that are easily recognizable, using classification schemes that are either currently in use or are under development.

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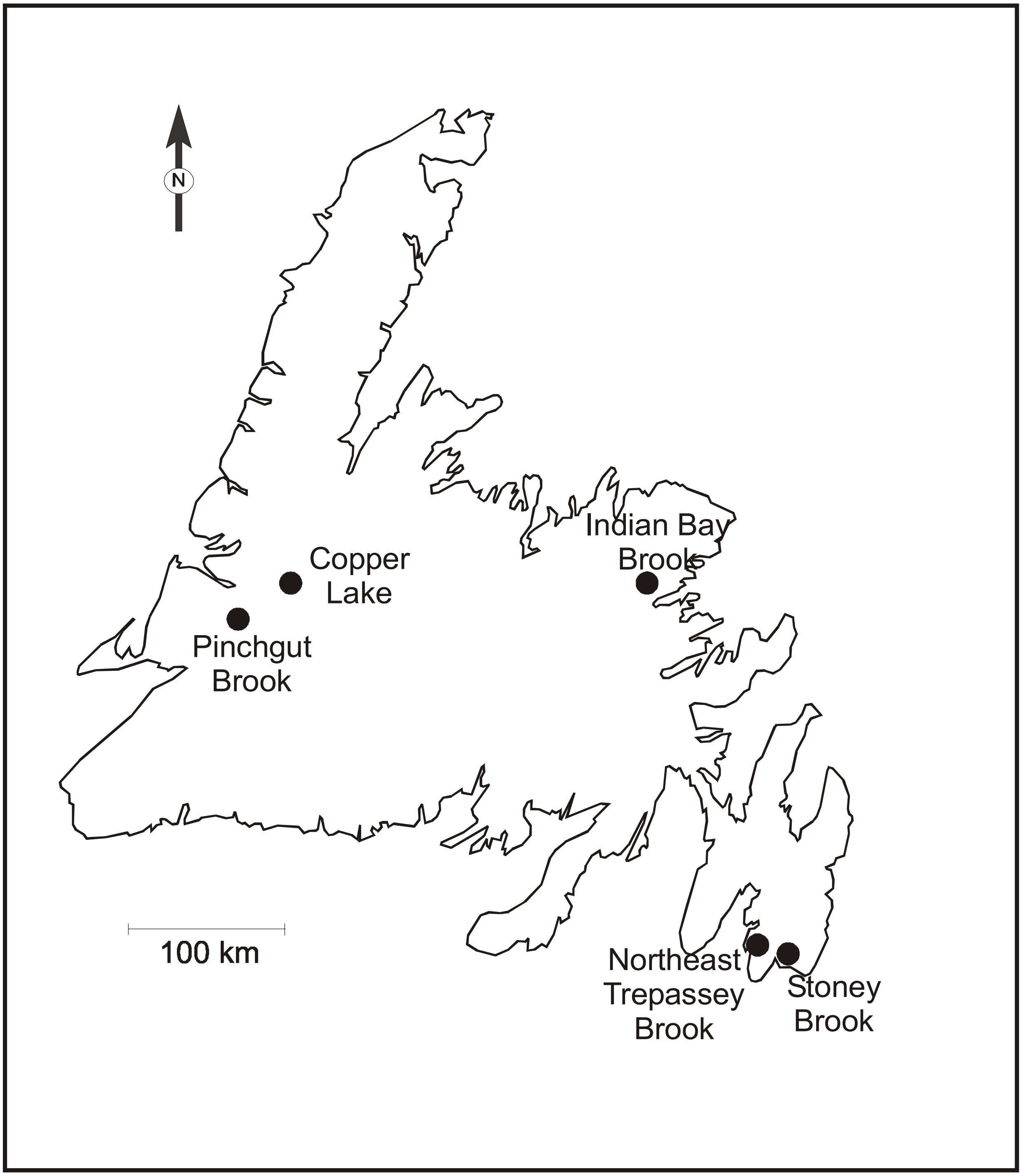

Figure 1: Geographic locations of historical and current projects being used to develop habitat productive capacity linkages within insular Newfoundland.

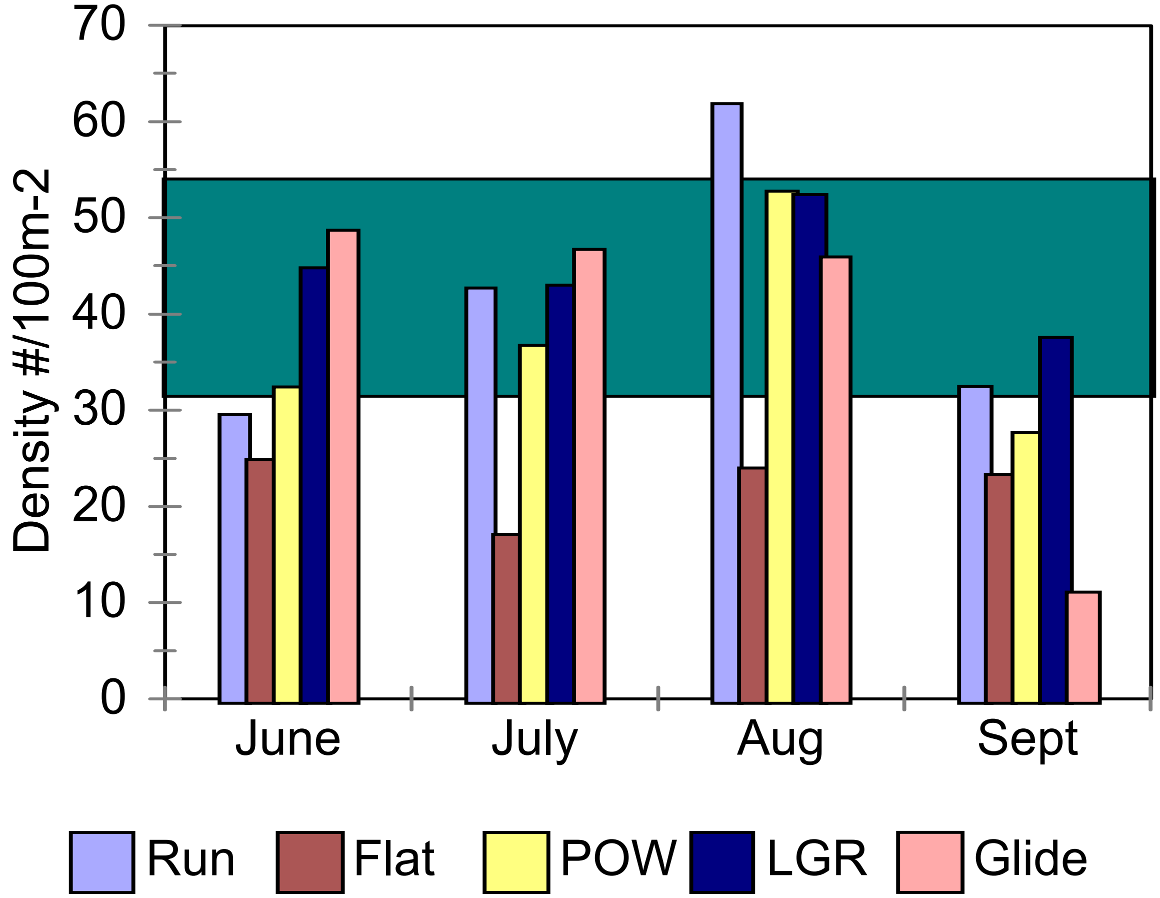

Figure 2: Salmonid densities estimated via one pass electrofishing in 5 meso-habitats of pinchgut brook during the summer of 1999. The band in the backgroud in the range in ten year average density from multiple pass removal (C. Mullins pers. comm. - DFO Corner Brook, Newfoundland).

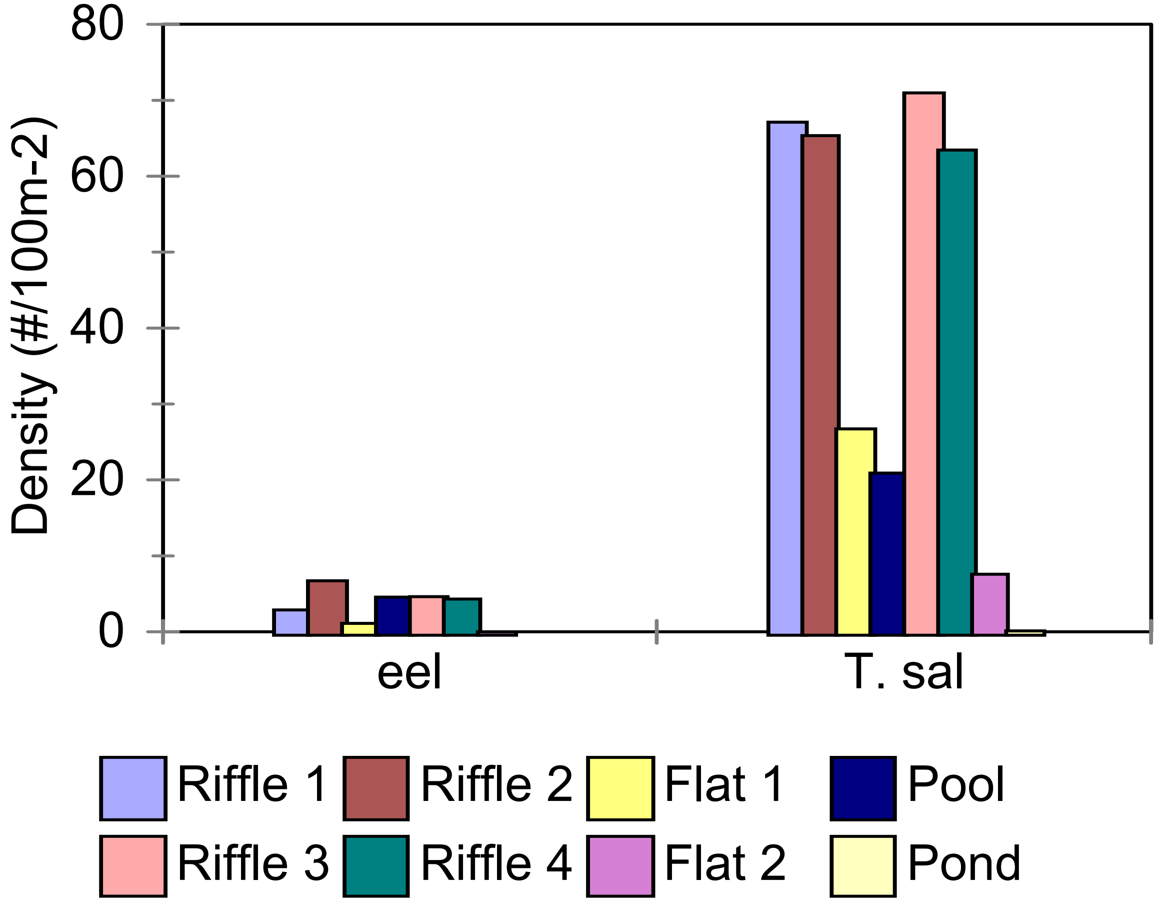

Figure 3: Average densities for total salmonids and yellow phase eels in the meso habitats of Stoney Brook watershed during September, 2000.

Report 3. Assessing nearshore fish community associations with differing habitats by using an underwater video camera *(Smokorowski)*

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Fish/habitat associations and the supply of specific habitat types are used to estimate the productive capacity of fish habitat in aquatic systems and to support habitat management plans based on the DFO policy of no net loss of fish habitat. We developed methods, using an underwater camera, to assess the association of nearshore fish assemblages with habitat. Specifically, we tested if similar habitats in different lakes related similarly to fish relative abundance, and if the relations between fish density and habitat type remained constant among aquatic systems and years. We work in a range of systems differing in size, location, physical habitat, and fish community structure to assess fish/habitat associations and attempt to explain variation in associations among systems. By using an underwater video camera (Fisheye) in combination with habitat data and other fish capture techniques, we will answer:

- Is fish abundance similar among habitats among seasons/years/lakes?
- How does fish abundance as estimated from the video image relate to minnow trap (MT) catches in the same habitat?

Habitat Classes

Habitat categories included both natural and transportable artificial habitats (designed to provide a “standard” habitat measurement and mimic a natural habitat). The six classes of habitat include:

1) **Coarse woody debris (CWD)**: natural log anchored above/at the water line, extending into the water at angles between 30° and 150° from the shoreline. Log diameter is between 15 and 65 cm, and is a minimum of 15 cm off the bottom at the Fisheye (underwater camera) location, with no other piece of CWD within 0.5 m of either side.
2) **Natural vegetation**: areas where there was at least 0.5 m^2 with >5 plants of emergent aquatic vegetation in < 1m depth.
3) **Open areas**: open areas were 2 m x 2 m where there was no CWD, vegetation or boulders.
4) **Artificial coarse woody debris**: a wooden plank (5.08 cm x 20.32 cm x 3.66 m) anchored above the water line and floating on the surface but secured with anchors to the bottom.
5) **Artificial vegetation**: a 1 x 1 m mat of black polyvinyl floor covering with foam strips anchored to the mat simulating macrophytes 40 cm in height and spaced 25 cm apart and placed in an open area.
6) **Rock**: areas where Cobble/rubble were the major substrate. Each of these sites were heavily sloped (>20º) and there was no natural vegetation within 2m.

Data Collection (2000)

We sampled 10 sites in each habitat class, recording 5-min video footage with the Fisheye (underwater camera) at each. We set the camera underwater at the shoreline facing the lake, and commenced the 5-min filming 10 minutes after deployment of the camera in natural habitat and 0.5 hrs after placing the artificial habitats in position. At a total of 10 sites (5 per lake) we filmed complete 0.5 hr episodes immediately after camera deployment to determine the time it takes for fishes to acclimate to the camera. Analysis is ongoing. To compare the fisheye with an alternate fish capture technique, we deployed baited minnow traps (MT) at all sites (10) per habitat class for 0.5 hr sets immediately following each 5-minute filming episode.

We sampled in early June (spring) and mid-July (summer) in Quinn and Little Turkey Lakes in 2000. We observed no fish on film or captured any fish in the minnow traps in the fall 1999. As a result, we did not sample in September 2000 in either lake.

We collected samples in five classes of habitat (1-5 above), in the same locations, in the same 2 lakes (Quinn and Little Turkey) as in 1999. Both of these lakes were subject to habitat modification in the fall 1999 – we removed all coarse woody debris from 50% of the shoreline in each lake (perturbed area). Sites in a perturbed area (approximately ½ the sites) no longer contained coarse woody debris. This had no effect on the open, natural vegetation or artificial sites. However, the natural log sites falling in a perturbed area (Plog on figure) were in reality 'open' in 2000. (For an explanation of acronyms used in figures, refer to Appendix 1)

We conducted a modified version of our methodology in Bayside Quarry, a small (0.37 ha) pond in Southern Ontario in early July 2000. We examined four habitat categories (5 reps in each) around the shoreline – open areas, rock, natural vegetation and artificial vegetation. In addition we sampled eight offshore, mid-lake sites, three of which will have structure added (artificial reef, fall 2000), and the remaining five will remain as is.

Video Analysis

We examined each 5-minute video recording as follows: We split the 5-minute filming period into 60 5-second periods. We randomly sub-sampled 10 of these periods for counting. Initially, we used a cumulative number of fish (all or migrating) and scaled the numbers to a 'per-unit-time' measure. Later, we used a 'mean number of fish per sample frame' to provide an index of fish abundance in each habitat (Fig. 1 & 2: mean of raw counts). Using data collected in 1999, we compared the two counting methods (per-unit-time vs. fish per frame). With each habitat type in Little Turkey as a replicate, the mean number of fish counted by the two methods did not differ significantly (Paired T-test, $t = 1.90$, d.f. = 13, $p = 0.08$). In other words, the method of examining the videotape did not affect our understanding of fish-habitat associations. Video capture and analysis continues and preliminary data are available for the July, 1999 and 2000 sampling for both Quinn and Little Turkey lakes.

To ensure that analyzing 10 5-second periods was adequate to represent the whole 5 minutes, we used a randomized block ANOVA to compare freeze frame counts at 2 sec intervals for 10 five sec counts (30 frames), 20 five sec counts (60 frames) and a whole 5 min count (151 frames). There was no difference between a levels of sub-sampling ($F= 2.264$, d.f. = 2,8, $p= 0.17$). However, the power to detect a difference was relatively low ($1-\beta = .25$). We examined periods by using 3 freeze frame counts taken at 0, 2, and 4 seconds in each five-second period. Due to a high number of 0 counts, fish counts from each of these freeze frame periods were sorted into 4 frequency classes (0, 1, 2, and 3+ fish) (Fig. 3-6: Abundance Classes and Habitat Classes) for all further statistical analyses.

Results

Log-linear Analysis Summary

Northern redbelly dace (*Chrosomus eos*) was the most common species filmed in both Little Turkey and Quinn lakes. Other species seen less frequently in included logperch (*Percina caprodes*) and white sucker (*Catostomus commersoni*) in Little Turkey and Golden shiner (*Notemigonus crysoleucas*) in Quinn Lake.

Results from summer 1999 and 2000 reveal no clear, consistent associations of small fishes with habitat classes. A 3-way log-linear analysis (year-habitat class-fish abundance class) found strong 3-way interaction among factors (Maximum likelihood $\chi^2= 54.0$, d. f .= 21, $p= 0.0001$).

Residual analyses indicated that there were more fish in 1999 than in 2000 in both Little Turkey and Quinn lakes. Isolating years in the analysis helped clarify habitat associations. In Little Turkey in 1999 the natural log habitat classes had the most fish, while the open and artificial habitats had fewer fish than expected. In 2000 the 'perturbed' open sites were associated with the greatest number of fish, while the open sites in an unaltered area and the artificial vegetation were associated with the fewest number of fish. In Quinn the natural log sites had the fewest fish while the open and artificial log sites had the most in 1999. In 2000 again more fish were associated with the open sites while the fewest were associated with the natural log and artificial vegetation. Statistical results from the log-linear analyses are summarised in this section; for details of analyses refer to Appendix 2.

Two-factor nonparametric ANOVA (Scheirer-Ray-Hare extension of Kruskal-Wallis)

The interaction between the treatments NP-log, P-log and the years 1999, 2000 addresses the effect of wood removal on fish abundance. In Little Turkey there were no significant differences between treatments (H = 0.28, d.f. = 1, p = 0.60) or year by treatment interactions (H = 0.0014, d.f. = 1, p = 0.97), but there was a year effect (H = 7.201, d.f. = 1, p = 0.007). Similarly in Quinn, there were no significant differences in fish abundance between treatments (H = 3.43, d.f. =1, p = 0.06) or within a treatment by year interaction (H = 0.173 d.f. =1, p = 0.68), but there were differences between years (H = 4.81, d.f. =1, p = 0.028). In other words, the removal of coarse woody debris did not change the number of fishes associated with that area – in 2000 as many fish were found in a natural log site as in a cleared site (P-log = open in 2000 – Table 1).

Table 1. Sums of ranks with median values of fish counts in brackets. N = 5 for each treatment/year combination.

Treatment	1999	2000
NP-log Little Turkey	73.5 (1.3)	38.5 (0)
P-log Little Turkey	67 (0.26)	31 (0)
NP-log Quinn	57.5 (0.27)	23 (0)
P-log Quinn	76.5 (0.5)	53 (0.13)

Comparison of Fisheye counts and 0.5 hr MT catches

There was no correlation between mean Fisheye counts and MT catches at $\alpha' = 0.013$ (Sequential Bonferroni correction for k = 4 comparisons). *Power was calculated using the corrected α' (Table 2).

Table 2. Correlation between mean Fisheye counts and 0.5 hr MT catches

Treatment	N	r	p	Power ($1-\beta$)*
Little Turkey– July 1999 Mean Fisheye count vs. MT	19	0.5349	0.018	0.45
Little Turkey– July 2000 Mean Fisheye count vs. MT	40	-0.0412	0.801	0.01
Quinn – July 1999 Mean Fisheye count vs. MT	19	0.3437	0.150	0.14
Quinn – July 2000 Mean Fisheye count vs. MT	50	0.0313	0.829	0.01

Future Work:

- Video analyses for Quinn and Little Turkey (spring) and Bayside need to be completed.
- In 2001, the Fisheye sampling will continue in Quinn and Little Turkey (2nd year post wood removal) with two sampling periods (spring and summer). Bayside Quarry (1st year post addition) will be sampled in the summer.
- A gravel pit pond (Gibb) will be added to the suite of systems in the summer of 2001. This system is to receive addition of woody bundles in the fall of 2001.
- The 2000 mark-recapture MT catch-habitat associations need to be analyzed and compared with the 1999 data.
- A method of scaling fish-habitat density estimates (association) to whole lake needs to be established.

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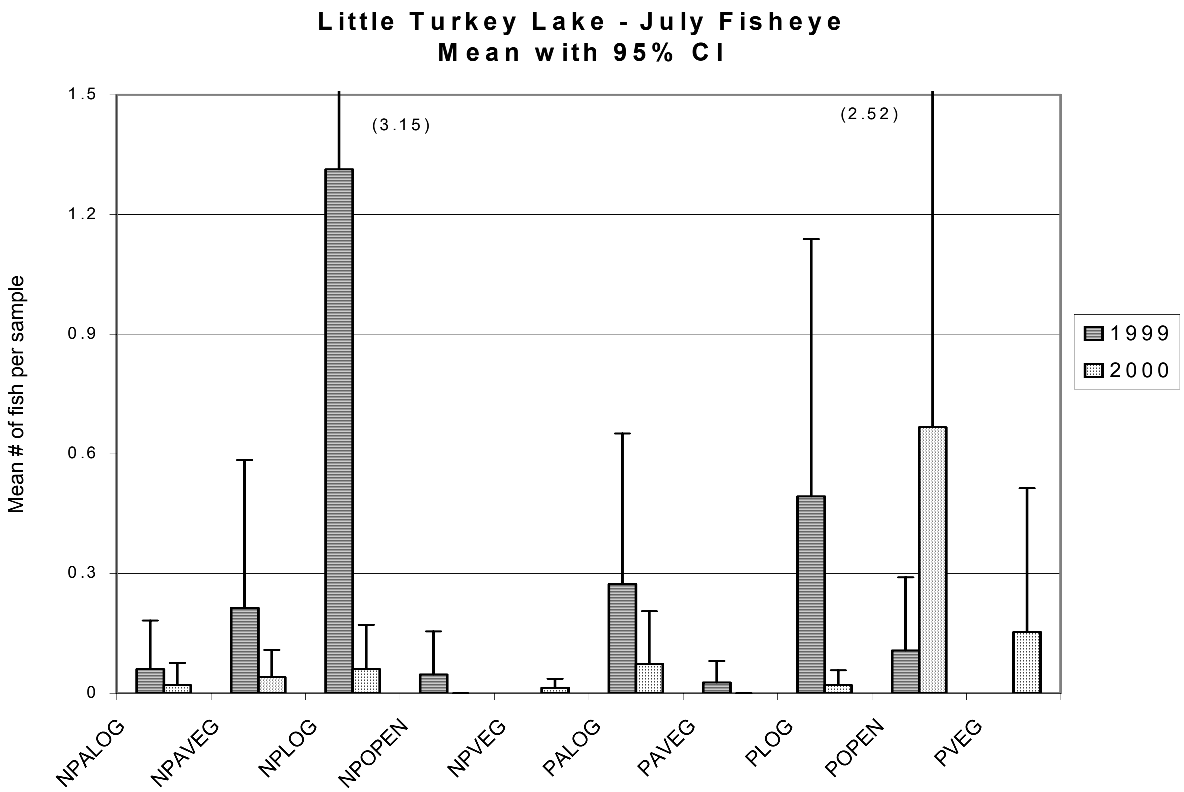
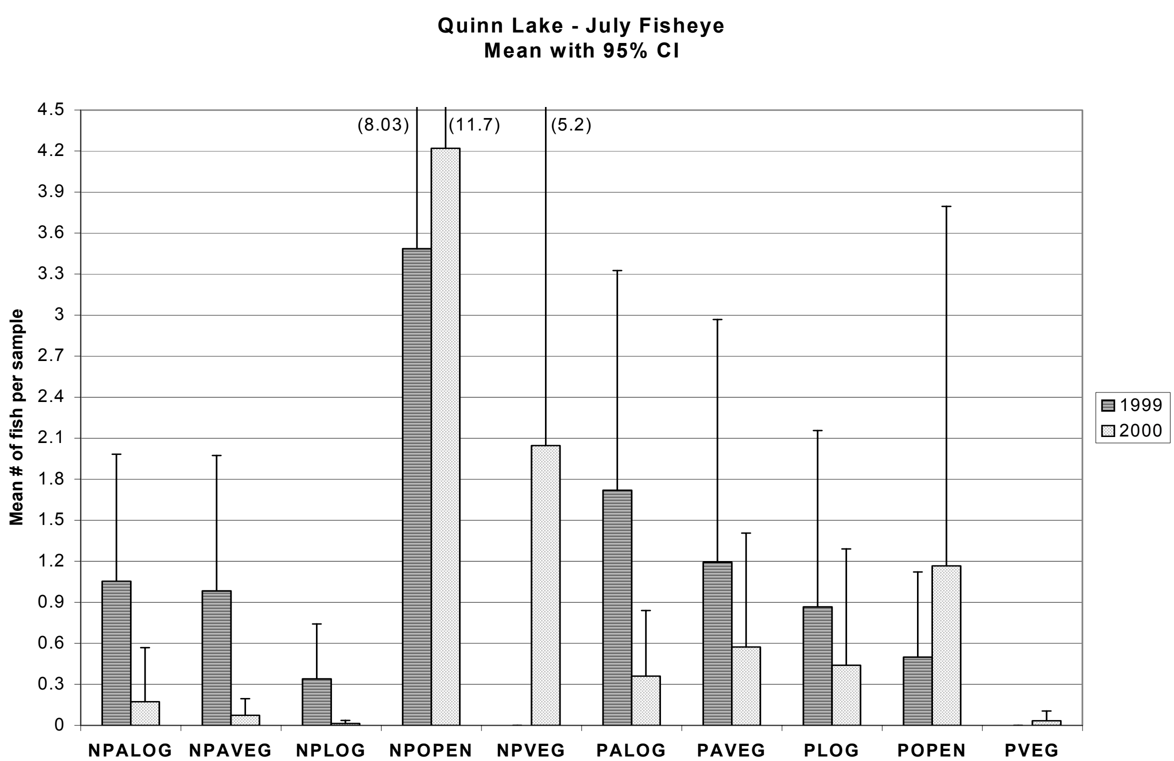
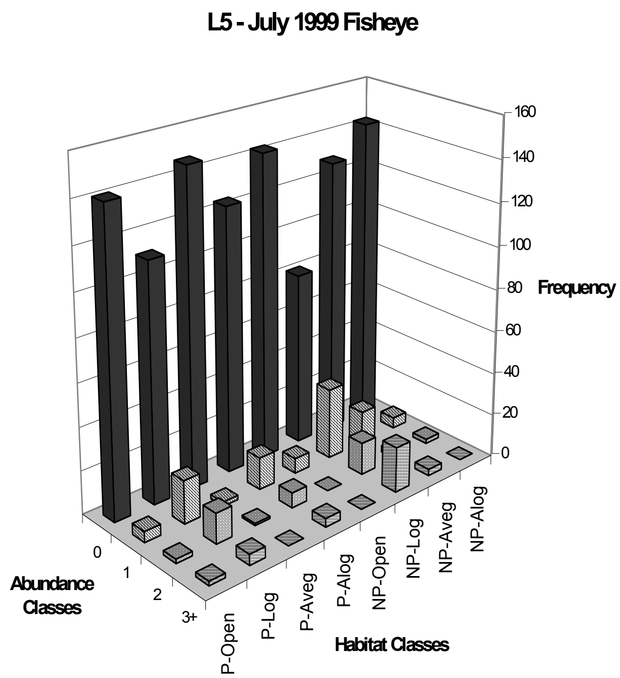
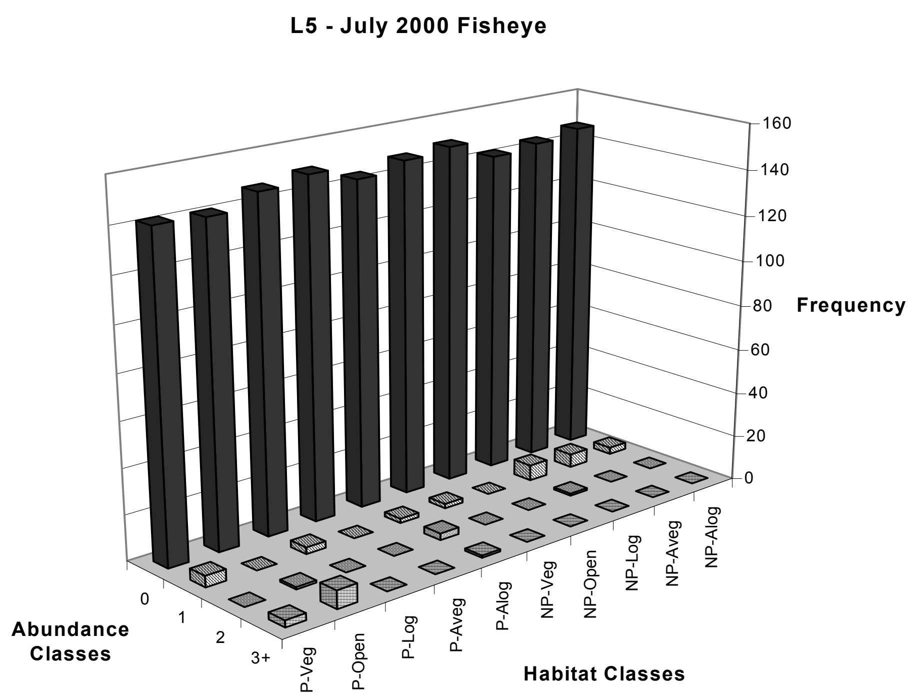


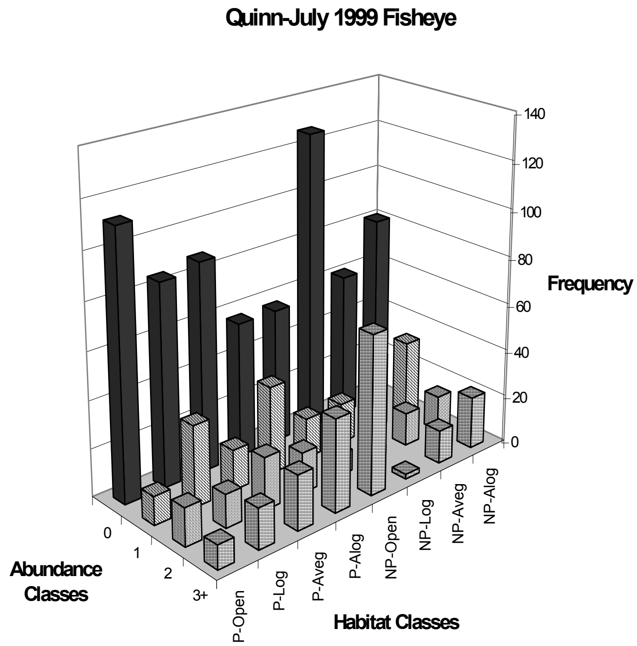


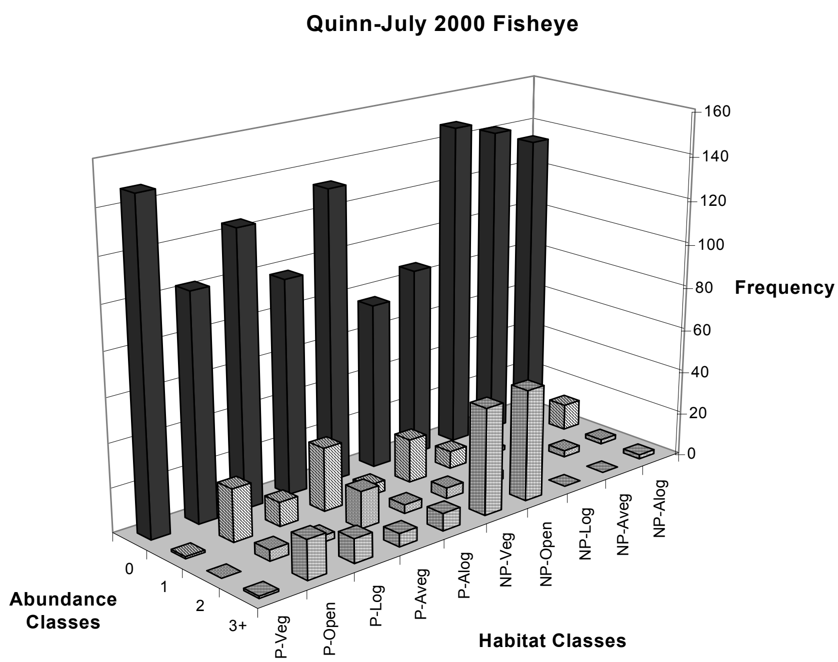
Figures 1 and 2: Mean numbers of fish per sample with 95% CI for Little Turkey and Quinn lakes.





Figures 3 and 4: Habitat classes showing abundance classes for Little Turkey July 1999 & 2000.





Figures 5 and 6: Habitat classes showing abundance classes for Quinn Lake, July 1999 & 2000.

Appendix 1

Fisheye Abbreviations

NP Non-perturbed, where coarse woody debris was not removed
P Perturbed, where coarse woody debris was removed.
Alog Artificial log (plank)
Aveg Artificial vegetation mat
Log Natural Log
Veg Natural Vegetation
Open Open areas with no coarse woody debris or natural vegetation.

Appendix 2

1. Little Turkey Lake 1999 and 2000

Log-linear Analysis Summary:
In our three-factor contingency table, the ln-transformed expected value of a cell is composed of:

$$\ln \hat{f} = \mu + y + t + c + yt + tc + yc + ytc,$$

where y = ln year, t = ln treatment, and c = ln class expected frequencies. μ is just the overall mean expected frequency.

A) Test to show independence among years (y), treatment types (t) and abundance classes (c).

$$Ho : \ln \hat{f} = \mu + y + t + c$$

The three factors were not independent (Maximum likelihood χ^2= 378.37, d.f. = 52, p<<0.0001) because the model was rejected. Because the three factors are not independent, there must be some sort of interaction and the next step is to find where the interaction lies. A hierarchical approach is recommended by Sokal and Rolf by examining the 3-way interaction first. If this is not significant, then the 3 pairwise interactions are examined.

B) Test to determine if the 3-way interaction (year x treatment x class) is the best fit.

H_o: y*t*c = 0
There is a strong interaction among years, treatments and abundance classes (Maximum likelihood χ^2= 54.0, d. f .= 21, p= 0.0001). Because we conclude that the term y*t*c is not 0, there is a significant 3-way interaction. The presence of a strong 3-way interaction eliminates the need to test for pairwise interactions.

Analysis of Residuals:
Year effect:
For the totals of the treatment by year residuals for each class, 1999 had fewer cases of class 0 video counts (-73) than 2000 (73), more cases of class 1 (40.5 vs. – 40.5), class 2 (19.5 vs. –19.5) and class 3+ (13 vs. –13) than expected if there was no interaction. Therefore, there were more fish in 1999 than in 2000 (i.e., more cases of class 1, 2, 3+ and fewer classes of 0).

Treatment effect:
- Using 1999 data only

2-way contingency table: Treatment and class were not independent (ML χ^2 for independence = 191.30, d.f. = 21, p << 0.0001). NP-log treatment had the fewest cases of class 0 abundance and the most cases of classes 1,2,3+ fish (i.e., the most fish). Residuals for NP-alog, NP-open, P-aveg and P-open treatments were of similar pattern and magnitude with the most class 0 abundance, and fewer class 1, 2 and 3+ abundance. That is, NP-log treatment had the most fish, treatments NP-alog, NP-open, P-aveg and P-open had fewer fish than expected if there was no interaction and the remaining treatments showed little interaction (or association) between treatment and class.

- 2000 data only

Test for treatment and class independence (ML χ^2 = 67.17, d.f. = 21, p << 0.0001). Therefore, there is a significant interaction. Here, P-open had the fewest cases of class 0 abundance, and the most cases of class 3+ abundance. P-alog had the most cases of class 2 abundance and NP-log had the most cases of class 1 abundance. NP-open and P-aveg had the most cases of class 0. That is, P-open was associated with the largest number of fish, NP-open, P-aveg were associated with the fewest number of fish.

2. Quinn Lake 1999, 2000

Log-linear analysis Summary:

A) Test to show independence among years, treatment types and abundance classes.

Ho: the terms, y, t, c = 0

The three factors were not independent (Maximum likelihood χ^2= 621.72, d.f. = 52, p<<0.0001).

B) Test for 3 way interaction: Ho: y*t*c = 0.

There was a significant 3-way interaction (ML χ^2 = 143.89, d.f.=21, p << 0.0001) between years, treatments and abundance classes. Again, because there is a significant 3-way interaction, there is no need to decompose the model into pairwise interactions.

Analysis of Residuals:

Year effect:

For the totals of the treatment by year residuals for each class, 1999 had fewer cases of class 0 video counts (-140.63) than 2000 (140.63), more cases of class 1 (52.35 vs. –52.35), class 2 (37.44 vs. –37.44) and class 3+ (50.84 vs. –50.84) than expected if there was no interaction. Therefore, there were more fish in 1999 than in 2000 (i.e., more cases of class 1, 2, 3+ and fewer classes of 0).

Treatment effect:

-1999 data only

Treatment and class were shown not to be independent (ML χ^2 = 204.86, d.f.=21, p << 0.0001). NP-log, NP-open and P-alog and P-open treatments showed the strongest association with abundance classes. NP-log had the more cases of class 0 abundance, and fewest cases of class 1,2,3+ abundance. NP-open had few cases of class 0, 1 or 2 abundance but the most cases of class 3+. P-alog and few class 0 cases, but many class 1 and 3 cases. P-aveg had the most cases of class 2 abundance. P-open had similar patterns of association like NP-log with more cases of 0 abundance and fewer class 1 and 3 occurrences. However, the interaction of P-open with class abundance is not as strong as NP-log since the magnitude of residuals is not as high. In essence, NP log had the fewest fish while NP-open had the most, followed by P-alog.

-2000 data only

Treatment and class were shown not to be independent (ML χ^2 = 251.61, d.f.=21, p << 0.0001). In 2000, NP-open had the most cases of class 3+ abundance, as well as the fewest cases of class 0 abundance than expected. P-aveg also had fewer cases class 0 abundance but mostly class 1 and class 2. P-open had mostly class 1 and class 3 cases with few class 0. NP-alog, NP-aveg, NP-log, P-alog had mostly cases of class 0 abundance. Therefore, the most fish were associated with the NP-open treatment and fewest with the NP-log and NP-aveg treatments.

Report 4. Estimating productive capacity of fish habitat in the shallow littoral zone of Lakes based on the cyprinid community *(Ridgway)*

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Introduction

Conceptualizing productive capacity of fish habitat requires parsing a system-level property, production, among repeatable units of habitat that are distributed around a lakeshore. Two elements must converge for success in this approach of empirically assigning productive attributes to habitat. First, habitat designations must be consistent and repeatable. Second, fish abundance and biomass estimation must be precise and specific to the different habitats. The failure of either one or both of these elements often defines the empirical limits of any research on productive capacity of fish habitat.

In this project, the focus has been on applying line transect distance sampling for use underwater in an attempt to determine precisely the density of fish in different habitats. The purpose of adapting this method for use underwater has been to overcome the limitations of passive gear in estimating fish abundance or presence (Jackson and Harvey 1997). Also, utilizing underwater visual census methods offers the promise of a finer level of precision in defining the location of fish with respect to different habitat designations. The focus of this work has not been to refine methods of habitat definition. Instead, generally acceptable designations (e.g., rocky) have been mixed with two classes of macrophyte communities to develop an overall means of dividing the habitat around the shore of a lake.

Methods

Mykiss and Scott lakes are small Precambrian shield lakes in Algonquin Park that contain self-sustaining brook trout populations. Small shield lakes that support self-sustaining brook trout routinely have a littoral zone fish community comprised of cyprinids, white suckers and benthic fish species. In Mykiss Lake, this fish community contains fathead minnows, dace (*Phoxinus*), creek chub, white sucker and Iowa darter. In Scott Lake, fathead minnow, dace (*Phoxinus*), and brook stickleback comprise the littoral community.

The area of each habitat in the lakes was determined using the Ontario Base Map series at a scale of 1:10,000. Habitat boundaries were set using the OMNR field guide to aquatic macrophyte communities (Harris et al. 1996) and a planimeter to determine lakeshore length in each habitat. In 1999, the width of habitats was the nearshore zone extending 4.75 meters out from the lakeshore margin. This distance was selected because this was the line length used in the transect sampling to determine fish density. This measure was not used in 2000 for two reasons. In Mykiss Lake, line transect length varied depending the width of the littoral zone section being sampled. Typically this line length varied between 4.5 and 7 meters. Therefore in each habitat section in Mykiss Lake, the width of a habitat was the mean line length of transects used in that section. In Scott Lake, the high abundance of littoral fish often made it difficult to carry out a line transect because small movements needed to conduct the transect would cause a response in the proximity and movement of fish. This may have been the result of the warm year in 1999 and the production of abundant littoral zone fish. Whatever the reason, in 2000 I used 1 m^2 quadrats placed within 2 meters of the lakeshore margin in Scott Lake. The areas of the different habitat types in Scott Lake were approximately half the area of these habitats in 1999. Table 1 summarizes the habitat categories and associated areas of each habitat that were in turn used to estimate abundance of fish associated with each habitat.

Table 1. Habitat types and areas in Mykiss and Scott Lakes.

Habitat Areas for Mykiss and Scott Lakes for analysis of 2000 data. All areas in m^2. Two area values for Mykiss represent the areas for the first and second summer samples respectively. One area for each habitat in Scott Lake for both samples	
Mykiss Lake = 20 ha Rocky Habitat = 1,833; 2,006 Woody Habitat = 4,671; 5,148 Cove Habitat = 989; 1,097 Pipewort Habitat = 3,690; 4,152 Inlet Habitat = 701; 799 Outlet Habitat = 1,060; 1,217 Samples collected on July 4-5 and again on August 10-11.	Scott Lake = 28 ha Rocky Habitat = 2,234 Woody Habitat = 1,995 Cove Habitat = 1,935 Pipewort Habitat = 1,916 Sill Habitat = 290 Samples collected on July 7-8 and again on August 8-9.

Rocky habitat shoreline consisted of rubble, boulder and steep rock faces that were largely devoid of aquatic macrophytes or soft sediments. *Woody habitat* consisted of shoreline where coarse woody debris defined the structural complexity of the nearshore littoral zone. In these areas, the number of woody debris pieces can be quite high (> 20 per 20 m of shoreline; Mallory et al. 2000). Since this wood may have been in the water for centuries (Guyette and Cole 1999), and thus represent fish habitat over the long-term, this kind of structural complexity in the littoral zone appears to warrant its own designation. Emergent macrophytes with floating leaves and soft organic sediment define *cove habitat*. On more exposed shores with mineral substrates, the presence of pipewort and water lobelia define *Pipewort habitat*. Pipewort habitat is defined by relatively dense vertical stems of the plant species. In Mykiss Lake only, there is a well-defined *inlet habitat* described by a small delta and plant community as well as a small bay at the *outlet*. These two habitats were distinguished from the other habitats in Mykiss Lake. Scott Lake is a headwater lake with no distinctive inlet or outlet (a large cove habitat). It is a two basin lake separated by a *sill habitat* that is large and flat on the western side of the lake separating two large stretches of woody habitat.

Density estimation of fish was based on distance sampling or quadrat methods in 2000. Distance sampling using the line transect method was used in 1999 in both lakes and again in 2000 in Mykiss Lake only. Quadrat sampling replaced line transect methods in 2000 in Scott Lake. Briefly, distance sampling is based on the ability of observers to detect objects at distances from a line or point (Buckland et al. 1993; Cassey and McArdle 1999). Since detection falls off as a function of distance from the line, the objective is to find objects with 100% efficiency at or near the line and then with less efficiency away from the line. Since detection is the result of a number of factors such as fish behaviour, school size, visibility etc. this method can directly account for sighting bias and therefore lead to more precise estimates of density. For the quadrats in Scott Lake, all fish observed over the quadrat in a quick count (after waiting for 30 seconds or so) were recorded.

For biomass and production estimates, fathead minnows, dace and creek chub in Mykiss Lake and fatheads, dace and sticklebacks in Scott Lake were collected on the first and second sample dates. All fish were dried at 80^{o}C overnight to obtain dry mass estimates for each species in each lake. All biomass and production estimates were based on dry mass estimates in combination with density estimates for each species in each lake. Dry mass estimates for each species were not derived from sampling in each habitat but from a general sample collected in the lake. Results are focused on the data for the cyprinid community as a group, as well as for each of the cyprinid species.

Mean dry mass (grams per fish) and density (fish per m^2) for each species in each lake were combined to obtain biomass density estimates (grams per m^2) for each habitat. The biomass density estimates can be converted to production estimates with an appropriate P/B ratio based on weight at maturity (Randall and Minns 2000). Lake-specific estimates of weight at maturity were not recorded for the cyprinid species in 2000 so species values of P/B listed in Randall and Minns (2000) were used to estimate production (biomass density * P/B). Biomass was based on the mean of two estimates taken approximately one month apart in each lake. The P/B rations used were 1.51 for fathead minnow, 2.07 for redbelly dace, and 1.06 for creek chub.

Results

Based on the distribution of biomass (as dry mass) among habitats in Mykiss and Scott Lakes, the P/B ratios for each species permits a conversion to production per square meter. When this multiplied by the area of each habitat then an estimate of total annual production is possible. These estimates are presented in Tables 2 and 3 for Mykiss and Scott Lakes, respectively. The percent of the total lakeshore habitat represented by each habitat type is also included.

For Mykiss Lake (Table 2), there are clear differences among the three cyrpinid species in the distribution of annual production in lakeshore habitats. Woody debris habitat produced approximately a third of all annual production for each species (as a percentage) but other habitats were ranked differently depending on species. Dace production appeared to be higher in Cove and Outlet habitat relative to the lakeshore area represented by these habitats (15.0% of production vs. 7.6% of lakeshore area for Cove; 24.2% of production vs. 8.3% of lakeshore area for Outlet). Likewise, Cove and Inlet habitat were important areas for creek chub production relative to the areas each of these habitat types represents in the entire lakeshore area (19.8% of production vs. 7.6% of lakeshore area for Cove; 27.5% of production vs. 5.5% of lakeshore area for Inlet). For fathead minnow, the distribution of annual production in Inlet (8.7%), Outlet (11.9%) and Pipewort (32.7%) habitats was higher relative to the representation of these habitats in the total lakeshore area (5.5%, 8.3%, and 28.7% of lakeshore for Inlet, Outlet and Pipewort, respectively).

For cyprinids as a group, the distribution of production in the two largest areas of Mykiss Lake, Woody and Pipewort habitats, was somewhat less than the representation of these habitats in the lakeshore area. In Woody habitat, 32% of all cyprinid production occurred in an area that represented 35.9% of the lakeshore. In Pipewort habitat, 25% of all cyrpinid production occurred in an area that represented 28.7% of the lakeshore. Rocky habitat for all species as well as combined cyprinid production did not contribute in an equivalent way to annual production. In this case, 7.26% of annual cyprinid production occurred in 14% of the lakeshore area. Cove, Inlet and Outlet habitat contributed more production relative to their representation in the lakeshore area depending on species. For total cyprinid production, Outlet habitat appeared to contribute to annual production in proportion to its representation in the lakeshore area. Cyprinid production in Cove (10.8%) and Inlet (11.6%) habitats contributed more to annual production relative to their representation in the lakeshore area (7.6% and 5.5% for Cove and Inlet, respectively).

Table 2. Distribution of annual production (grams) in Mykiss Lake among different shoreline habitats. Percentages in brackets represent the percent of total species-specific or cyrpinid production in each habitat.

Habitat Type	Fathead Minnow	Dace (Phoxinus)	Creek Chub	All Cyprinids	Percent of Total Lakeshore Habitat (13,683 m^2)
Rocky	708 g (9.8 %)	112 g (3.8 %)	94 g (3.8 %)	914 g (7.26 %)	14.0 %
Woody	1,473 g (30.8 %)	942 g (32.1 %)	861 g (35.2 %)	4,027 g (32.0 %)	35.9 %
Cove	433 g (6.0 %)	441 g (15.0 %)	485 g (19.8 %)	1,359 g (10.8 %)	7.6 %
Inlet	630 g (8.73 %)	151 g (5.2 %)	673 g (27.5 %)	1,454 g (11.6 %)	5.5 %
Outlet	858 g (11.9 %)	710 g (24.2 %)	120 g (4.9 %)	1,688 g (8.1 %)	8.3 %
Pipewort	2,360 g (32.7 %)	575 g (19.6 %)	214 g (8.75 %)	3,149 g (25.0 %)	28.7 %
Total	7,213 g	2,931 g	2,447 g	12,591 g	

For Scott Lake (Table 3), there are again differences between the two cyprinid species in the distribution of annual production among different lakeshore habitats. In the two largest habitats, Woody and Pipewort habitat, annual production was similar (e.g., fathead in woody habitat) or somewhat higher for both cyprinids relative to the representation of these habitats in the lakeshore area. In the case of Pipewort habitat, fathead production was noticeably higher (43.6%) relative to the area of this habitat in Scott Lake (22.3%). A similar difference is noted for dace in Woody habitat. Rocky habitat accounted for approximately a quarter of lakeshore habitat but only 5.6% of total cyprinid production. Annual production in Cove habitat was about in proportion to the area represented by this habitat in the lakeshore. Fathead production in the sill was clearly higher than the representation of Sill habitat in the lakeshore area.

Table 3. Distribution of annual production (grams) in Scott Lake among different shoreline habitats. Percentages in brackets represent the percent of total species-specific or cyprinid production in each habitat.

Habitat Type	Fathead Minnow	Dace (Phoxinus)	All Cyprinids	Percent of Total Lakeshore Habitat (8,370 m^2)
Rocky	1,187 g (5.4 %)	592 g (6.1 %)	1,779 g (5.6 %)	26.7 %
Woody	4,945 g (22.6 %)	3,751 g (38.4 %)	8,696 g (27.4 %)	23.8 %
Cove	4,373 g (20.0%)	2,666 g (27.3 %)	7,039 g (22.2 %)	23.1 %
Sill	1,845 g (8.4 %)	222 g (2.3 %)	2,067 g (6.5 %)	3.5 %
Pipewort	9,369 g (43.6 %)	2,527 g (25.9 %)	12,096 g (38.2 %)	22.3 %
Total	21,919 g	9,758 g	31,677 g	

Over half of annual production occurred in the Woody and Pipewort habitats in Mykiss Lake (55% of annual production) and Scott Lake (65.6% of annual production). In Mykiss Lake these two habitats represent 64.6% of habitat in the lakeshore area whereas in Scott Lake these habitats represent 46.1% of lakeshore area. In both lakes, Rocky habitat produced relatively little in terms of annual production when considering the amount of this habitat in the lakes. This is clearly the case in Scott Lake where Rocky habitat was also steep in most locations. However, Rocky habitat was most abundant in downwind locations in both lakes and in 1999 there appeared to be an abundance of young-of-year cyprinids present in these areas due to advective forces of wind and water movements.

Annual production of cyprinids in Cove habitat in both lakes appeared to be in proportion to the representation of this habitat in the lakeshore areas of each lake. In Mykiss Lake, with relatively little Cove habitat (7.6% of lakeshore), 10.8% of annual production took place in coves. In Scott Lake, with large areas of Cove habitat (23.1% of lakeshore), 22.2% of annual production occurred in these areas.

Sill habitat in Scott Lake and Inlet habitat in Mykiss Lake were areas where the proportion of annual production exceeded the representation of these habitats in each lake.

Management Recommendations

- Annual production occurred in all habitats in the two study lakes. However, the distribution of production was not even across all habitats nor was it always in proportion to the amount of these habitats in the lakeshore area.

- Detailed sampling of fish density in the nearshore zone of lakes can reveal patterns of biomass and production distribution among different habitats. It is possible to determine changes in productive capacity in the field and to compare these among different habitats.
- There are species-specific differences in the distribution of annual production among cyprinid species in different habitats. This finding may run counter to most assumptions on the ubiquitous nature of small cyrpinids in the lakeshore area.
- In both Mykiss and Scott Lakes, Woody and Pipewort habitats represented over half of all production in the lake in approximate proportion to the amount of these habitats in the lakes. Annual production of all cyprinids in Cove habitat is also in approximate proportion to the amount of this habitat in the lakes.
- Rocky habitat in both lakes was the least productive relative to both the total amount of annual production estimated to occur in the lakes but also relative the amount of this habitat type in the lakeshore area.
- Unique habitats in each lake, (sill in Scott and inlet in Mykiss), were important sites of production. The importance of these habitats may be based on the broad flat aspect of these areas rendering them warm and productive as well as areas with the potential for nutrient subsidies from other locations in the watershed.
- Focus on habitat assessment of productive capacity should include methods, such as distance sampling underwater, that can increase precision in density estimates.
- Cove habitat and inlet deltas are relatively common across shield lakes and should be the focus of further efforts in the field to assign relative measures of productive capacity. Focusing on repeatable and easily identified habitats, such as cove habitat or inlets, could be facilitated by spatial methods of determining such factors as exposure and fetch. For cove habitat in particular, computer-based mapping of areas with relatively little exposure would be a significant aid to identifying these locations prior to field assessment.
- The data suggest that identification of macrophyte areas (coves in relatively low exposure areas) in shield lakes would be a good first step in any habitat mapping exercise.

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Report 5. Assessing productive capacity in southern Ontario streams: interim report for the fall 2000 Burlington workshop *(Stanfield)*

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Project Objectives

The objectives of this study are to develop a defensible and objective approach to assessing the productive capacity of streams in southern Ontario. This project will build on work carried out over the past 9 years. Past work has resulted in the development of a repeatable yet efficient means of assessing habitat, a quantitative and objective means of linking the habitat conditions to fish communities, and a database for the management of the extensive field data. Future work will be directed at increasing the diagnostic capabilities of these tools, developing new tools to quantify the relationships of landuse and landscape characteristics and productive capacity, and developing a better understanding of the causes of variance in the datasets.

The short-term objectives for the 2000/01 fiscal year were to:

1. Develop a protocol for identifying and characterizing valley segments into areas expected to behave in similar ways to disturbances;
2. Initiate sampling in reference sites which can be used to provide the template for fish and habitat conditions from which to measure disturbance;
3. Revise stream assessment manual and submit for peer review
4. Finalize analysis on the most efficient study design for electrofishing surveys in wadable streams
5. Initiate sampling in wadable streams to evaluate the most effective study design for characterizing the bankfull cross-sectional profile.

Linkages to ESSRF Goals:

Goal 1: Define linkages between habitat categories and fish abundance and diversity.

Suitability criteria have been developed based on habitat attributes and fish biomass. However, fish-habitat relationships tend to have low diagnostic power due to what has been termed the wedge phenomenon (Figure 1). Biomass of fish varied considerably from one site to another, independent of the habitat measure, or temporally at the same site. Unfortunately, field surveys are carried out by people with varying experience (skills) and with varying fishing effort (from 3 – 21 sec/m^2). Researchers have been unable to ascertain the degree to which the wedge phenomenon is due to errors in the model (i.e., an inability to explain biomass from the selected habitat attributes) or to differences in fishing effort.

As reported in the 1999 report, surveys were carried out at Wilmot Creek to compare the catches of fish with different levels of electrofishing effort (5, 10 and 15 sec/m^2). We also evaluated the efficacy of subsampling at sites. Sites were subdivided into quarters and sampled in sequence, keeping catches for each quadrat separate.

The results indicate that, for species and size classes that are vulnerable to electrofishing, five seconds of effort per meter of stream is sufficient to catch most of the fish (Figure 2). There was little difference in mean catches between efforts of 10 and 15 sec/m^2 , except possibly where densities of fish were high. These results indicate that fishing effort at a site played a relatively minor role in determining the numbers of fish captured. Much of the variance in fish density was natural.

We should caution that this relationship was based on sites with moderate densities of fish, that is, less than 250/site or about 0.8 fish /m^2 (Figure 3). Netters have a finite ability to capture fish and as densities increase above this threshold, surveyors must either increase effort or miss fish. In Jones and Stockwell (1995), densities were greater than observed in this study and hence more effort was required to ensure the relationship between one and three pass estimates was maintained. In this study, few sites had densities that matched the high densities observed in 1992, thus effort had little influence on the observed catches.

A second caution is required regarding species-dependent catchability. Catches of bottom dwelling species such as sculpins and lamprey increased with increasing effort (Fig. 4), confirming that there are species and guild differences in vulnerability to electrofishing.

With these cautions in mind, we recommend that project managers with limited budgets and generic objectives, consider the benefits of a study design where large numbers of sites are sampled at lower levels of electrofishing effort.

Given the consistency of the relationship between catch and effort, we were able to develop correction curves for each species to estimate maximum catch. As an example, a curve for rainbow trout fry is given in Figure 5. This curve has not been corrected for instantaneous mortality. These correction curves, once available for all species, can potentially be used to standardize catches by estimating maximum catch, thus improving the ability to compare catches between sites and years.

Given the most efficient study design for effort was to survey at between 5 and 10 sec/ m^2, we used the following formula from Cochran (1977) to determine the most efficient number of subsites to sample (m):

$$m = \sqrt{\frac{s_2^2 c_1}{\left(s_1^2 - \frac{s_2^2}{M}\right) c_2}}$$

Equation 1

Where: S^2_2 = within site variance; S^2_1 = between site variance; c_1 = the cost of travel to and setting up a new site; verses the c_2= cost of sampling and processing data from a subsite; and M the number of subsites sampled (4).

For this analysis we used a 4 person crew with a salary rate of $10.00/hour. We included a set cost of $10.00 to represent the time required to measure out the subsite boundaries (site length and widths). We ran the test using two scenarios, one where the sites were close together such that crews could pack up and travel to a new site in about ¾ of an hour (c_1= $40.00). The second scenario had the sites being a little more spaced out, requiring 1 ¼ hours of travel or c_1= $60.00. The actual sampling cost of a subunit was set at $15.00. For this study the within site variance was twice that (S^2_2 = 1.902) of the between site variance (S^2_1 = 0.891), reflecting the natural differences in distribution of fish within a stream.

For scenario one the most effective number of subunits to sample was 3.5, while it was 4.2 for the second scenario. These scenarios probably cover the majority of field cases and suggest that there is little to be gained from subsampling. Results from this study will be completed and incorporated into the Ontario Stream Assessment Protocol (OSAP) manual (Stanfield 1999).

Goal 2: Development of standardized field methods for measuring fish and habitat in the shallow waters of lakes and rivers

During 2000/01, the OSAP field manual was revised and was submitted for peer review. Results of the work from this project will be incorporated into the manual during 2001. In addition, a study was carried out to determine the most effective study design for characterizing the bankfull cross-section profile in a study reach. Profiles were carried out at 10 m increments along a 500 m reach on three rivers with varying hydrology. Results of this study will be reported in 2001.

Goal 3: Development of a production index to be used as a surrogate for fish production

Sampling of 'least disturbed' streams was conducted across southern Ontario. Regional biologists were asked to use the following criteria to identify sites: 'no signs of hydrologic or sediment alteration at the stie; wood supply in the channel representative of the surrounding valley lands; and no obvious anthropogenic disturbances in the valleylands, upstream for the length of that valley segment, as defined by Seelbach et al (1997)'. However, few sites were found that met these criteria. Instead crews sampled a number of sites that biologists felt were representative of reference conditions within their jurisdiction. Crews documented the magnitude and extent of disturbances found at each site. These data will be used in future to quantify the effect of landscape and landuse conditions on productive capacity.

Goal 4: Standardized methods for monitoring and evaluating habitat compensation projects.

In 2000, a training course was held for users of the OSAP protocols, as applied to monitoring and assessment programs. Advice was also offered to prospective users on study design, to ensure that project objectives can be met.

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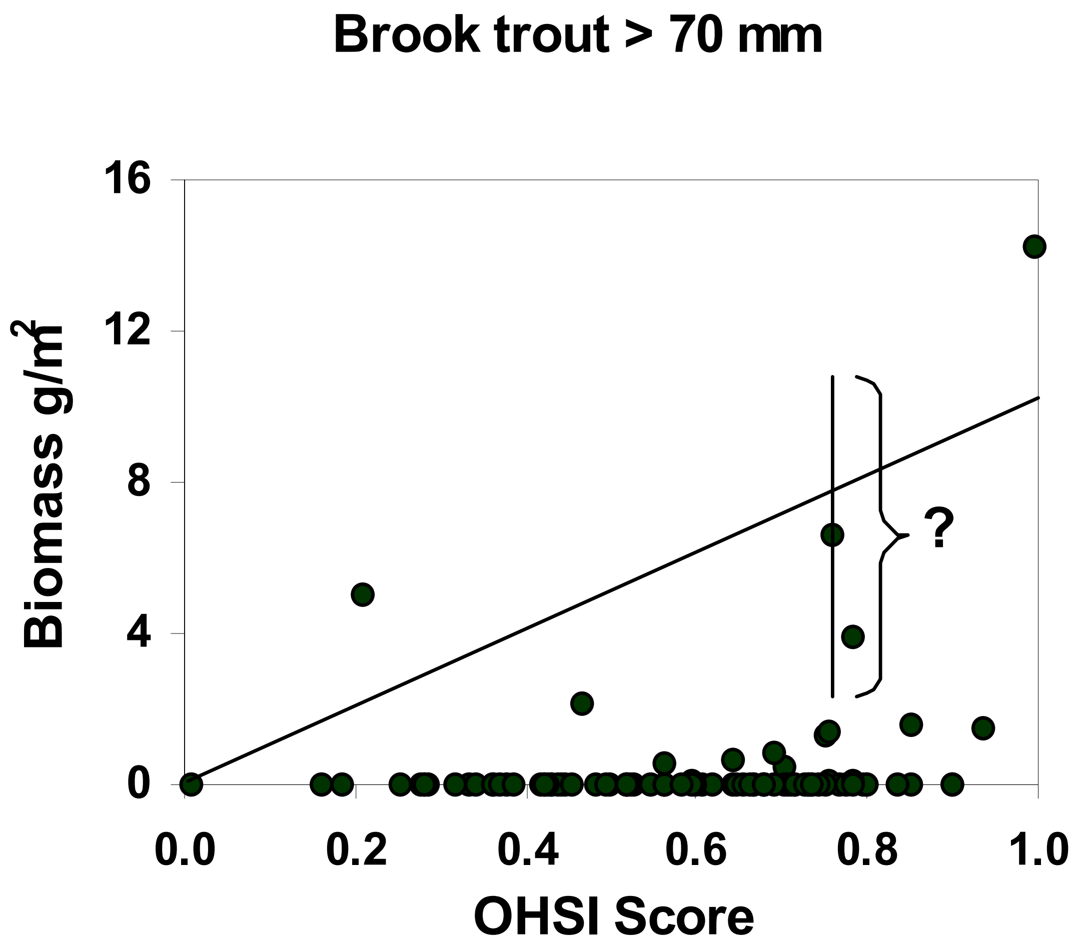

Figure 1: Illustration of the wedge phenomena in comparisons of habitat suitability and biomass

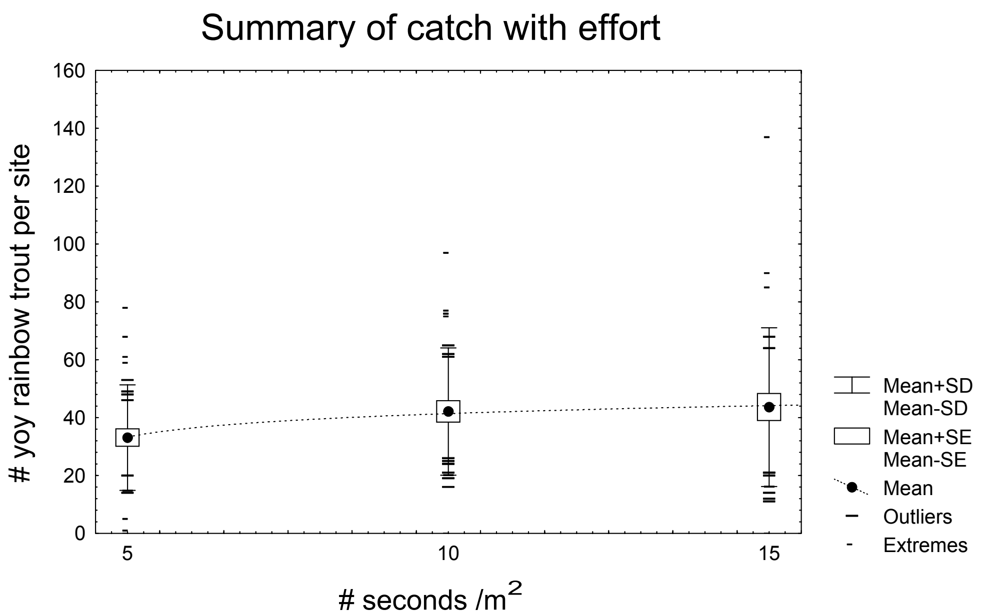

Figure 2: Catch of YOY rainbow trout with effort.

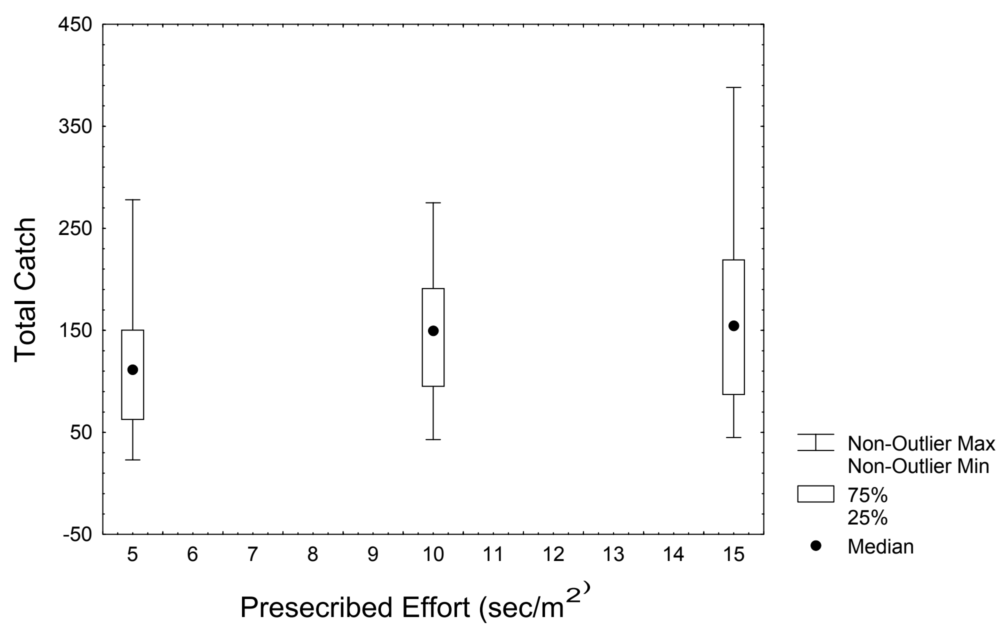

Figure 3: Catch of all fish with effort.

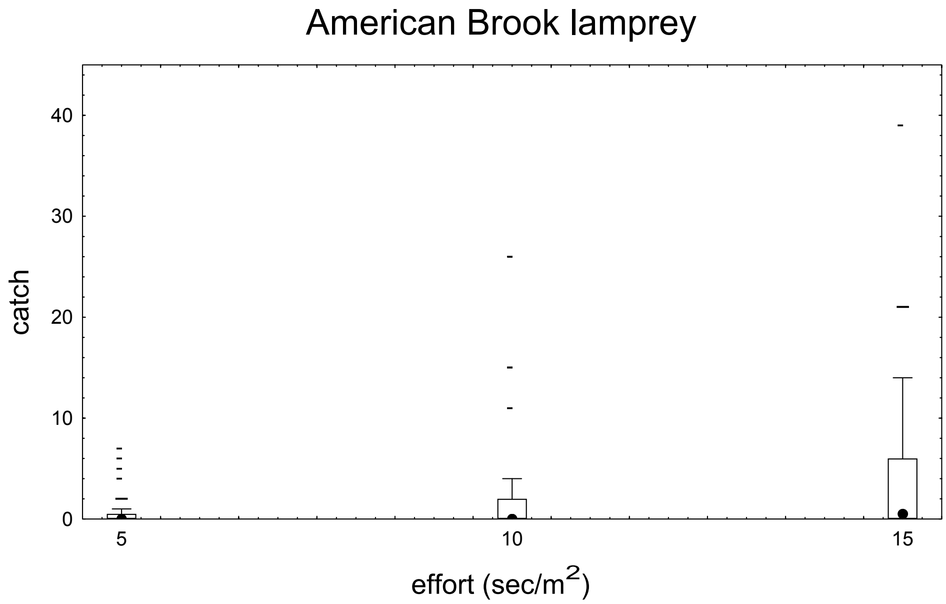

Figure 4: Catch of brook lamprey with effort.

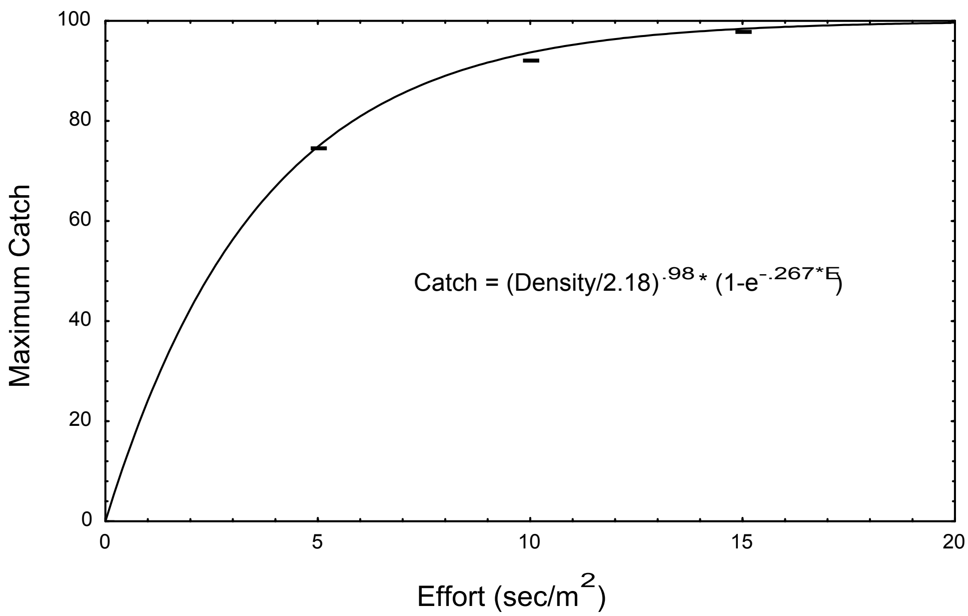

Figure 5: Formula for estimating maximum catch of YOY rainbow trout with varying effort. E = electrofishing effort (sec/m^2); Density = catch from survey.

Report 6. Applied biodiversity of aquatic systems: a comparative examination of the effects of dams and locks on fragmentation, stability, and metapopulation dynamics of fish species and communities. YEAR 2. *(Carl et al.)*

Leon Carl, Chris Wilson and Nick Mandrak. Ontario Ministry of Natural Resources, Peterborough, Ontario

We are assessing the effects of barrier systems on aquatic biodiversity in two river systems in southern Ontario using new standard methods for estimating fish community structure and fish habitat. We are comparing two rivers that differ in the level of fragmentation due to dams. By taking a comparative approach at several hierarchical scales, this study will establish explicit links between barriers and their effects on aquatic communities, species, and metapopulations. We will also determine whether the methods used in the study are suitable for widespread use in non-wadable streams.

Study Rivers

The Trent River system in southern Ontario has been extensively modified over the last century by the construction of multiple barriers. As well, there is an extensive set of reservoirs upstream of the study area that is used to stabilize flow for the lock system on the river. The system has a fairly diverse aquatic community and is highly subdivided. This degree of habitat fragmentation and modification should facilitate the detection of past and present human activities on the resident aquatic communities. The Grand River has few dams and large sections of riverine habitat. It also has a reservoir in an upstream area that partially stabilizes flow.

Sampling methodology

Biodiversity of the resident aquatic communities is being assessed using a hierarchical sampling design. For the Trent, the basic design involves sampling throughout the river system in areas under the influence of dams/locks (above and below), and in adjacent free-flowing sections, to determine fish community attributes. In addition, three reaches within the Trent system that are separated by dams but do not have locks have been sampled. On the Grand River, we sampled 3 valley segments for comparison with the Trent.

The synoptic nature of our sampling will also allow us to examine any cumulative effects of these structures on the fish community. A crew trained by the principal investigators did sampling this summer under low flow conditions. This should reduce sampling error and variability due to temporal changes in community structure. We will also be able to sample other rivers in the future by employing these standard methods and using a staircase design of re-sampling some of our sites on the Trent at the same time.

Habitats were sampled using a 5KW pulse DC electrofisher powering a boom anode. By keeping the amount of power at the electrode constant and using a standard power source, capture efficiencies should be comparable regardless of habitat type. At all sampling sites, standard transect runs were made and electrofishing time recorded along with the number, size and species of fish captured.

For each transect, a lead line marked in 0.5 m intervals was laid parallel to the float line. An underwater video camera was used to film the substrate. Velocity and depth were also recorded. Data will be analysed this winter.

ESSRF Goals

This year's work examines ESSRF Goal 2 – development of standardized field methods on large rivers. In the next year we will also examine linkages between habitat and fish abundance and diversity that support Goal 1.

Potential for further research and adaptive management

If the sampling protocol adequately describes the fish community in the Trent and the Grand Rivers, we will pursue using it on a river without barriers to verify its usefulness. Following this, we will recommend field-testing by management agencies in Ontario.

If the results from the Trent show that locks have an ameliorating effect on habitat fragmentation by providing access around barriers, the third year of the project may involve tagging experiments that monitor movements of individual fish in relation to locks. This would involve both mark / recapture studies and radio-tagging of fish to record time spent below and in locks, as well as their subsequent movements. This work would also capitalize on recent research that has used experimental manipulation of lock gates to encourage movement of fish between river sections.

Second Year Objectives

1.) Collect genetic material across the system to determine whether or not we can measure gene flow in 4-5 species across barriers. Begin analysis of genetic samples.

2.) Test large river sampling protocol: stratified random sampling within valley segments using a basic 50 m electrofishing transect; habitat measurement by recording mean depth, water velocity and video recording of substrate.

Preliminary Results Year 2

Genetic sampling was finished as per objective 1. Analysis will begin this winter.

Electrofishing sampling was completed on over 60 sites in 26 valley segments on the Trent and 3 valley segments on the Grand in 2000. Histograms of Trent River species richness at the valley segment scale suggested that richness was greatest at the river mouth section, and where large lakes were connected to the system near valley segment 11, 19 and 29, and declined the farther the segment was from the potential species sources in these lakes (Fig. 1). Results were similar between the two years (Fig. 1). The river redhorse, one of four redhorse species captured, was the predominant redhorse at the river mouth and was rare above that segment. No redhorse was taken above the tenth dam.

A preliminary analysis of cumulative species richness plotted against the number of transects at a site indicated the number of new species captured started to drop off after six to seven shoreline transects (Fig. 2). For channel areas, a minimum of 8 transects was needed before the cumulative species curve flattened out (Fig. 3). For all transects, cumulative species richness in a valley segment flattened out at three or more sites, although the trend was not as pronounced in 2000 (Fig. 4).

The species richness at the valley segment level on the Grand River was similar to the Trent segments near lake sources (Fig. 1 and 5). The cumulative curve appeared to be slightly higher compared to the Trent curve for three valley segments (22 species vs 18).

Management Implications

Currently there are no standardized methods for assessing the fish community or habitat parameters in non-wadable rivers. The development and testing of a repeatable method will allow managers to measure changes in community structure in relation to perturbations and changes in the watershed. This will improve their ability to manage these large systems on a sustainable basis.

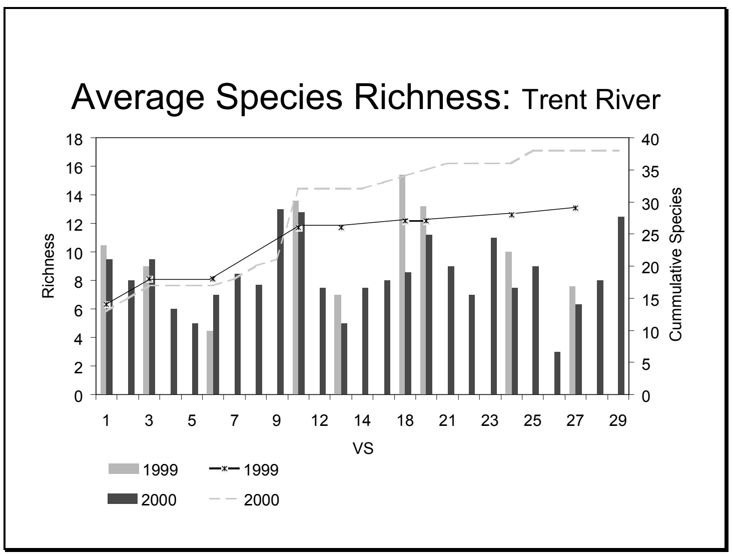

Figure 1. Average species richness by valley segment (VS) in the Trent River, 1999 and 2000.

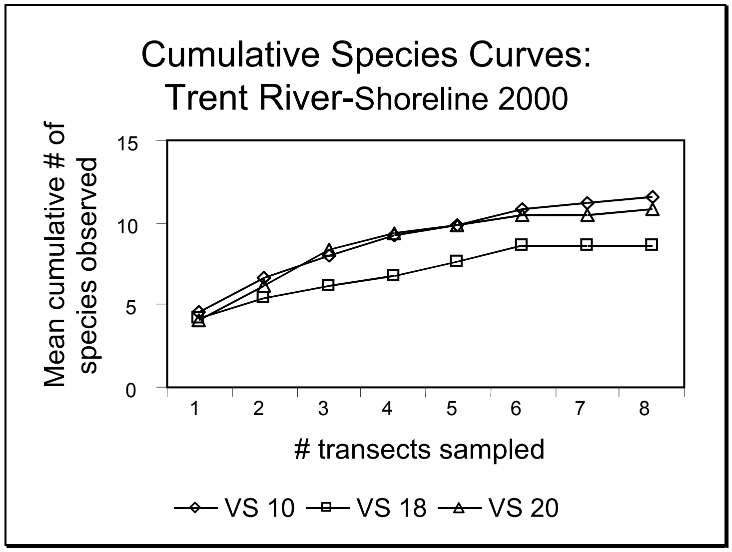

Figure 2. Cumulative species curves for samples from shoreline transects at three valley segments that were surveyed in 2000.

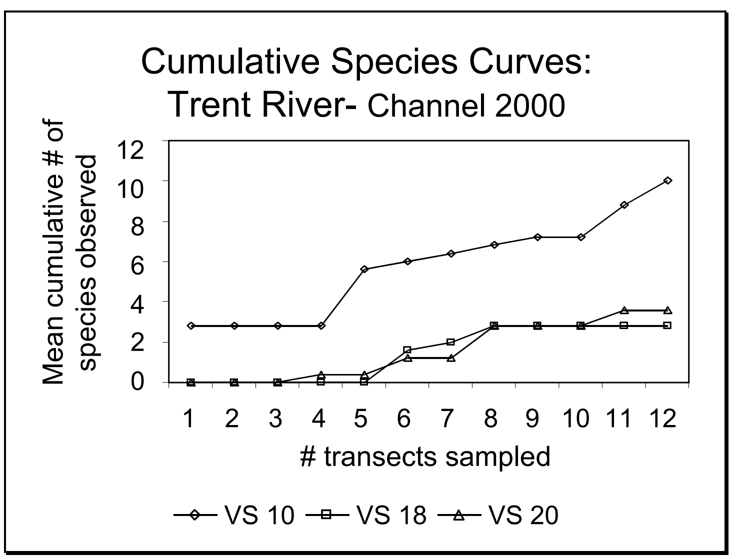

Figure 3. Cumulative species curves for samples from channel transects at three valley segments that were surveyed in 2000.

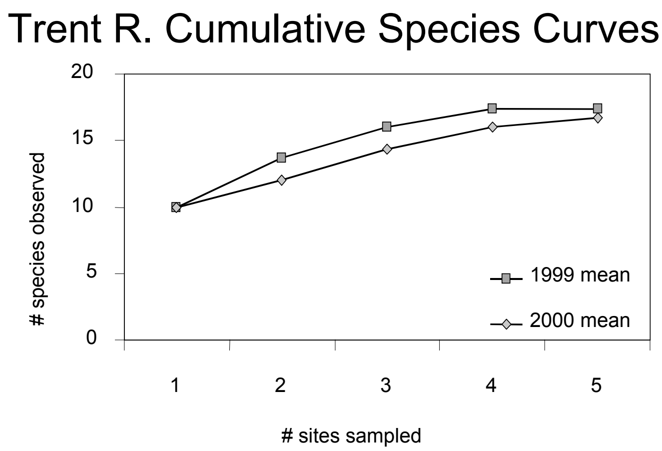

Figure 4. Cumulative species curves for samples from channel transects at three valley segments that were surveyed in 2000.

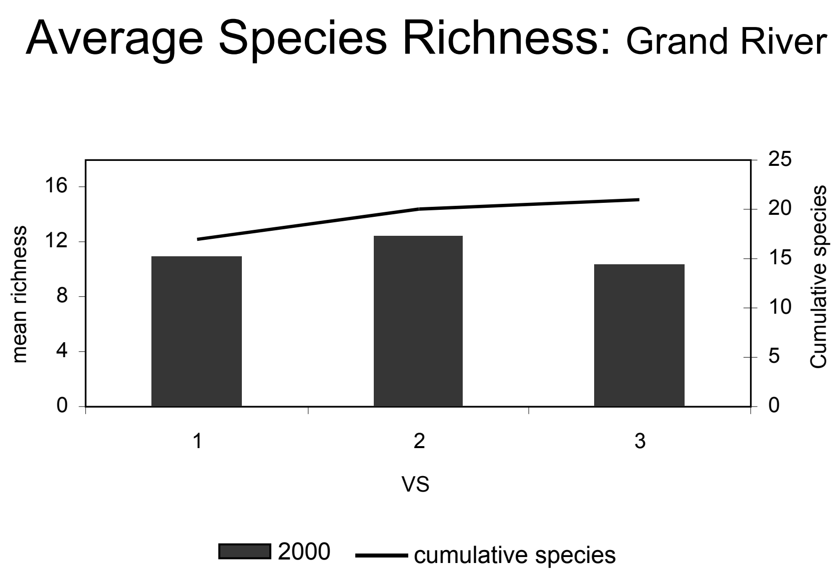

Figure 5. Average species richness at valley segments surveyed in the Grand River, 2000.

Report 7. Productive capacity of littoral habitat in the Great Lakes: comparison of line transect and point sampling methods for surveying the fish community *(Boston et al.)*

C. M. Boston, M.G. Clark, and R.G. Randall. Fisheries and Oceans Canada, Burlington, Ontario

Background and Objectives

Detailed fish and habitat surveys in nearshore areas of the Great Lakes have been conducted as part of the GLLFAS Productive Capacity project since 1988. Field data are being used to develop analytical tools to link productive capacity with specific habitat features. The objective of the year 2000 field program was to compare sampling protocols and gear types in littoral areas of eastern Lake Ontario. Standard 100 m line transect electrofishing surveys and point sampling methods were compared. In addition, a survey of fish abundance was conducted using a video camera. Both studies addressed the ESSRF objective of developing standardized methods for sampling fish and habitat.

Electrofishing: Points vs. Transects

A point sampling protocol has two key advantages over the line transect method: 1. point sampling takes into account the spatial structure of a fish population by systematically sampling the area under study (Persat and Copp 1990; Perrow *et al*., 1996); and 2. multiple small samples are more statistically reliable than a few large samples (Copp and Garner 1995). Fish catch data from point samples can be linked to localized specific habitat variables (*e.g*., depth, substrate, and macrophyte cover) at the sampling point, providing a higher spatial resolution for interpreting fish-habitat linkages. Also, point sampling may make it possible to estimate absolute abundance (biomass or numeric density) in addition to relative abundance (CPUE) because of the restricted area that is sampled.

Traditionally, the line transect surveys have been conducted at the 1.5 m depth contour. Point sampling provided catch data at the 1.5 m transects, as well as in shallower and deeper water adjacent to the transect. Point samples from the vicinity of line transects can be used to help evaluate the line transect protocol for measuring the near shore fish community.

Methods

During 2000, 12 existing transects from the Productive Capacity database were re-surveyed by boat electrofishing. Surveys were conducted in June, July, and September in Prince Edward Bay, Lake Ontario. The study was conducted at four habitat areas with 3 transects in each area: Little Bluff and MacMahon Bluff, both of which were moderately exposed to wind with cobble/boulder substrate, and relatively protected areas near the mouth of Black River with cobble and vegetated transects. At each transect, fish and habitat samples were collected using standardized methods (Valere 1996). All transects were 100 m in length and were sampled at the 1.5 m depth contour.

For point sampling, a stratified random method was used within the same 100 m shore boundary markers (i.e. transect area) as the line transect surveys. In the vicinity of each transect, up to five random samples (habitat and fish) were taken at each of the following depths: 0.5 m, 1.0 m, 1.5 m, and 2.0 m for a total of 15-20 samples per transect area. Small floats were used to mark individual points. During fish sampling, each point was approached slowly and sampled for 10 seconds with a single anode off the bow of the stationary boat. The electrofishing output was about 8.0 amperes, except at 0.5 m depth where a maximum of 6.7 amperes was used.

Results

Both transect and point sampling were conducted in June, July, and September. In total, 33 samples were collected from transects (Table 1) and 556 from point samples (Table 2). Point sampling catch data showed a highly skewed distribution for both fish numbers and species richness (Figure 1). The same pattern was seen for point data at 1.5 m only and for all point data combined. A high percentage of zero and low catches contributed to the skewed distribution (Table 3). At 1.5m, the average monthly catches ranged from 2.3 to 4.1 per point and the maximum catch per point ranged from 16 to 23 fish. Species richness ranged from 1.3 to 1.8 (Table 3). For all points combined, catches and species richness were slightly higher per point, ranging from 2.8 to 4.4 and 1.5 to 2.0, respectively. The maximum catch for combined points ranged from 18 to 31 (Table 3). Higher values for combined point data can be attributed to higher catches and species richness at 0.5 m and 1.0 m in comparison to 1.5 m and 2.0 m (Figure 2).

The mean size of fish increased with increasing depth (Figure 3). Lengths ranged from 84.4 mm at 0.5 m to 120.7 mm at 2.0 m. The mean size of fish from transect data was larger than any of the point sample means (Table 4) but closest to the mean fish size from 2.0 m point samples. The size range of fish did not vary significantly between point sampling and transect samples (Table 4).

Catch and species richness data at 1.5 m points and at all points were plotted against the transect data (Figure 4). The results indicate a strong positive correlation between the point and transect data, with slightly higher catches and species richness for the combined point data (Figure 4).

The cumulative number of species increased with the number of point samples and the asymptote depended on the area (Fig. 5). Species richness was higher at Black River cobble and Black River vegetated sites than at either Little Bluff or MacMahon Bluff. In the less productive areas (Little and MacMahon Bluffs) it took fewer samples to reach an asymptote than in the more productive Black River sites.

Discussion

Point sampling is a desirable method of surveying fish and habitat in nearshore areas as large areas and a variety of habitats can be systematically surveyed in a relatively short time frame. Although a high proportion of zero catches was observed, the average catch per point was high enough to provide information on the abundance and characteristics of the nearshore fish community. Catch per unit effort (CPUE) ranged from 0 to 31 fish; catches were similar to or higher than other studies of point sampling (catches between 0 and 5 fish; Persat and Copp 1989; Perrow *et al*. 1996). The latter studies found that point sampling provided a significantly higher estimate of population abundance than other methods because of high catches of small fish. Similarly, in our study, the average size of fish in point samples was smaller than in transect samples. In addition, the catch and species richness were greater at shallow depths (0.5, 1.0 m) than in deeper water (1.5, 2.0 m) and on average the size of the fish increased with depth.

A positive correlation between point and transect fish catches confirmed that both methods were sampling the near shore fish community in a consistent manner. Additional sampling in 2001 and a more detailed analysis of the catch data will be useful for comparing the advantages, disadvantages and utility of each method. Which method is used in future will depend on the objectives of the survey, particularly the level of resolution needed for evaluating the fish habitat linkages.

In summary, preliminary analyses of the fish catch data collected during the 2000 field season showed that point sampling is a robust sampling method that warrants further study in the Great Lakes. Future work will include:

1. A detailed analysis of existing and new fish catch data from point sampling.
2. Comparison of fish data with point habitat attributes.

3. Additional comparison of point and transect samples in new areas.
4. Investigation of gear efficiency to determine numeric and biomass density.

Fisheye Camera

Underwater filming is an alternate method for determining fish community and habitat interactions in the nearshore areas of the Great Lakes. It is a desirable method of sampling because it is non-intrusive and does not harm the fish. In 2000, three sampling trips (2 in August, 1 in October) were made to collect underwater video data. The survey protocol developed by Smokorowski and Kelso (1999) was used as that this would allow a comparison of the results between the two projects (inland lakes and Great Lakes). The survey sites in the Great Lakes were the same as the point-sample electrofishing sites in 2000.

In total, 66 five-minute video samples were collected. Preliminary observations indicated that twelve to fifteen samples included observations of fish (Table 5). During the last sampling trip in October, video sites were also sampled with a backpack electrofisher but no fish were caught (the backpack unit did not produce enough power, as fish were sometimes observed at the site). The video data are currently being analyzed.

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Smokorowski, K. and Kelso, J. 1999. Assessing nearshore fish community associations with differing habitats using an underwater video camera in inland lakes in Ontario. In Randall, R.G. et al. 1999. Field measurement of the productive capacity of freshwater fish habitat-proceedings of a scoping workshop. Fisheries and Oceans Canada, Workshop Report, 60 p.

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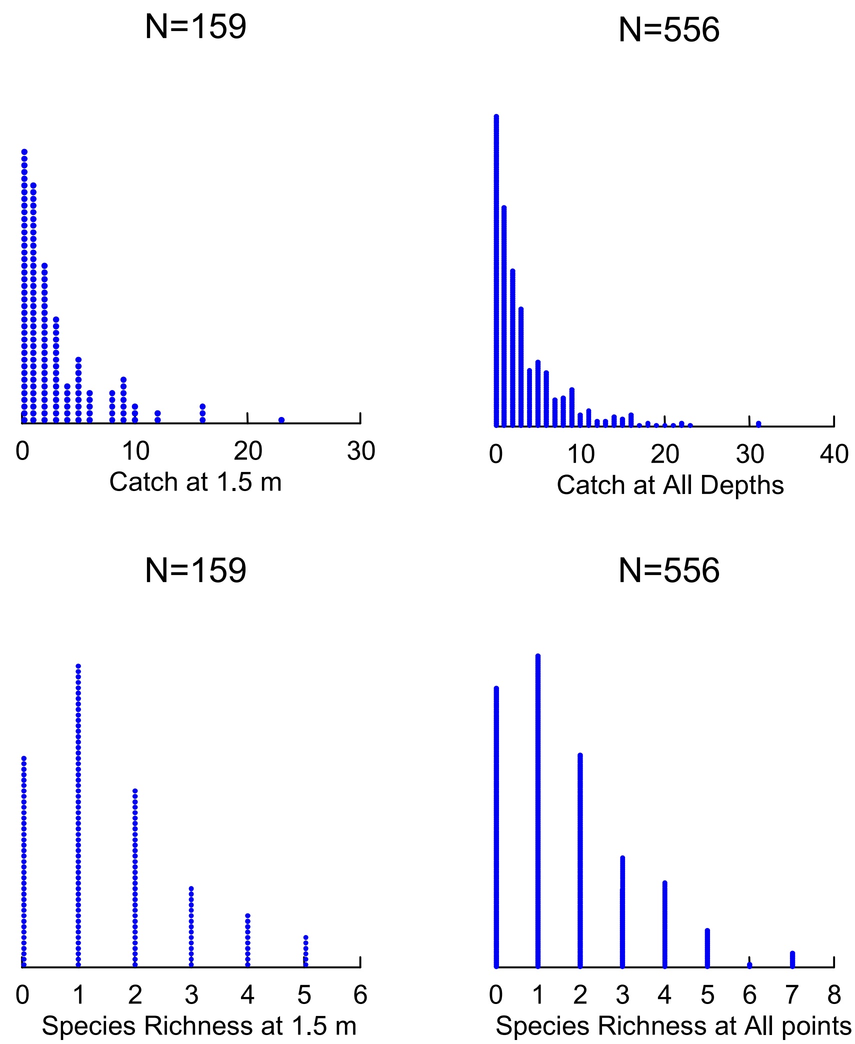

Figure 1. Frequency plots of fish catch in numbers (top) and species richness (bottom) at 1.5 m and all points.

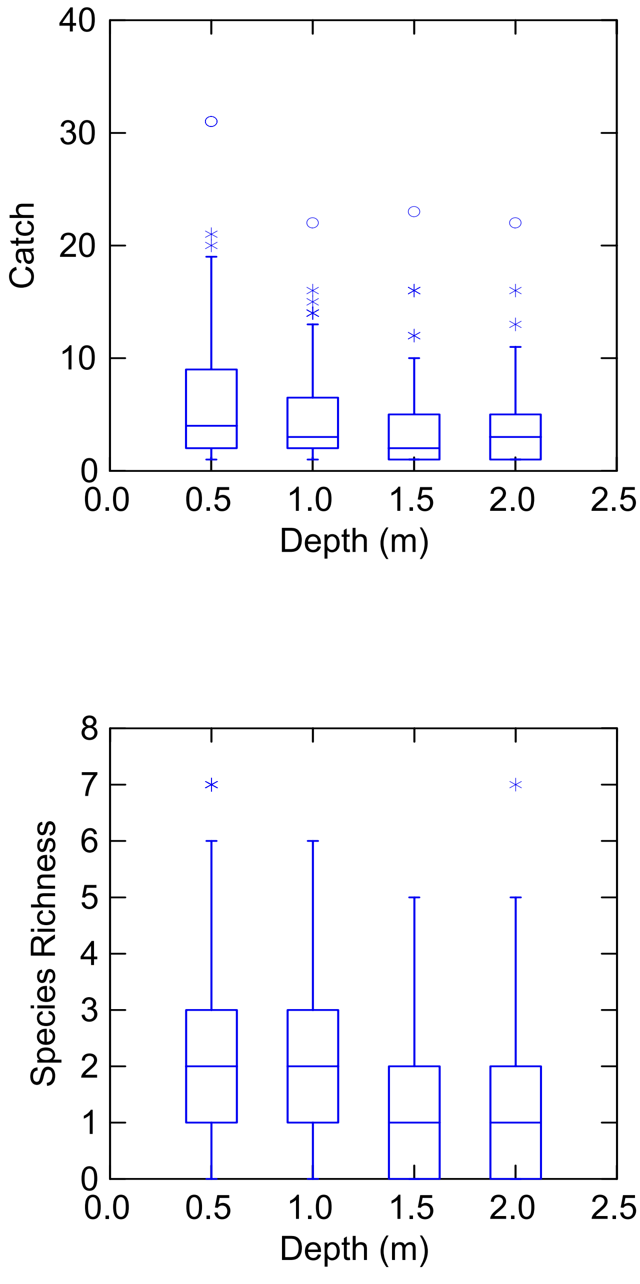

Figure 2. Box plots of fish catch (top) and species richness (bottom) by depth (pooled data for all months, N=556).

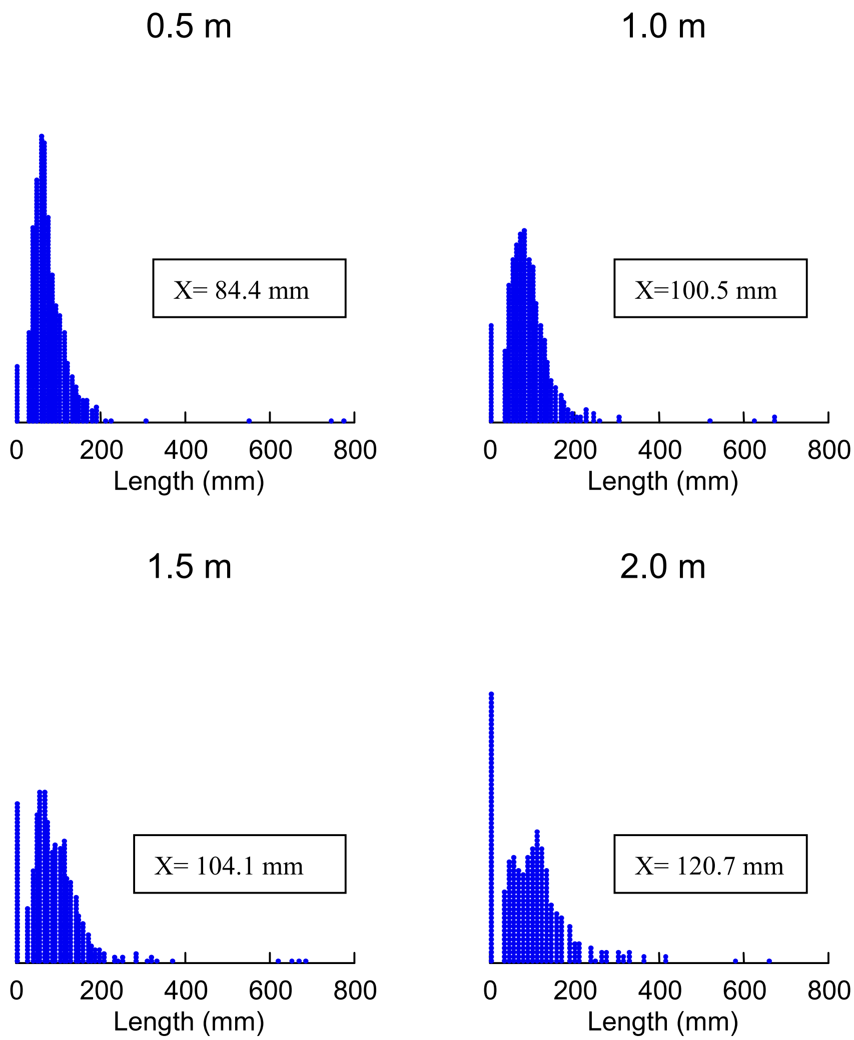

Figure 3. Point sample length frequency by depth.

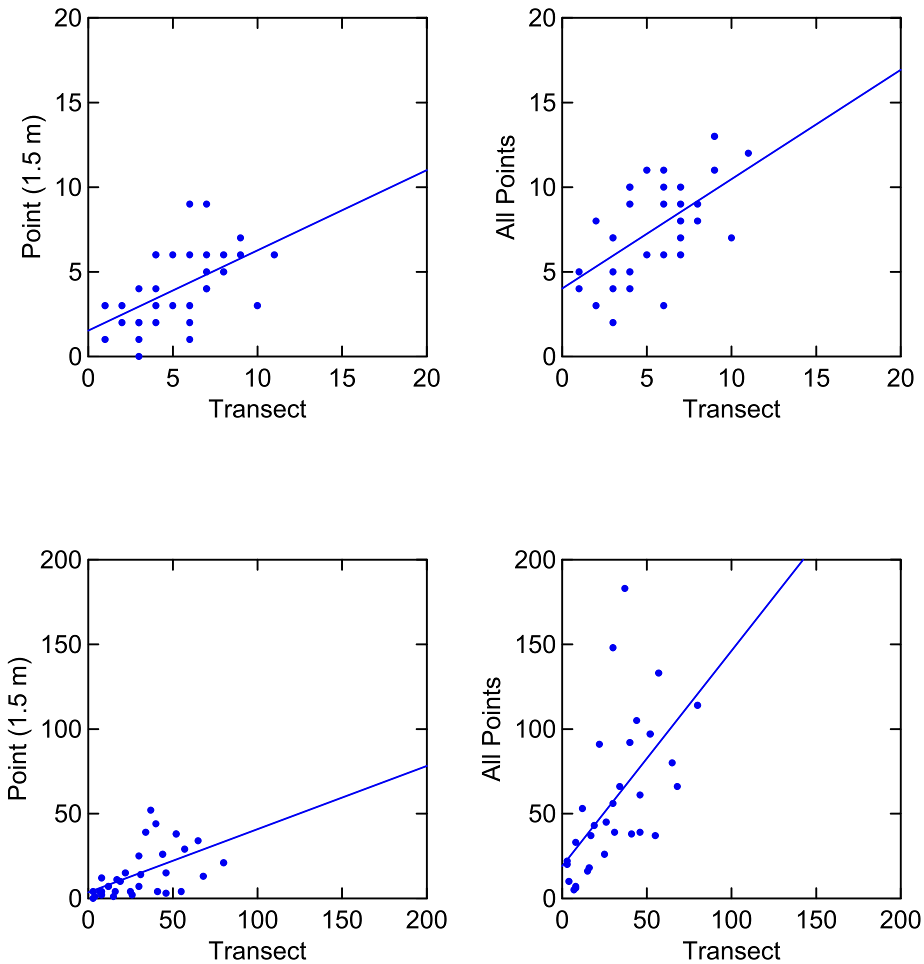

Figure 4. Scatterplots of species richness (top) and catch (bottom) from point sampling versus transects. Each point represents the total catch or species richness for one transect sample versus the sum of the total catch or species richness at 1.5 m points (n=5) or the sum at all points (n=15 to 20) (see text).

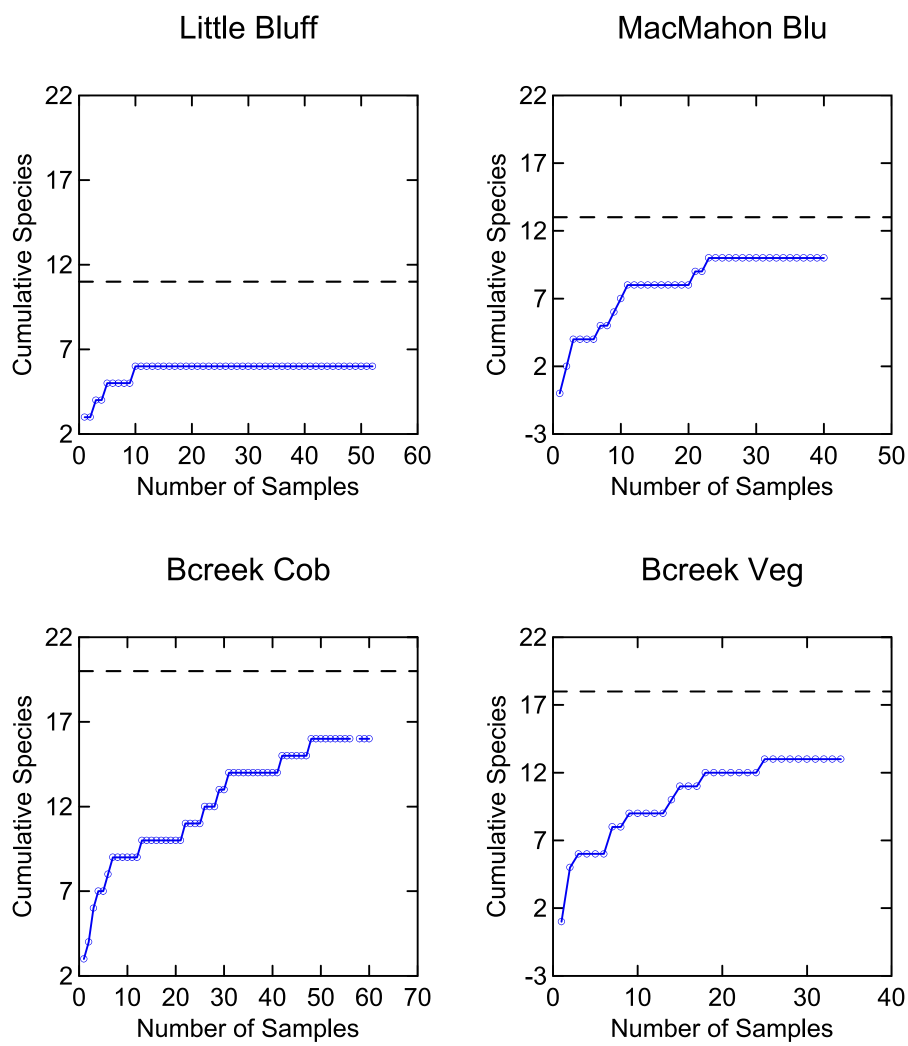

Figure 5. Increase in the cumulative number of species with number of samples from point samples (July). The dashed line is the total species richness determined for these areas from transect surveys in the past (n=27 transect samples per area).

Table 1. Number of transect samples collected by area and month. All transects were at 1.5 m depth.

Area	Little Bluff	MacMahon Bluff	Black R. cobble	Black R. vegetated	Total
Transects	9804-9806	9807-9809	9810-9812	9813-9815	
Month					
June	3	2	3	3	11
July	3	3	3	2	11
Sept	3	3	2	3	11
Total	9	8	8	8	33

Table 2. Number of point samples collected by area, month and depth.

Area	Little Bluff	MacMahon Bluff	Black R. cobble	Black R. vegetated	Total
Transects	9804-9806	9807-9809	9810-9812	9813-9815	
Month					
June	47	41	45	43	176
July	51	40	60	33	184
Sept	55	59	40	52	196
					556
Depth (m)					
0.5	21	38	40	11	110
1	45	25	25	40	135
1.5	45	40	40	40	165
2	44	40	40	40	164
					556

Table 3. Average, median and maximum catch of fish from point sampling at 1.5 m and all depths (0.5, 1.0, 1.5, 2.0), by month (year 2000).

Month	Number	Zero catch (%)	Mean Catch	Max	Median	Mean Species Richness	Max	Median
1.5 m								
June	57	19(33)	2.3	16	1	1.3	5	1
July	48	5 (10)	4.1	23	2.5	1.8	5	2
Sept	54	20(37)	2.5	16	1	1.3	5	1
Total	**159**							
All points								
June	176	48(27)	3.0	31	2	1.5	5	1
July	184	30(16)	4.4	31	3	2.0	7	2
Sept	196	68(35)	2.8	18	1	1.5	7	1
Total	**556**							

Table 4. Fish lengths from point (by depth) and transect samples.

Sampling Method	Depth (m)	Samples (n)	Mean Length (mm)	Minimum	Maximum	SD
Point	0.5	604	84.4	31.0	775.0	55.0
Point	1.0	506	100.5	36.0	100.5	62.0
Point	1.5	464	104.1	27.0	685.0	104.1
Point	2.0	322	120.7	31.0	660.0	77.5
Transect	1.5	1051	133.0	32.0	745.0	70.3

Table 5. Number of samples and habitat for the video camera study.

Date	Location	Transect	Habitat: Substrate/ Macrophytes	Number of samples	Number with fish
01-Aug	Black River	9812	Substrate: gravel, cobble and woody debris. Vegetation: sparse, some *Elodea.*	5	2-4
03-Aug	Black River	9811	Substrate: cobble and gravel. Vegetation: none	5	0
03-Aug	Black River	9813	Substrate: organic. Vegetation: sparse; *Vallisneria, Elodea*	5	0
15-Aug	Black River	9812	Substrate: cobble, gravel and woody debris. Vegetation: sparse, few floating plants.	5	5
15-Aug	Black River	9811	Substrate: cobble/gravel. No vegetation	5	3-4
16-Aug	Black River	9808	Substrate: cobble, bedrock. No vegetation.	5	0
16-Aug	MacMahon Bluff	9808	Substrate: cobble, bedrock. No vegetation.	5	0
17-Aug	Black River	9813	Substrate: organic, woody debris. Vegetation: sparse.	5	2-4
03-Oct	Black River	9812	Substrate: cobble, gravel and woody debris. Vegetation: sparse	5	2
03-Oct	Black River	9811	Substrate: cobble and gravel. No vegetation	5	0
04-Oct	MacMahon Bluff	9807	Substrate: cobble, bedrock. No vegetation.	1	0
04-Oct	Black River	9814	Substrate: organic and cobble. Vegetation: moderate, *Potamogeton pectinatus* and *Vallisneria*	5	1
05-Oct	Black River	9810	Substrate: bedrock, cobble and zebra mussels. No vegetation.	5	0
05-Oct	Black River	9813	Substrate: organic, woody debris. Vegetation: moderate; *Myriophyllum, Vallisneria*	5	1
Total				66	12-15

Report 8. Assiniboine River productive capacity *(Nelson and Franzin)*

Patrick Nelson and William Franzin, Fisheries and Oceans Canada, Winnipeg

Fish habitat associations

Information on fish-habitat associations were collected at Lido Page, a 1-kilometre reach of the Assiniboine River (Fig. 1), during 1999 and 2000 to test the applicability of the large-scale associations developed between Portage la Prairie and Winnipeg in 1995 and 1996. Fish CPUE at the Lido Plage site was comparable to the regional samples collected during the same months in 1995 and 1996 (Fig. 2 and 3). The only appreciable difference was the decrease in CPUE for the shorthead redhorse, which was likely due the lack of till-plain outcrops. Till-plain outcrops downstream of the Lido Plage reach sampled during the 1995 and 1996 had large numbers of shorthead redhorse. These outcrops were not present at the Lido Plage site.

Biomass data for all samples will be compiled by spring 2001, in order to apply the index of productive capacity model as defined in Randall and Minns (2000). Further testing of the transferability of current fish-habitat associations as predictors of local fish catches will be carried out on four 1-kilometre reaches during the 2001 field season, sampling in the same manner as was done at Lido Plage during fall 1999 and spring 2000.

Regional geologic effects on ETD and habitat distributions

Knowledge of the effect of regional geology on habitat distributions is required to assess the dependence of habitat distribution processes on erosion, transport and deposition (ETD). In addition, the integration of river ecology paradigms (river continuum, flood-pulse, serial discontinuity concepts and a river productivity model) into our understanding of fish-habitat and river process may lead to a better understanding of the relationship between river hydrology, geomorphology, and ecology.

Information on the distribution of regional geology has been collected for the lower 100 kilometres of the river. The upper 60 kilometres will be surveyed during the 2001 field season. These data will be used to estimate areas of different geological composition, which may affect the distribution of depth, velocity, and substrate and the subsequent use of these habitats by fish. These data will be used in conjunction with the macrohabitat features to more precisely estimate the relation between ETD, geological properties, physical habitat and fish distribution.

Estimations of habitat distributions in relation to ETD have been collected for a 13 kilometre section of the Assiniboine River (Figure 4) with additional data to be collected during the summer of 2001, in areas with differing geological properties. Depth and substrate contours will be used to estimate total areas of ETD-dependent macrohabitat features (point bars, outside bends, till-plain outcrops, thalweg width, and channel meandering). River geomorphic indices (bend radius, arc length, angle of deviation, slope, and mean bankfull width) are being collected from the digital stream file (Table 1) on 300+ bends. These data are required to assess the predictability/regularity of area of macrohabitats in relation to ETD. The integration of meander geometry and areas of macrohabitat features will be related to fish-habitat associations to calculate production estimates.

Deliverables Fall 2001:

The remaining data required to compile a deliverable report at the end of the project will be collected during the 2001 season. Fish-habitat associations will be used to extrapolate (using re-sampling procedures) biomass on a substrate basis, using the integrated effects of geology and ETD on substrate distributions, to calculate a reach-wide estimate of productive capacity.

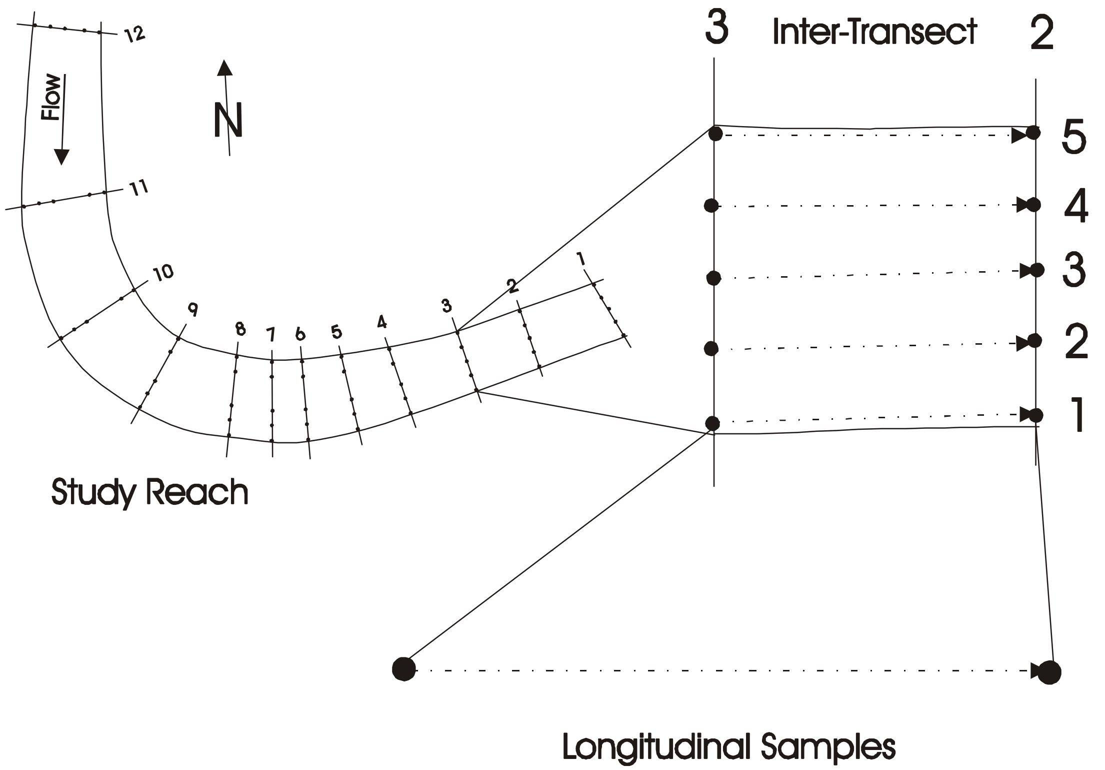

Figure 1: Illustration of the sampling protocol at the Lido Plage 1 km study reach. The reach was sampled during the fall of 1999 and spring of 2000, and will be re-sampled during the summer of 2001.

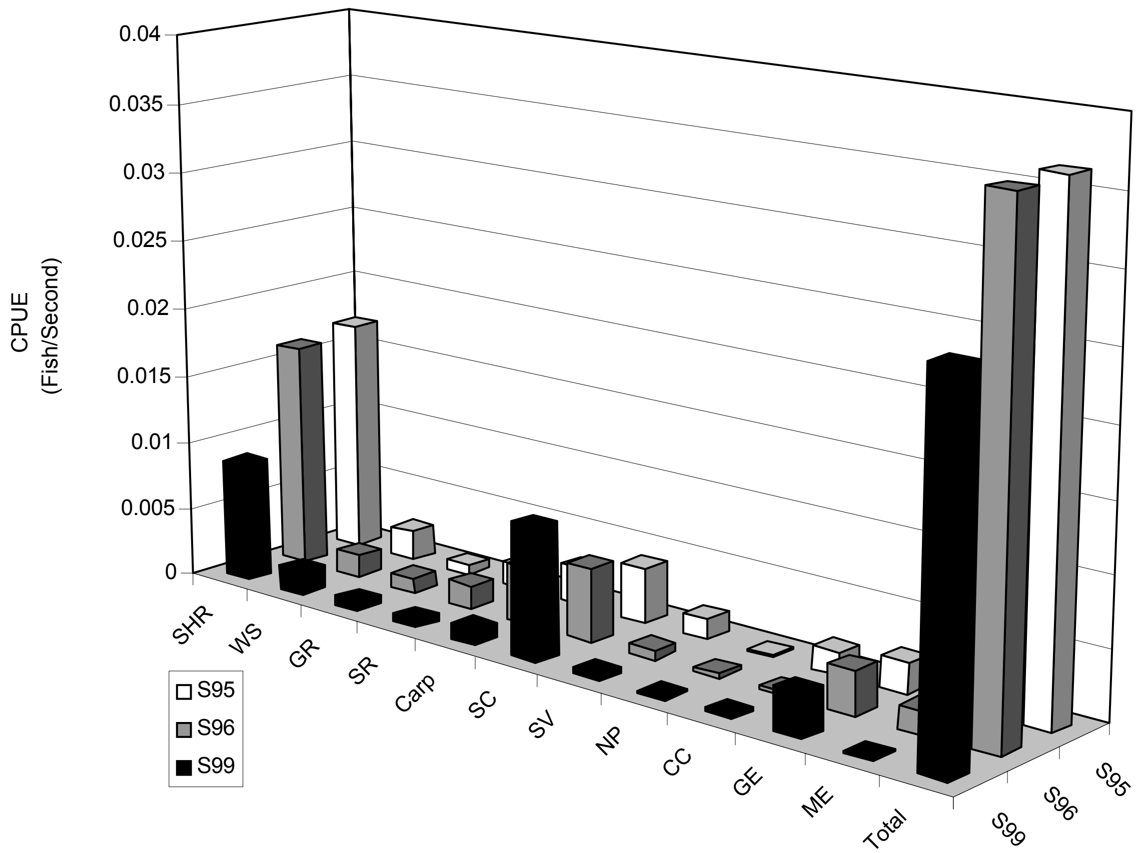

Figure 2: Fish CPUE comparisons between September 1995, 1996 regional samples, and September 1999 Lido Plage samples. SHR = shorthead redhorse; WS = white sucker; GR = golden redhorse; SR = silver redhorse; Carp = common carp; SC = sauger; SV = walleye; NP = northern pike; CC = channel catfish; GE = goldeye; ME = mooneye; Total = CPUE for all 11 species; S95 = September 1995; S96 = September 1996; S99 = September 1999.

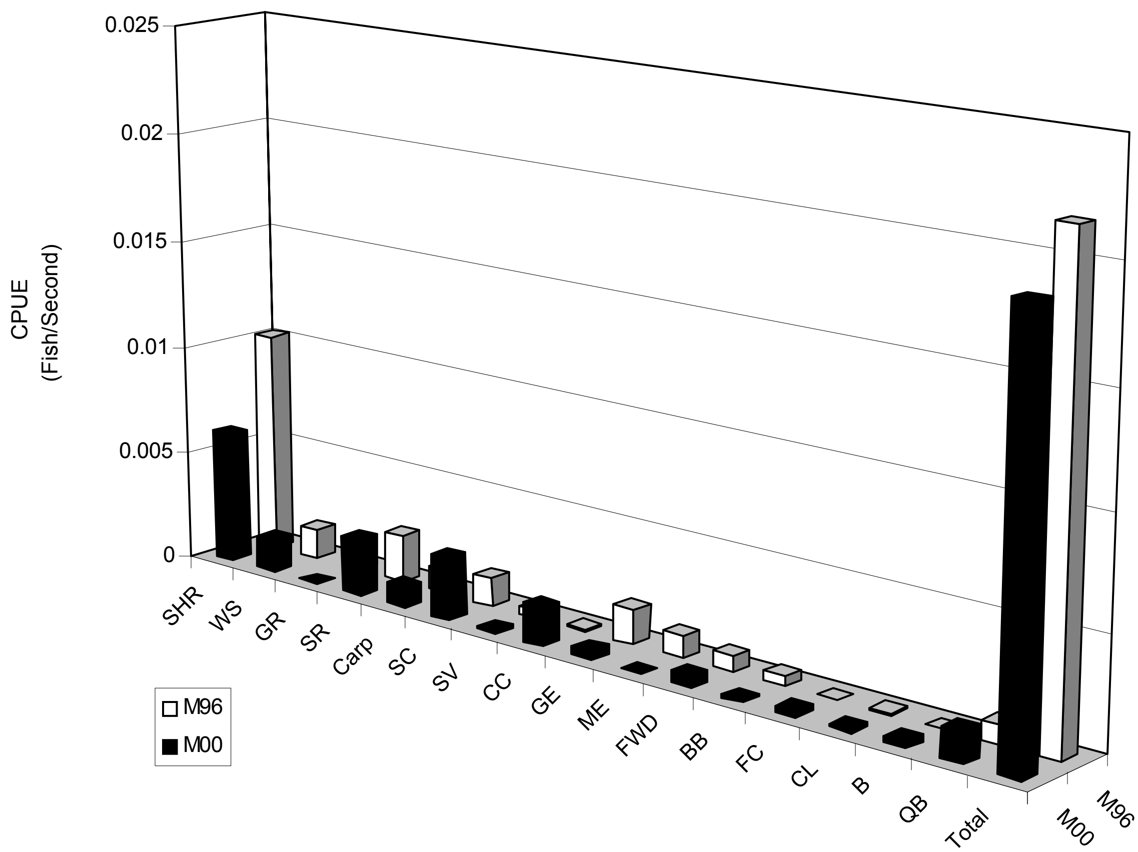

Figure 3: Fish CPUE comparison between May 1996 regional samples and the May 2000 Lido Plage samples. SHR = shorthead redhorse; WS = white sucker; GR = golden redhorse; SR = silver redhorse; Carp = common carp; SC = sauger; SV = walleye; NP = northern pike; CC = channel catfish; GE = goldeye; ME = mooneye; FWD = freshwater drum; BB = bigmouth buffalo; FC = flathead chub; CL = chestnut lamprey; B = burbot; QB = quillback; Total = CPUE for all 16 species; M96 = May 96; M00 = May 2000.

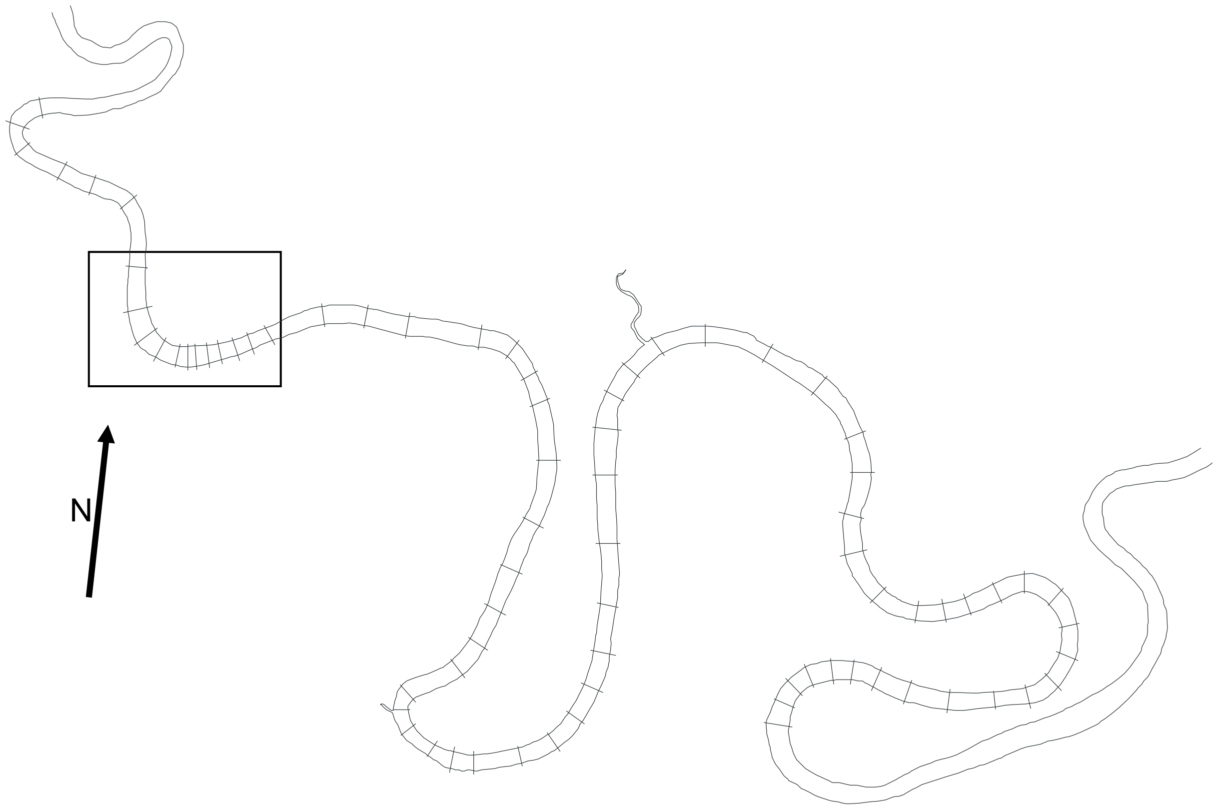

Figure 4: Sketch of the location of 77 transects collected over 13 kilometres of the Assiniboine River. The highlighted box shows the location of the Lido Plage study site.

Table 1: Geomorphic indices collected for the first 30 kilometres of stream, starting at the confluence with the Red River at Winnipeg.

Arc No.	X-UTM	Y-UTM	Radius	Arc Length	Start Angle	End Angle	Total Angle	Width 1	Width 2	Width 3	Reach
1	634314.29	5526748.79	866.32	705.89	82	129	47	58.31	64.27	70.56	1
2	633044.09	5528149.08	1015.51	653.17	274	311	37	67.57	60.24	51.44	1
3	632861.27	5526806.89	310.72	114.20	91	112	21	58.52	60.92	53.35	1
4	632737.68	5526889.87	187.28	359.42	118	228	110	59.80	59.41	54.80	1
5	632554.65	5526424.77	196.77	369.83	265	13	108	56.07	56.27	46.21	1
6	632533.50	5526493.05	265.46	266.00	210	268	58	77.82	75.29	56.07	1
7	631946.78	5526496.53	247.67	433.13	23	124	101	65.74	61.73	71.34	1
8	631277.15	5526967.28	510.47	765.52	222	308	86	59.88	58.47	58.94	1
9	630547.68	5526471.47	337.20	364.12	45	107	62	87.47	73.68	63.20	1
10	629954.90	5527041.17	398.81	301.07	254	297	43	72.28	96.00	97.01	1
11	629676.93	5526150.11	527.47	324.39	80	115	35	96.33	102.19	112.07	1
12	629014.49	5527216.80	729.89	395.64	264	295	31	93.63	73.10	79.63	1
13	628848.73	5526379.34	113.43	200.65	83	185	102	72.00	76.00	79.00	1
14	628620.58	5526237.17	114.60	181.92	264	355	91	76.76	70.10	74.50	1
15	628325.79	5525723.14	462.71	352.89	71	114	43	89.60	103.46	97.77	1
16	627772.62	5526419.38	377.04	396.64	235	296	61	71.75	89.12	98.55	1
17	626917.35	5525308.40	1012.62	865.87	59	108	49	72.67	122.33	94.43	1
18	626367.05	5526588.41	384.26	337.14	252	303	51	78.60	63.58	71.33	1 and 2
19	626221.08	5526093.88	128.20	137.09	89	150	61	65.95	92.96	83.12	2
20	625940.15	5526286.17	212.80	175.45	273	321	48	83.12	77.05	96.99	2
21	624991.73	5526169.67	349.18	277.21	259	305	46	97.50	82.34	92.54	2
22	624738.02	5525274.69	569.12	405.05	87	128	41	88.24	94.89	101.00	2
23	624028.88	5525976.27	416.03	444.45	246	307	61	92.14	84.14	89.61	2
24	623780.21	5525448.26	164.32	211.82	67	141	74	95.54	96.26	103.62	2
25	623947.80	5525349.97	366.06	299.50	156	203	47	107.22	107.80	105.56	2
26	623461.55	5524667.09	294.18	642.33	246	11	125	94.60	89.67	82.85	2
27	623395.72	5524679.48	281.63	287.13	192	250	58	89.71	94.22	94.24	2
28	622882.00	5524628.44	231.80	247.82	14	75	61	80.33	86.83	83.44	2
29	622349.29	5525310.73	416.93	301.66	239	281	42	79.14	77.34	73.01	2
30	621535.88	5524173.95	977.27	593.90	57	92	35	74.03	85.38	74.75	2
31	621413.92	5525284.97	127.98	188.16	179	263	84	71.06	80.43	88.13	2
32	620941.20	5525411.57	328.09	261.85	3	49	46	106.23	110.19	108.07	2
33	620784.82	5525555.61	277.97	345.19	83	154	71	76.36	80.56	92.66	2
34	620073.57	5525808.65	477.44	379.59	294	339	45	107.45	99.11	96.16	2
35	619785.13	5523653.08	1413.05	670.12	105	132	27	88.32	98.17	110.80	2
36	618670.07	5524794.30	173.37	245.78	233	314	81	107.80	100.33	97.74	3
37	618736.25	5524773.54	208.91	267.78	137	211	74	97.74	102.95	116.04	3
38	618474.24	5525214.57	284.43	541.13	328	77	109	109.16	114.15	121.54	3
39	618244.39	5524345.35	1163.05	546.81	88	115	27	135.92	104.24	97.57	3
40	617107.39	5526661.86	1037.90	406.88	276	298	22	91.85	90.14	88.99.77	3
41	617376.41	5525010.57	252.92	290.49	101	167	66	88.19	92.90	93.18	3
42	616740.58	5525101.84	373.61	311.40	287	335	48	94.72	103.89	103.34	3
43	616654.96	5525459.69	740.88	742.42	232	289	57	103.34	81.62	86.76	3
44	616017.47	5524728.56	224.35	318.88	56	137	81	77.25	88.25	101.54	3
45	615562.86	5525100.97	360.67	544.15	225	312	87	92.22	105.27	114.92	3
46	614660.60	5524584.04	670.95	625.38	30	84	54	108.90	114.83	103.58	3
47	614672.72	5526652.81	1379.96	460.08	246	265	19	96.08	102.97	87.40	3
48	613753.50	5525056.10	402.29	345.77	82	131	49	82.50	71.68	74.40	3
49	612813.62	5525410.84	533.83	750.63	241	322	81	81.43	103.59	88.14	3
50	612409.60	5525368.41	335.64	309.35	204	257	53	72.17	76.53	78.49	3
51	611761.41	5525360.59	251.21	487.92	22	134	112	70.27	78.65	93.48	3

Report 9. Comparison of fishing gears in different habitat types in Harrison Lake: 2000 progress report *(Hume et al.)*

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Introduction

The limnetic zones of large B.C. lakes and reservoirs have been extensively studied, particularly when they are used as rearing areas by anadromous sockeye salmon *(O. nerka)* or by kokanee, a non-anadromous form of sockeye (see references in Hume et al 1996). However, little information exists on littoral and nearshore habitats in these lakes, particularly with respect to the relative value of various habitat types to salmonid and non-salmonid fish species. In an attempt to better understand the utilization and relative fish productivity of the littoral and limnetic areas we used various sampling gears to investigate the abundance, density, and biomass of fish in the nearshore and deep water habitats of Harrison Lake, which is located in B.C.'s Fraser Valley. In both 1999 and 2000 we studied four nearshore habitats types - mudflats, sand/gravel beaches, rubble and bedrock. At the same time as this study, we investigated the limnology and fish ecology of the lake's limnetic zone. The limnetic data will be reported at a later date.

Objectives

Our study took a comparative approach to address the first two project goals: 1 - determine fish diversity, abundance and biomass in different habitat types; and 2 - develop sampling techniques that effectively sample the fish species in all habitats.

Study Area and Habitats

Harrison Lake is large (surface area=220 km^2), deep (mean depth=151 m) and flushes rapidly (water renewal rate=2.3 yr). It is located at a low (10 m) elevation 120 km upstream of the mouth of the Fraser River (Table 1). Riparian vegetation is a mixture of conifers (mostly fir, hemlock) and deciduous trees (alder/maple), with a thick deciduous understory. Annual fluctuations in water-level average about 2 m, but unusually high levels in the spring and early summer of 1999 resulted in a 3.5 m variation. For about two months in 1999, much of the lake's riparian zone was flooded. In 2000, when water-level fluctuations were normal, there was no observed flooding in the riparian zone.

Harrison Lake is highly oligotrophic, with low phosphorus loading (spring overturn total phosphorus concentrations average 3.8 µg/L) and seasonal average epilimnetic chlorophyll concentrations of 0.75 µg/L. The lake has an average pH of 7.0, an average conductivity of only 34 µS/cm, and a low total alkalinity of 13.6 mg $CaCO_3$/L. The lake's largest tributary enters at the uppermost end of the lake and is both cold and glacially turbid. As a result, Harrison Lake has a relatively low average euphotic zone depth of 11.2 m and a cool (mean May-October temperature = 12.6^{o}C) epilimnion that averages 21 m in depth. Maximum summer surface temperatures were <20ºC. Salient chemical and physical variables collected at the nearshore sampling locations were not significantly different from variables collected at limnetic sampling locations.

The five nearshore habitats we sampled were:

1) Mudflats - extensive (9 km^2) shallows (3-6 m) at the southern (outlet end) of Harrison Lake. The substrate was almost entirely mud/sand. Although water clarity made observations difficult at times, abundant periphyton growth was frequently observed as well as locally extensive late summer growth of macrophytes.
2) Sand/Gravel Beaches - about 40 beach areas (mostly fluvial fans at the outlets of creeks) occurred around the Harrison Lake shoreline. Our beach sampling site had a mostly sand/gravel substrate with the occasional cobble area. Slopes were gradual (5-

15%). Some macrophytes were observed and areas sheltered from wave action had substantial periphyton growth.

3) Rubble - most of the lake's shoreline consisted of angular jagged boulders and cobble interspersed with solid rock outcrops and with occasional small areas of gravel/cobble. Slopes were steep, ranging from 30 to 90%. Throughout the study a thin layer of periphyton was observed in rubble areas. Large woody debris was most often found in these rubble areas. There were no macrophytes observed.
4) Bedrock – in a few areas, solid rock is the predominate substrate, overlain in places with angular boulders/cobble. The rock occurred as relatively flat ledges (slope 6-20%) with near vertical drops to greater depths. A thin layer of periphyton was observed throughout the study.
5) Deep Water - comprises all waters that were deeper than 20 m. We sampled for fish and *Neomysis mercedis* down to 80 m using both hydroacoustics and midwater trawling (0-60 m). Limnological sampling was carried out at 4 locations located along the longitudinal axis of the lake.

Methods

In 1999, fish were sampled using 6 sampling gears where conditions permitted: Gee® minnow traps (2-cm mouth opening); large minnow traps (9-cm opening); variable mesh gill net gang – 97.5 m total length consisting of 7 nets ranging from 25-89 mm (1"-3.5") stretched mesh; trap-net made of 13-mm-mesh consisting of a trap box, a 30-m centre lead and 25-m wing leads; beach seine with 7-mm mesh in the bunt; nearshore surface trawling with a 3x3-m mouth opening and offshore trawling from 0 to 60 m in a series of trawls using a 3 x 7(height) m trawl (Table 2).

In 2000 we reduced the number of fishing gears used based on two criteria. The first was gear types that could be effectively fished at all sites in all weather conditions. These criteria eliminated the use of trap-nets, as we were not able to maintain effective fishing ability during moderate to high wind conditions. It also eliminated beach seining, as it could not be done effectively in the rubble and bedrock areas. The second was a range of gear types that sampled all known species over the largest possible size range (Hume and Shortreed 2000). This was accomplished by fishing with: Gee minnow traps (2-cm mouth opening); large minnow traps (9.5 -cm opening); variable mesh gill net gang – 52.2 m total length consisting of 7 nets ranging from 19 - 89 mm (0.75"-3.5") stretched mesh; surface trawling nearshore with a 3x3-m mouth opening and offshore trawling from 0 to 60 m in a series of trawls using a 3 x 7(height) m trawl. We had difficulty deploying the large minnow traps and instead used a modified trap originally designed for the capture of the marine black cod. This trap was circular (1-m diam.), 58 cm high, and had a single 9-cm funnel shaped opening on the side.

The study areas were sampled 3 times in both years –spring (early June), summer (late July-early August) and fall (mid September-mid October). In both years similar substrate types and similar limnological variables were sampled.

Results and Discussion

A number of sampling techniques were considered for this project but were rejected due to the particular conditions encountered in Harrison Lake. The lake's very low conductivity made electroshocking ineffective, while the relatively high turbidity made visual techniques (including cameras) ineffective. High water levels in 1999 made beach seining impossible until late in the year, and the nature of the boulder substrate made seining ineffective at all times. DFO policy did not allow us to use gill nets in October 1999, as there was a possibility of capturing threatened adult coho salmon.

Gear Bias

There was considerable variation among gear types in the number of taxa and in the size of fish captured (Table 3, Fig. 1). More than 16 species and/or age classes were captured by all gear types. This includes three age-0 salmonid species - sockeye salmon (*Oncorhynchus nerka*), coho salmon (*O. kisutch*), chinook salmon (*O. tshawytscha*), three older but immature salmonid species - kokanee (*O. nerka*), rainbow trout (*O. mykiss*), coastal cutthroat trout (*O. clarki clarki*), three adult anadromous salmon species - sockeye, chum (O. *keta*), and pink salmon (O. *tshawytscha*) and 11 other species that were not separated into age/maturity groups - bull trout / Dolly Varden (*Salvelinus confluentus /malma*), white sturgeon (*Acipenser transmontanus*), *m*ountain whitefish (*Prosopium williamsoni*), large-scale sucker (*Catostomus macrocheilus*), peamouth chub (*Mylocheilus caurinus*), redside shiner (*Richardsonius balteatus*), northern pike minnow (*Ptychocheilus oregonensis*), threespine stickleback (*Gasterosteus aculeatus*), longfin smelt (*Spirinchus thaleichthys*), prickly sculpin (*Cottus asper*) and goldfish (*Carassius auratus*).

Gillnets captured the most taxa (15), including most of the salmonid taxa except age-0 sockeye. Although trawling on the mudflats often captured large numbers of age-0 sockeye, gillnets fished on the mudflats caught none. The gillnets did capture other age-0 salmonids, although in very low numbers. Gillnets, trapnets, and the large bottom traps captured large numbers of peamouth chub, redside shiner, and northern pike minnow relative to other gear types. Gillnets caught the largest size range (57-1000 mm) with 50% of the fish between 105 and 165 mm. White sturgeon (500-600 mm) were captured only in gillnets while adult anadromous salmon were caught only in the gillnets and trapnets.

Next to gillnets, trapnets captured the most taxa (10). They captured more chinook/coho than did the gillnets but few of the other salmonids. They were also effective on peamouth chub, redside shiner, northern pike minnow, and prickly sculpins. Trapnets captured a wide size range of fish (46-764 mm) with 50% of the fish between 75 and 165 mm. The trapnets captured adult anadromous salmon but not white sturgeon.

Minnow and the large bottom traps captured only 6 taxa. Prickly sculpin were by far the most abundant species caught, although three-spine sticklebacks were also captured in large numbers. The larger traps were more effective on redside shiner and northern pike minnow than the minnow trap. Virtually no salmonids were captured in either the minnow traps or the other 2 bottom traps. Minnow traps captured a relatively narrow size range of fish (24-199 mm) with 50% of the fish between 75 and 105 mm. The larger traps captured a wider size range (39-273 mm) with 50% of the fish between 75 and 115 mm.

Beach seines captured only 7 taxa. While the only salmonid taxa caught was chinook/coho, they were captured in large numbers. The seines were also effective on juvenile whitefish and three-spine stickleback. Beach seines captured the smallest fish of all of the nearshore gear (11-180 mm) with 50% of the fish between 55 and 85 mm.

The midwater trawl caught 8 taxa. They were the only gear to capture age-0 sockeye and the only gear that did not capture prickly sculpins. As we could only sample in water >6m deep with this trawl, the samples may be more representative of deep water habitat than the littoral region. Longfin smelt and three-spine stickleback were also captured in abundance in the nearshore trawls. These species are also very abundant offshore (data on file). The midwater trawl captured the smallest fish of all of the gear (11-128 mm) with 50% of the fish between 25 and 55 mm.

We were able to effectively fish only the large and small minnow traps and the gillnets in all habitat types and under all weather and lake height conditions. Beach seines proved to be ineffective in both the bedrock and rubble substrates. Capture rates on these substrates were virtually zero as it proved impossible to effectively seal the lead line against the uneven bottom. The apron at the mouth of the trapnets also needed to be sealed against the bottom to fish effectively and this proved difficult on steep slopes (the rubble site). Anchors were needed to maintain an effective fishing shape, but often the winds on Harrison lake were too strong to hold the trapnets in place. As mentioned before, the trawl net could only fish in water >6 m deep which is probably not representative of the littoral area.

The rest of the discussion is based on data from the minnow traps, large bottom traps and the gillnets only. We were able to fish these three gears at all sites and under all conditions. They sampled all littoral species of fish and all size ranges encountered in the lake. Two difficulties still exist with interpretation of samples collected by these gear types. First, besides the relative bias between gear types, the absolute bias between the individual gears and the lake population is still unknown. Second, comparisons of catch per unit of effort (C/UE) or biomass (g/set) between the gears is very difficult, as the relationship between a trap unit of effort and a gillnet unit of effort is also unknown.

Comparison between habitat types

Data from gillnets and minnow traps and large bottom traps were used to compare between the four substrate types. The same number of taxa (11-12) were captured on each of the substrates (Table 4). Overall, bedrock had the lowest biomass (g/set) and C/UE than any of the other substrates, although no significant difference in total biomass or C/UE could be shown between substrate types. Individual species were often captured in much greater abundance in some habitats than in others (e.g. peamouth chub on the mudflats, northern pike minnow and redside shiner on the rubble) (Fig. 2). However, significant differences could only be shown for prickly sculpin which were captured in greater numbers and biomass on the rubble and gravel than on the other two substrates (ANOVA, LSD test, $p < 0.05$). The lack of significant difference in other species is possibly due to patchy distributions that resulted in very large variations around the means. For example, the high catch rate of peamouth chub on the mudflats is entirely due to a single very large catch in the fall of 1999. Only prickly sculpins were captured consistently at all sites and seasons.

Seasonal Comparisons

Although total C/UE and biomass of all fish in all habitats approximately doubles from spring to fall (Table 5), the differences are not significant. Similar differences are apparent for each substrate type separately but no significant differences can be shown. Examination of some of the more commonly caught individual species shows little consistent variation in C/UE and biomass between seasons (Fig. 2 & 3). The one exception was prickly sculpins, which showed significant increases in biomass from spring (0.05 g/set) to summer (0.09 g/set) to fall (0.13 g/set), when data from all habitats was pooled (ANOVA $F=4.96$, $P = 0.01$, $DF=63$). Most of this increase appeared to occur in the gravel and rubble habitats. As mentioned, the patchiness in catch of the other species most likely resulted in the lack of significant differences.

Final Comments

This analysis is preliminary and does not include the deep water habitat. Both quantitative and qualitative sampling of the littoral areas of large oligotrophic lakes is difficult. The low conductivity severely restricts the fishing ability of electroshockers. Some gears that can fish most habitat types such as floating trapnets are difficult to maintain with the high winds that often occur on these lakes. Visual techniques may be suitable in some clear water lakes, but many B.C. lakes are relatively turbid due to glacial influences or organic stain. Other gears are only able to sample certain habitats, such as relatively smooth surfaces (beach seines) or water deeper than 6 m (trawls). We were able to consistently and effectively fish only a limited set of fishing gear – bottom traps and gillnets. However, although each gear is both size and species biased they did manage to capture most species and taxa and virtually all size ranges that were caught by all gears combined. Passive gear types such as these can provide quantitative information on species type and size but do not give absolute estimates of either density or biomass. Further, comparisons between the two gear types are difficult as the relationship between the each gear's units of effort are unknown.

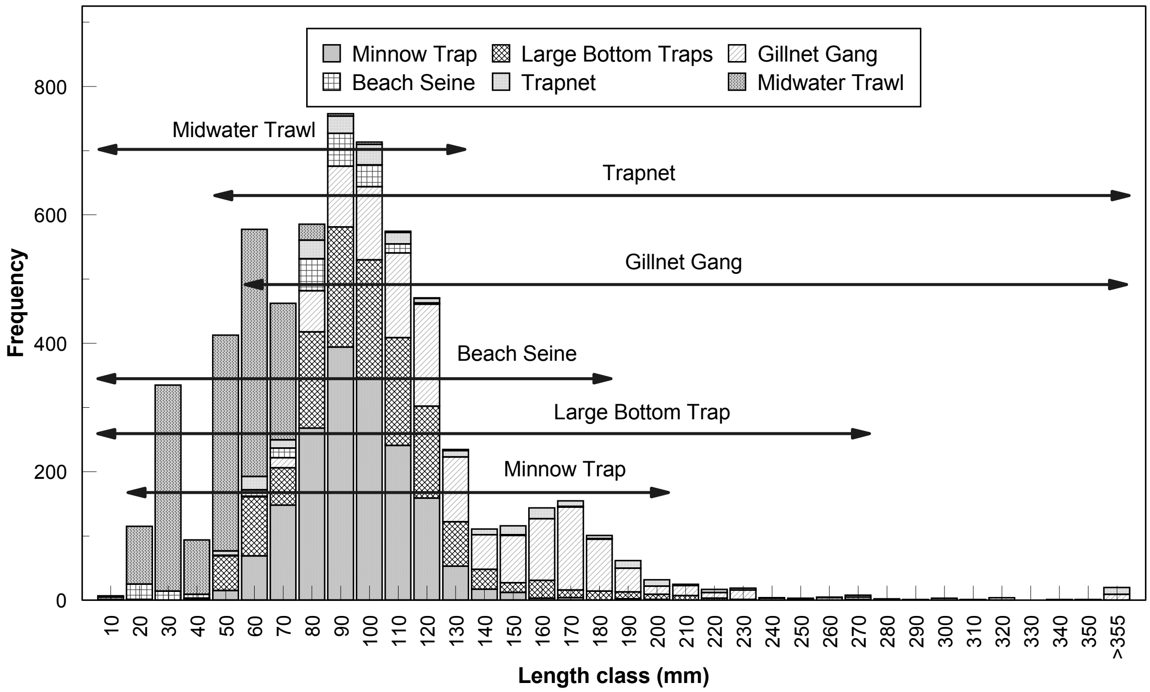
Literature Cited

Hume, J.M.B., K.S. Shortreed, and K.F. Morton. 1996. Juvenile sockeye rearing capacity of three lakes in the Fraser River system. Can. J. Fish. Aquat. Sci. 53: 719-733.

Hume, J.M.B., and K.S. Shortreed. 2000. Fish utilization of habitat types in Fraser River lakes. In: Randall *et al*. Field measurement of the productive capacity of freshwater fish habitat – proceedings of a scoping workshop. Fisheries and Oceans Canada, Burlington. Workshop report,60p.

Figure 1. Size range of the catch in all gears types used.

A.



B.

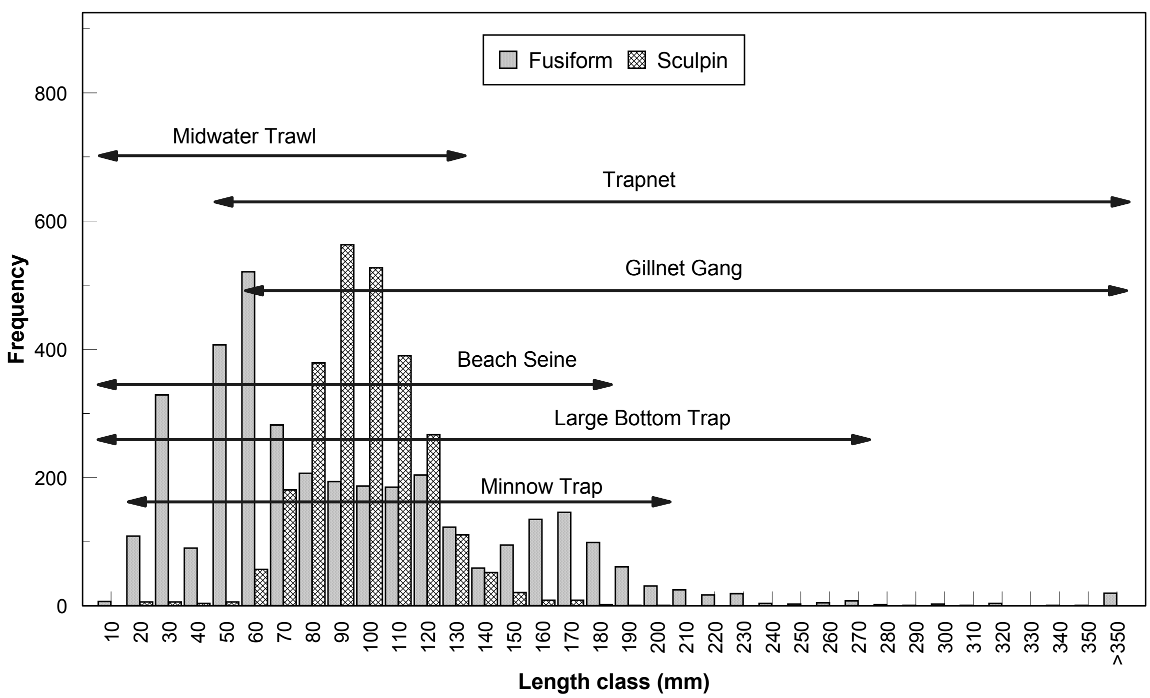


Figure 2. Seasonal catch (C/UE) of the most common species in bottom traps and gillnets, for both years combined.

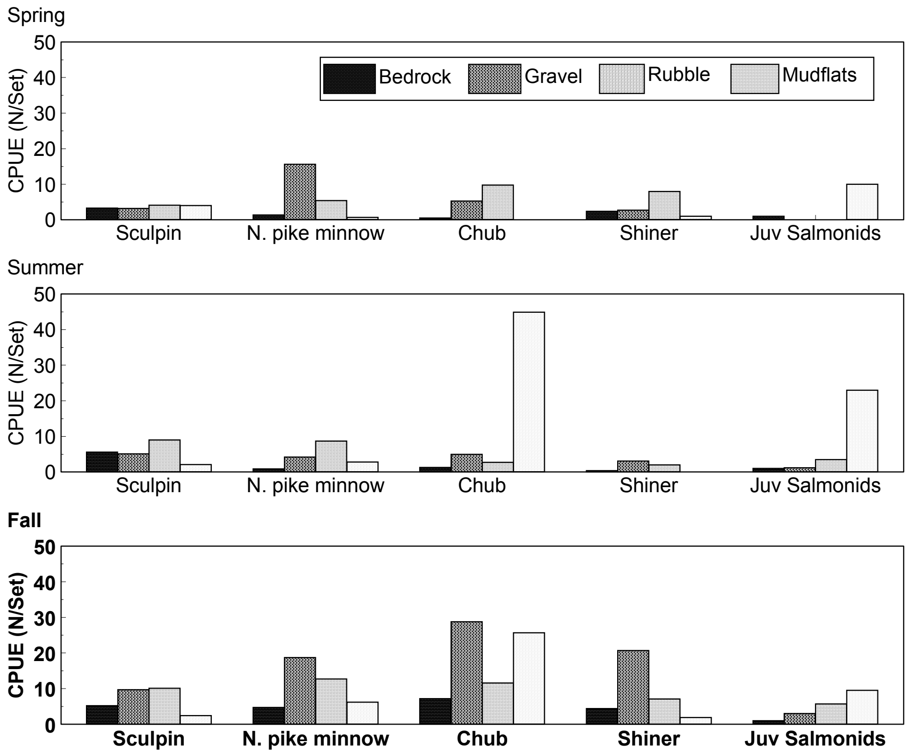


Figure 3. Seasonal biomass catch (g/set) of the most common species in bottom traps and gillnets, for both years combined.

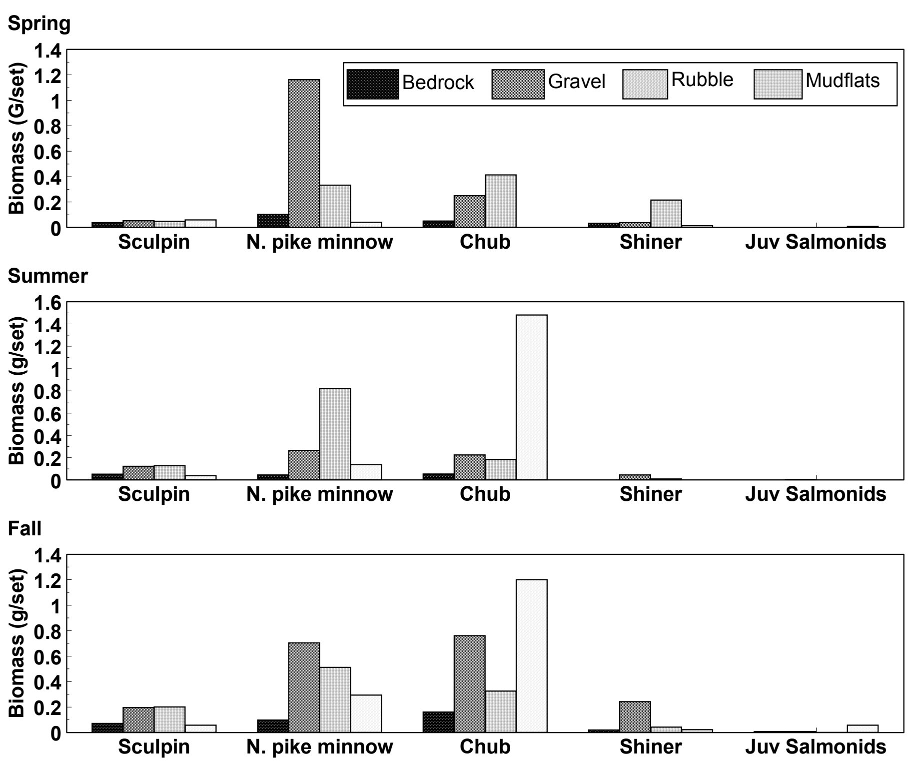


Table 1. Salient morphometric and limnological variables from Harrison Lake. Limnological data are seasonal (April-November) averages unless otherwise specified.

Surface area (km^2)	220	Elevation (m)	10
TDS (mg L^{-1})	34	Conductivity (µS cm^{-1} at 25ºC)	34
Turbidity (NTU)	1.0	pH	7.0
Total alkalinity (mg $CaCO_3$)	13.6	Epilimnion depth (m)	21
Mean epilimnetic temperature (ºC)	12.6	Secchi depth (m)	5.1
Euphotic zone depth (m)	11.2	Spring overturn total P (µg L^{-1})	3.8
Nitrate (µg N L^{-1})	47	Chlorophyll (µg L^{-1})	0.75
Soluble reactive P (µg L^{-1})	1.5	Daily photosynthetic rate (mg C·m^{-2}·d^{-1})	107

Table 2. Fishing effort for each survey at each habitat type. Minnow trap effort is individual traps, gill net effort is a gang of 7 gill nets of different mesh sizes, trawl effort is one 10 min trawl.

	1999	2000
Spring		
Minnow Trap (2cm opening)	10	10
Bottom Trap (9cm opening)		2
Gill net gang	2	1
Trawl (3X3 m)		1
Summer		
Minnow Trap (2cm opening)	12	8
Bottom Trap (9cm opening)		4
Gill net gang	2	1
Trap net	1	
Trawl (3X3 m)	1	1
Fall		
Minnow Trap (2cm opening)	16	8
Bottom Trap (9cm opening)	2	4
Gill net gang	2	1
Beach Seine	1	
Trap net	1	
Trawl (3X3 m)	1	1

Table 3. Gear type differences in species diversity based on mean C/UE (catch/set) summarized over all sites and dates.

SPECIES	Bottom traps 2 cm opening	Bottom traps 9 cm opening	Gillnet	Midwater Trawl	Trapnet	Beach Seine
Sockeye (Age-o)				13.3		
Kokanee (Age 2+)			1.0	1.0		
Chinook/coho (Age-0)	0.1		1.0	1.4	4.4	12.0
Cutthroat trout (Age-2+)			1.8		1.0	
Bull trout			0.9			
White sturgeon			1.2			
Mountain whitefish			1.8		1.0	76.5
Migratory Adult salmon			1.3		3.5	
Large scale sucker		1.0	3.3		1.7	1.0
Peamouth chub	0.2	0.7	24.5	1.0	4.4	5.0
Redside shiner	0.5	5.6	12.7	2.0	12.9	7.5
Northern pike minnow	0.7	6.2	12.9	1.5	8.2	
Three spine Stickleback	3.7	3.5	1.0	36.2	1.5	11.3
Goldfish			0.5			
Longfin smelt			2.1	66.2		
Prickly sculpin	7.6	3.2	5.4		4.3	6.0
Mean C/UE	3.1	3.4	12.3	23.8	5.3	18.3
No. of Taxa	6	6	15	8	10	7

Table 4. Habitat differences in species diversity based on mean C/UE (catch/set) summarized over all sites and dates.

SPECIES	Bedrock	Rubble	Gravel	Mudflats
Sockeye (Age-o)				
Kokanee (Age 2+)				1.0
Chinook/coho (Age-0)	1.0	0.7	0.1	1.0
Cutthroat trout (Age-2+)		1.0	2.5	
Bull trout	0.5	1.0	1.0	
White sturgeon	1.0			1.5
Mountain whitefish	1.0	1.0	1.2	2.8
Migratory Adult salmon	1.5	1.0	1.0	
Large scale sucker	1.0	3.8	3.0	1.0
Peamouth chub	5.3	13.0	9.7	36.9
Redside shiner	1.7	11.6	3.8	1.9
Northern pike minnow	2.5	15.7	9.7	4.2
Three spine Stickleback		1.0	0.1	5.0
Goldfish				0.5
Longfin smelt	5.0	1.0	2.3	1.3
Prickly sculpin	4.9	6.6	9.0	2.8
Mean C/UE	3.3	8.6	6.3	7.2
No. of Taxa	11	12	12	12

Table 5. Seasonal differences in species diversity based on mean C/UE (catch/set) summarized over all sites and dates.

SPECIES	Spring	Summer	Fall
Sockeye (Age-o)			
Kokanee (Age 2+)			1.0
Chinook/coho (Age-0)	1.0	0.6	0.7
Cutthroat trout (Age-2+)	3.0	1.5	1.0
Bull trout		1.0	0.8
White sturgeon		1.0	1.3
Mountain whitefish	1.0	2.3	1.6
Migratory Adult salmon			1.3
Large scale sucker	2.2	1.0	4.3
Peamouth chub	6.1	15.8	18.8
Redside shiner	3.8	1.2	8.3
Northern pike minnow	5.7	4.0	11.1
Three spine Stickleback	0.1	5.4	1.5
Goldfish	1.0		
Longfin smelt	1.5		2.3
Prickly sculpin	3.6	5.6	7.4
Mean C/UE	4.0	5.4	8.3
No. of Taxa	11	11	14

Report 10. An introduction to ETD concepts in understanding fish habitat *(Franzin et al.)*

W.G. Franzin, P.A. Nelson and P.M. Cooley. Fisheries and Oceans Canada, Winnipeg

Abstract

Erosion, transport and deposition (ETD) are hydraulic processes that, combined with geology and geomorphology, determine substrate conformation in water. Geomorphology includes the landscape in which water resides and local geology is the source of materials arranged by hydraulic forces into the substrates we see in stream beds and littoral areas of lakes. Gravitational energy is the basis for hydraulic processes in aquatic habitats but it is provided by different sources in streams and lakes. In streams, energy comes from slope of the landform while in lakes, energy is provided by wind-driven waves. The available energy is a scalable product of landscape or lake area and climate. Human activity in watersheds modifies natural landforms, stream channels and lakes, and therefore also affects habitat. Geologists, engineers and oceanographers have taken a physical approach to water for decades but biologists have tended to be preoccupied with descriptive approaches. Adoption of an energetic/hydraulic approach to physical fish habitat both simplifies the forcing functions that form and maintain habitat and improves communication between biologists and physical scientists. We present a simplified approach for modeling fish habitat, and provide examples of fish use of habitat in relation to ETD.

Fish habitat

The Fisheries Act definition of fish habitat is: “Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.” (Fisheries Act, Sec. 34 (1)). The ‘life process’ elements of aquatic habitats necessary for fish are water, shelter, food, and reproductive space, which may vary temporally in their availability due to natural stochastic processes. All elements are required for the success of an individual, population, species or community of species populations. For any one species, fish habitat approximates the ‘Hutchinsonian niche’ comprising, at any instant in time for an individual fish, a hypervolume, or for a population or species, a biogeographic space, within which that individual, population, or species can complete its life cycle. Figure 1 illustrates this concept, which is applicable to an individual fish or a species. In a broad sense, we understand these habitat features quite well for most common species, and reasonably well for many restricted populations that comprise recreational or commercial fisheries. The central blue rings represent the degree to which any particular point in space meets the requirements of an individual fish, population or species. Each of the spheres of habitat conditions impinges on this space and of course the spheres interact in complex multivariate ways. The overall gray sphere represents the over-riding effects that the watershed and human alteration of the global environment have on fish habitat, increasing towards the outside until no habitat exists. A reasonable base of empirical science in ecology, fisheries biology, physiology and biochemistry provides fairly strong theoretical bases for our understanding of the chemical and biotic spheres of fish habitat indicated in Figure 1. We would argue that we lack much of that theoretical underpinning for the physical sphere of fish habitat (other than temperature) and it is this area that we address in this paper (Fig. 2).

Much of our understanding of physical fish habitat is based on a suite of autocorrelated measurements collected with varying degrees of precision over a range in space varying from point locations of individual fish to community samples caught in grid areas or transects. Physiologists have addressed swimming performance for many fish species and behaviorists provide much useful data on optical and olfactory cues to explain why a fish might be found in a particular spot. Indeed accumulated observations allow reasonable understanding of the range of physical habitat conditions ‘preferred’ by many important species as implied by their frequency of capture over a range of available conditions within the environment. Undoubtedly we have learned much from these approaches which appear to work well in smaller stable streams. Where this approach fails is in larger rivers and in lakes. Many fish species in North America seem to thrive in both rivers and lakes or even in estuaries or coastal marine environments. Obviously broad application of fish preference curves for physical aspects of habitat then becomes problematic.

The ETD concept and fish habitat

We advocate a change in approach to accommodate the broader physical habitat conditions found in the full spectrum of aquatic habitats whether that habitat is in the smallest stream or on a marine coast. We advocate a scale-independent hydraulic/energetics approach to fish habitat - the Erosion, Transport, Deposition (ETD) method.

Erosion, Transport, and Deposition (ETD) are universal features of aquatic habitats, applying to streams, lakes of all sizes, and the oceans. Physical aquatic habitats are formed and maintained by hydraulic forces in water. ETD is an energetic approach to understanding habitat and is the basis for utilization of habitats by biota.

Physical habitat, the realm of ETD, is governed by two factors: 1) parent geology and 2) hydraulics (the manifestation of energy). Parent geology is a scale-dependent watershed factor that provides the working materials for ETD. Hydraulic factors are scale-independent forces that modify the distributions of particles in water, creating the physical habitat conditions within which biota live and interact.

ETD is the physical manifestation, in aquatic habitats, of gravitational energy acting through hydraulic processes to distribute substrate particles along an energy gradient (Figure 3). Because ETD are scale-independent processes, all aquatic habitats can be described within the context of two characteristics: parent geomorphology (controls availability of particles) and available energy. Available energy, or power, in aquatic habitats is a scale-dependent property; mass times force applied provides energy to do work, i.e. large rivers have more hydraulic power to move larger materials as do larger waves in large lakes. The source of energy as indicated above is gravity; provided in rivers by slope and in lakes and the oceans by wind driven waves (and in the oceans and very large lakes, tides also) acting on shorelines. Fig. 4 compares the energetics of a river and a lake to illustrate similarities and differences. Fig. 5 and 6 demonstrate the universality of ETD processes; riverine environments occur within lakes and wave induced beaches occur in rivers. Currents and waves occur in all water bodies regardless of size. ETD is not a new idea; in fact it has been an accepted explanation for observed physical structure of rivers and beaches by hydrologists, physical limnologists, oceanographers, and water engineers for decades. The concept is backed fully by strong quantitative science and is the subject of many textbooks in these disciplines.

How can ETD help our understanding of fish habitat? Physical fish-habitat features usually are accumulated observations over time and space that, taken together, describe the mean conditions in which we find a species. Point measurements in time and space offer little real information about these mean conditions because we may not know why a fish was captured in a particular spot at a particular time, i.e. we don't know what particular function of the fish's life cycle was being fulfilled by the particular habitat at that time. Fish use habitat to obtain the three basic needs of food, shelter and reproduction. Understanding the energetic/hydraulic state of a site provide clues, which, in combination with knowledge of the fish's reproductive status (e.g. time of year, spawning habits) and feeding habits, allows one to predict why the fish might be at that site. Knowledge of the distribution of food organisms like macrobenthos, that also respond to ETD, help to affirm how specific habitats are used by fish. ETD provides a theoretical context for an apparent discontinuity presented by the unexpected presence of species in certain habitats. For example, fish species like longnose dace, mottled sculpin, and many darters are considered to be stream species. These species are common inhabitants of headwater streams in Manitoba, but they also occur on wave-washed gravel-boulder shores of Lake Winnipeg, the 10th largest freshwater lake in the world. The link is the energetic state of these habitats which meet the mean habitat requirements for the species (Fig. 7). The ETD approach links fish biology (distribution) with benthological and hydrological science. Research to explain the distribution of benthic organisms has embraced hydrological principles for many years, perhaps because sampling designs for mainly sedentary invertebrates are more tractable across the range in scale of aquatic habitats, and the connections between various groups and their habitats seems more obvious than for fish. ETD provides the link among the disciplines, the various aquatic organisms, and their habitats whether in rivers, lakes or oceans.

Summary

Our intent is to introduce alternative ways of analyzing physical fish habitat. We seek to develop a universal approach to aquatic habitat that fits both lotic and lentic water bodies from the smallest stream to an ocean. We believe that an ETD approach will provide a common understanding of fish habitat among aquatic biologists, hydrologists, limnologists, oceanographers and engineers. This outline is a beginning only; much of the theory, formulae and viewpoints need to be integrated both conceptually and mathematically. Further integration of habitat science across disciplines in needed. We invite your critical comments.

Figure 1. An approach to understanding fish habitat.

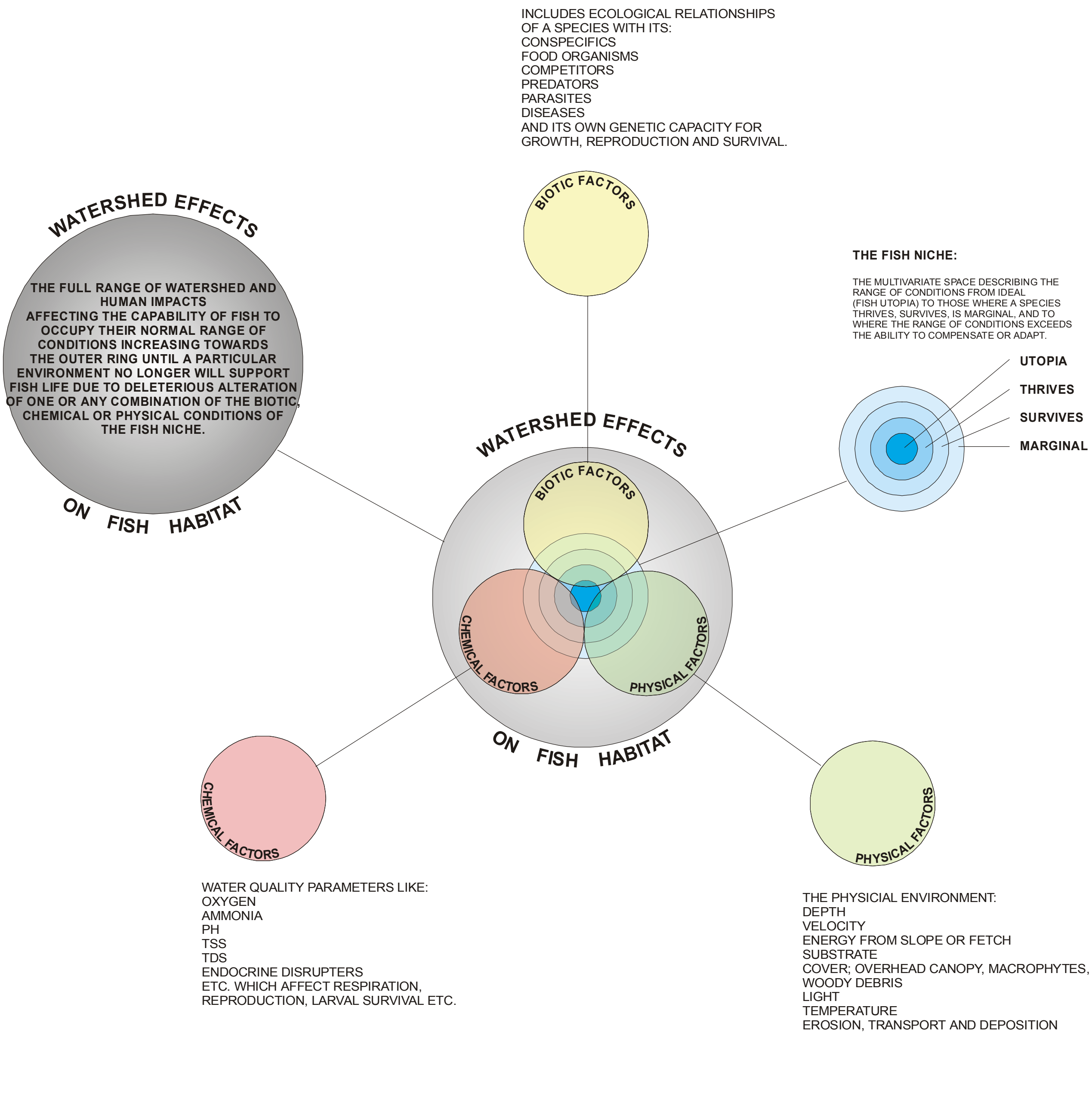


Figure 2. The physical characteristics of fish habitat.

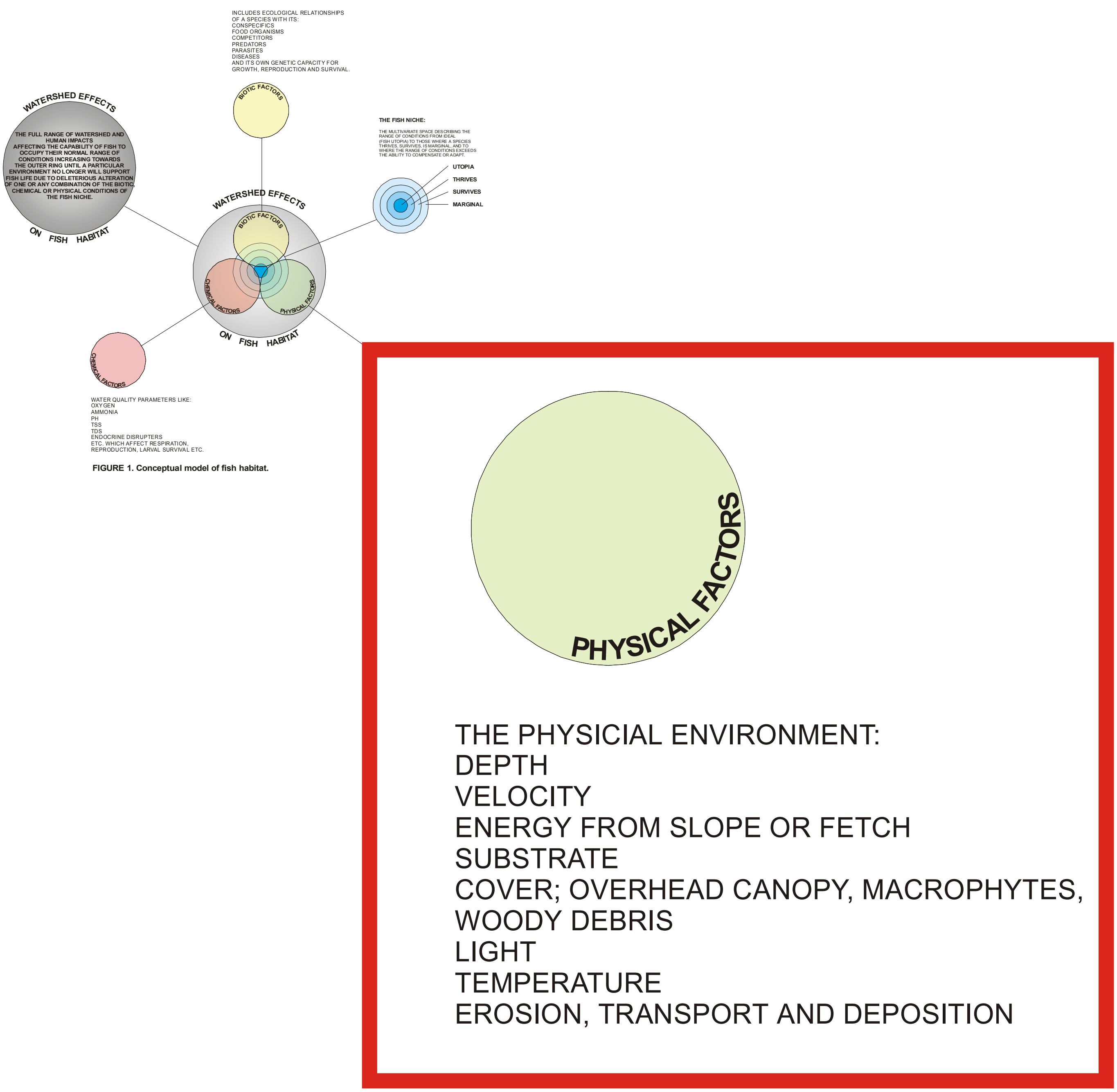


Figure 3. ETD represented as a spectrum of energy and particle size.

Figure 4. This figure compares the energetics and hydraulic processes in a river segment and a bay in a lake. The main difference is where the focus of energy is applied: in a river maximum erosional energy is in the deepest part of a channel (thalweg) while on a beach, greater force is exerted by an incoming wave than by the returning wave, consequently less energy is available to move particles downslope. The deposition of coarsest particles, in both instances, is in the zone of highest energy.

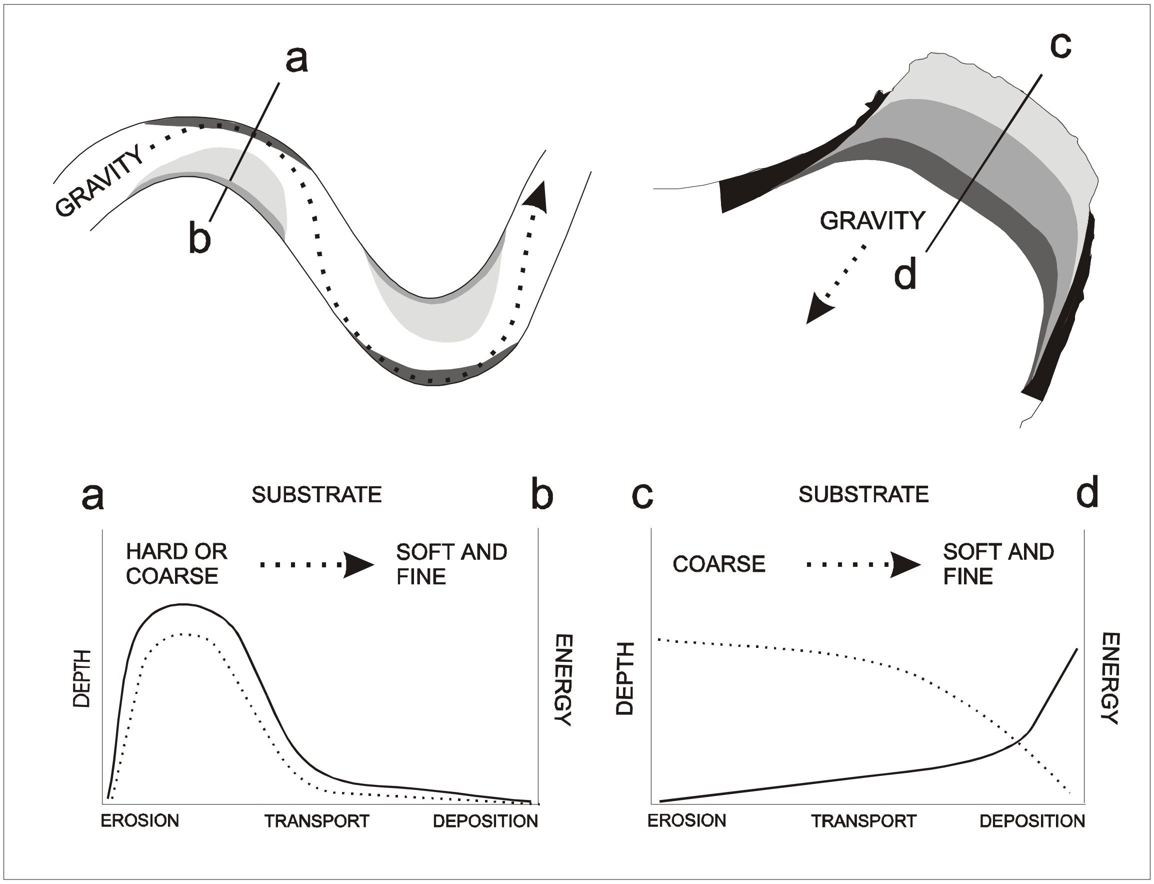


Figure 5. This figure illustrates how a larger river might develop a beach. Larger rivers in alluvial soils may develop semi-permanent bays on the downstream margins of point bars.

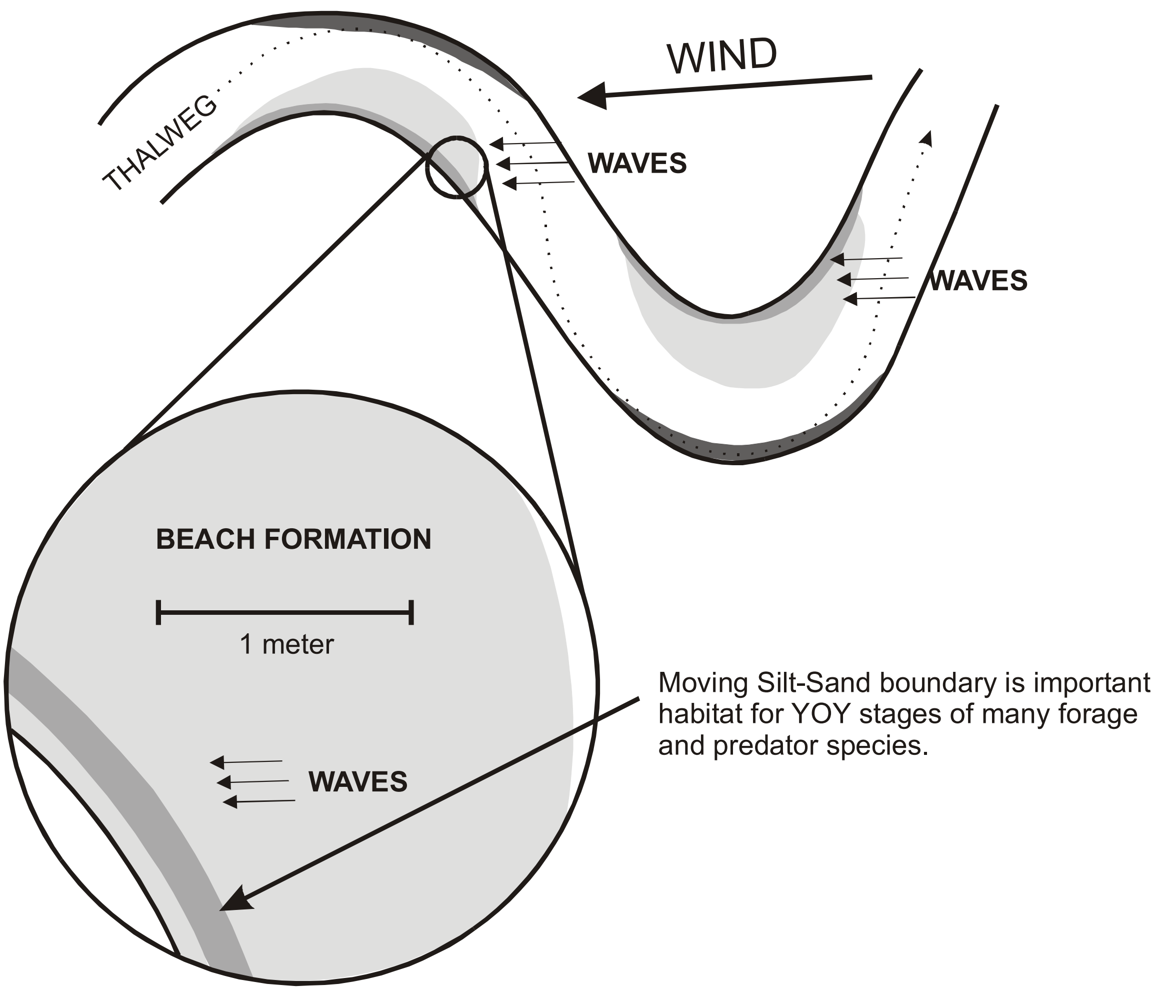


Figure 6. This figure illustrates how wind set in a lake can create both longshore currents and riverine conditions when there is a constriction between two basins. If the prevalent wind directions coincide with the main axis of a lake as in this figure such constrictions may be important spawning grounds for lake resident 'stream spawners'.

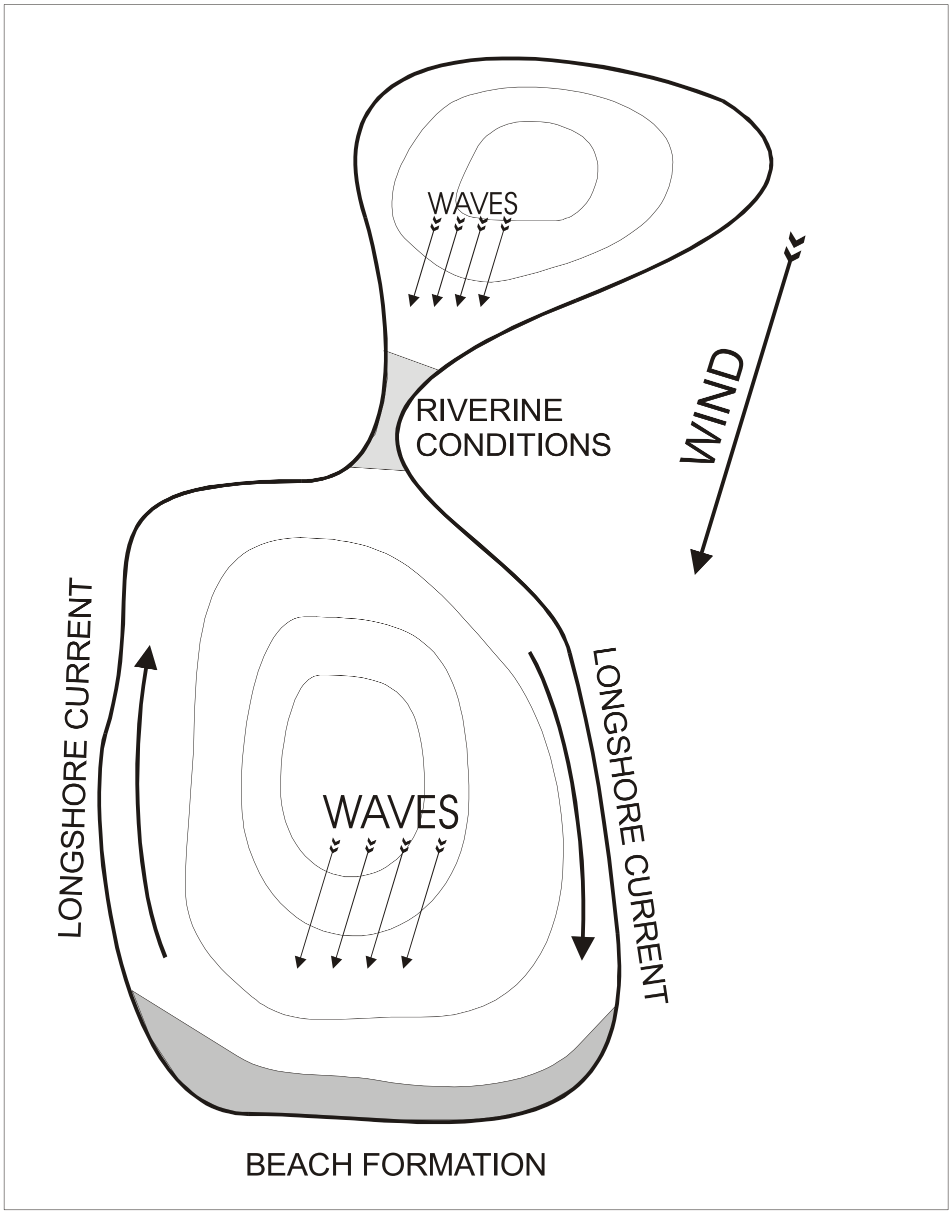
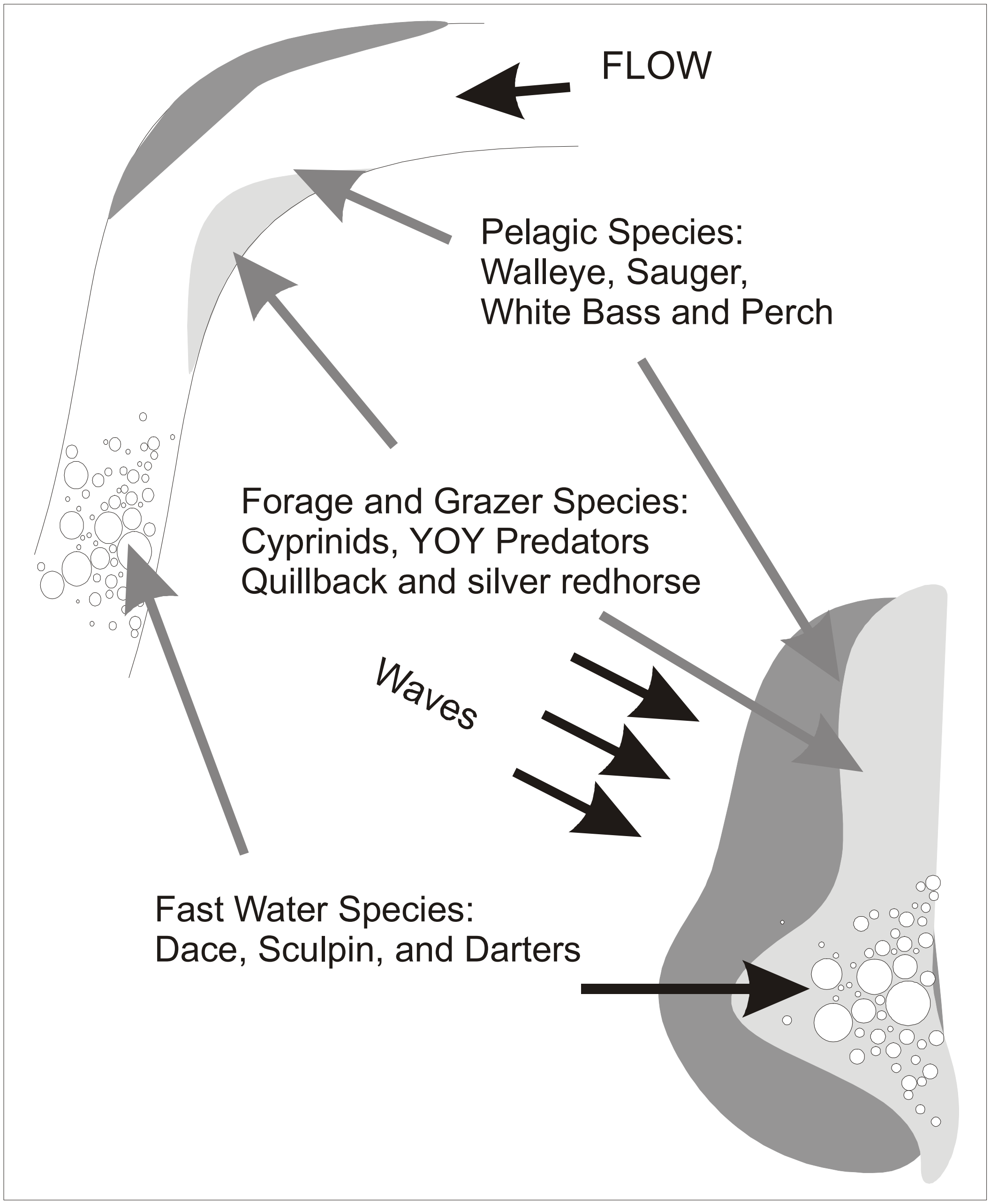


Figure 7. Many fish species are found on habitats that are energetically or hydraulically similar as indicated by substrates formed by ETD processes.



Report 11. Preliminary analysis of the relationship between fish habitat classifications and topological lake units *(Frezza and Minns)*

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Objective

The goal of this study is to objectively assess subjective fish habitat classification systems using topological measurements of lake units such as depth, slope, and fetch. Analyses are based on the erosion, transport, and deposition (ETD) concept, previously described by Hakanson (1983) and Franzin (1999), whereby hydraulic processes based on energy from wind driven waves determine substrate conformation in littoral areas of lakes (Franzin 1999).

Fish habitat assessment is traditionally based on subjective classifications of substrate and cover and is reliant on personal judgement and interpretation of definitions of classes by observers. The ability to predict habitat using topological lake units would provide a predictive modeling tool for fish habitat managers and reduce inherent subjectivity. This tool will allow managers to assess fish habitat in lakes based on measurements that can easily be obtained from bathymetric maps.

Methods

Two small (<25 ha) lakes in Ontario were used for this analysis, Little Turkey and Wishart Lakes, both located within the Turkey Lakes Watershed (84^{o}25'W, 47^{o}03'N).

Substrate was classified into different habitat types by particle size (Table 1). The spatial distribution of substrate composition was mapped for the area between shore and the 2 m contour. On the maps, substrate was classified into zones of the dominant habitat type present, and the size of each zone determined by the surface area covered.

Within a GIS, the nearshore area of each lake (from shore to the 2 m depth contour) was divided into 2 m^2 grids. We systematically selected every 5th grid as a sample location, using the centroid of the grid as the sample point.

A range of fetch indices for each sample point was calculated. This included the minimum, maximum, and average fetch, the minimum, maximum and average effective fetch, and the effective fetch in the strongest wind direction.

Bathymetric maps with 0.5 m contour intervals were used to interpolate surface maps of slope and depth. The depth and slope at each sample point were determined, in addition to the habitat class at each point.

To reduce the number of variables, Principal Component Analysis (PCA) was done. The variables that were not eliminated were used in a Discriminant Function Analysis (DFA) to predict the habitat classification at each sampling point. Three different sets of habitat classification were used for the DFA: 1) all the original substrate classes (Table 1); 2) general size groupings of fine, medium, and large; and 3) large particle sizes separate from all others (bedrock, boulder, and others). This was done to determine if the success of predicting habitat classification from topological lake units increased with a simplification of the classification scheme.

Preliminary results

The number of variables used was reduced from nine to five based on the contribution of each variable to the principle component variates. The variables selected for use in the DFA were depth, slope, minimum effective fetch, maximum effective fetch, and effective fetch in the strongest wind direction.

An example of a classification matrix from the DFA is given in Table 2 using Little Turkey Lake and general size groupings of fine, medium, and large as habitat units. In general, the success of predicting habitat units from topological lake units was low for both lakes (Table 3). With an increased simplification of habitat units, the classification success of predicting habitat units using the topological variables increased, especially for Wishart Lake (Table 3). An example of the distribution of factor scores from the DFA of Little Turkey Lake using bedrock, boulder, and other classes is given in Figure 1.

Future Work

This analysis was a preliminary look at the relationships that exist between topological features and habitat classifications. In addition to the information from the two lakes presented, we have bathymetric maps and habitat classifications available for three other lakes. We will include macrophyte and woody material coverage in this analysis, as well as offshore (beyond 2 m depth) sampling points.

Further analyses will include incorporating the Kappa statistic to determine the success of classification from the DFA with the occurrence of chance agreement removed. Also, we will investigate the use of classification trees and compare these results with those from the DFA. We will make between lake comparisons of the results obtained from both the DFA and classification trees. This will determine if the criteria used to predict habitat are consistent across lakes.

References

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Table 1. Definition of substrate types revised from Lester *et al*. (1998).

Substrate types	Definition
Bedrock	Exposed rock, no overburden
Boulder	>25 cm
Rubble	8 - 25 cm
Gravel	0.2 - 8 cm
Sand	<0.2 cm
Silt/Muck/Detritus	Inorganic, soft and decaying organic
Clay	Inorganic without structure
Other	Does not fit into any of the other categories

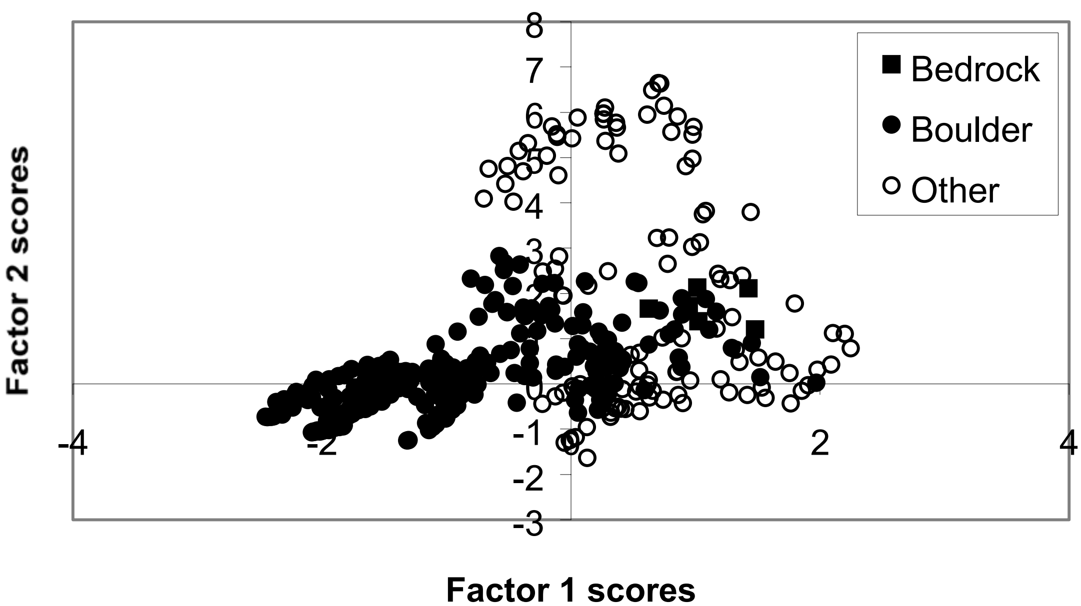
Table 2. Classification matrix from the Discriminant Function Analysis indicating the success of predicting habitat units at sampling points using topological variables. Habitat units from field classification are in rows and the predicted classification in columns. Numbers in the diagonal are successful predictions of habitat classification.

	Fine	Medium	Large	% Correct
Fine	1023	755	954	37
Medium	393	663	227	52
Large	34	48	231	74
Total	1450	1466	1412	44

Table 3. Overall success of predicting habitat units at sampling points using topological indices. Success is measured by the percentage of sample points where habitat units are correctly classified.

Habitat units	Classification success (%)	
	Little Turkey	Wishart
All habitat classes	35	48
Fine, medium, large	49	53
Boulders, bedrock, other	55	70

Figure 1. Factor scores from the Discriminant Functional Analysis of Little Turkey Lake using



habitat units of bedrock, boulder, and other. The classification success of each habitat unit was 75% bedrock, 71% boulder, and 54% other. The total classification success was 55%.