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Characterization of Littoral Fish Assemblages and Their Habitat in the St. Lawrence River near Cornwall, Ontario

by

© **Sandra C. Ribey**

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In memory of a little angel,

Brittanya Dee Hadland (1989-1996)

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Abstract

This project was aimed at i) characterizing and comparing littoral fish communities upstream and downstream of the Moses-Saunders hydroelectric dam on the St. Lawrence River near Cornwall, Ontario and Massena, New York and ii) exploring relationships between habitat characteristics (including depth gradient - the distance from shore to a 1m depth, percent aquatic vegetation, and percent substrate type) and fish community characteristics (diversity, abundance and biomass). A total of 74,419 fish (43 species) were captured in 36 sites (14 upstream and 22 downstream) using a standard sampling protocol in 1994 and 1995. The downstream region (western portion of Lake St. Francis) had significantly higher number of fish species and biomass when compared to the upstream reservoir (Lake St. Lawrence). A clustering analysis of a Jaccard similarity matrix based on the presence-absence of species for each site revealed largely distinct interregional fish community composition with relatively homogeneous intra-regional communities. A principal component analysis (PCA) of fish species caught in 60% or more of sites allowed the definition of the main fish assemblages. The downstream fish community was characterized by a high abundance of *Notropis volucellus*, *Fundulus diaphanus* and *Notemigonus crysoleucas*, where as upstream a high abundance of *Pimephales notatus* was found. A PCA of habitat variables revealed a dispersal of downstream sites throughout the graph. The upstream sites clustered together. This suggests a broad spectrum of habitat types downstream, while upstream is more homogeneous. Regression and correlation analyses found relationships between fish variables and habitat variables. The downstream area had a wider variety of habitat types, as well as the higher percentage of vegetation cover, boulder and gravel, which supported a more diverse and abundant fish community.

Résumé

Ce projet a pour objectifs de: i) définir et comparer les communautés ichtyennes de la zone littorale du fleuve Saint-Laurent en amont et en aval du barrage hydroélectrique Moses-Saunders, près de Cornwall, Ontario et Massena, New York et ii) examiner les relations entre certains paramètres de l'habitat (gradient de profondeur, couvert végétal aquatique, substrat) et les caractéristiques des communautés ichtyennes (richesse, abondance et biomasse). L'échantillon total contient 74,419 poissons (43 espèces) provenant de 36 sites (14 en amont et 22 en aval). Les poissons ont été capturés selon un protocole d'échantillonnage standard lors des étés 1994 et 1995. Les sites de la région en aval du barrage (secteur ouest du lac Saint-François) contiennent, en moyenne, un nombre plus élevé d'espèces et une plus grande biomasse ichtyenne que les sites en amont (Lac Saint-Laurent). Une analyse multidimensionnelle par groupements d'une matrice de similarité de Jaccard construite en utilisant le critère "présence/absence" de chaque espèce par site a montré des différences inter-régionales prononcées au niveau de la composition en espèces des communautés et une homogénéité intra-régionale assez marquée. Une analyse en composantes principales (ACP) des espèces capturées dans plus de 60% des sites a permis de mieux définir les composantes distinctives des communautés de poissons. La communauté de poissons en aval du barrage est caractérisée par une abondance de ménés pâles (*Notropis volucellus*), fondules barrés (*Fundulus diaphanus*), et chattes de l'est (*Notemigonus crysoleucas*). L'ACP des caractéristiques de l'habitat a révélé une importante dispersion sur les deux axes principaux des sites situés en aval par rapport aux sites de l'amont. Ceci suggère un plus grand spectre de de types d'habitat pour les sites en aval par rapport aux sites en amont. Finalement, des analyses de corrélation et de régression ont permis de trouver des associations entre les variables ichtyennes et les variables d'habitat. Les sites ayant une plus grande hétérogénéité au niveau de l'habitat ainsi que des pourcentages élevés de couvert végétal aquatique, de rochers et de gravier possédent une communauté plus riche en espèces ainsi qu'une plus grande abondance de poissons.

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Introduction

Most large rivers have been degraded by human activities (Anderson et al., 1990). These activities include chemical degradation from pollutants, biological degradation from species introductions and physical degradation through flood control, navigational dredging and hydroelectric damming (Bain, 1992). Because of the nature of the multiple disturbances in large rivers, it is extremely difficult to pinpoint any one as dominant (Yount and Niemi, 1990).

Fewer ecological studies have dealt with large river ecosystems than with lakes and streams (Bain, 1992; Niemi et al., 1990). This is due to highly variable physical properties within large rivers such as deep water and fast moving currents (Bain,1992). One way to overcome sampling problems is to restrict the study to the littoral zone (shallow, near shore water) of the river. Information on the species composition, relative abundance and habitat use patterns of the littoral fish community can be important for basic fish resource management (Bain et at., 1991).

There are several advantages in studying the littoral zone fish to assess ecosystem alteration. All common fish sampling equipment can be applied successfully (Bain et. al, 1991). The littoral zone is easier to sample because it has shallower, slower moving water. It is possible to capture many fish species because the littoral zone provides habitat for small bodied fish species and a nursery and foraging area for larger, deep water fish species (Bain et. al, 1991; Beauchamp et. al, 1994). Many small fish species are sensitive to environmental degradation, therefore changes in the abundance of these species reflect the overall health of the ecosystem (Karr, 1981; Karr et al., 1986). Most habitat alterations (such as flooding and channelization) have an adverse effect on the physical structure of the littoral zone, thus fish diversity, abundance and biomass in these areas should be indicative of changes.

The St. Lawrence River is an example of an ecosystem that has been degraded by human activities of all kinds. The St. Lawrence River is the main outlet of Lake Ontario and provides the main link for the Great Lakes basin to the Atlantic Ocean. This river has been subjected to repeated chemical and physical degradation since the mid 1800's as a result of human settlement, industrial activities, the construction and operation of several types of dams and the opening of the St. Lawrence Seaway (Anderson et al., 1990). The ecosystems of the St. Lawrence River have also been exposed to the adverse effects of species introductions. Elements of its natural biota have been extirpated or are now extinct (Patch and Busch, 1984; Mills et al., 1993). There have been over 139 aquatic species introductions in the Great Lakes basin since the 1830's, including 25 fish species (Mills et al., 1993). Approximately one-third of the species introductions have occurred since the opening of the St. Lawrence Seaway in 1959 (Mills et al., 1993). The Seaway has created opportunities for quick dispersal of species throughout the entire Great Lakes system.

In 1973, the International Joint Commission (IJC) identified 42 Areas of Concern (AOCs) (which increased to 43 in 1982) within the Great Lakes Basin - 26 in the United States, 12 in Canada and five in international waters (Minns et al., 1994). An AOC was defined as an area with impaired ecosystem and human health. In 1986, the IJC suggested that Canada and the United States prepare Remedial Action Plans (RAPs) to outline ways to restore stability within the degraded ecosystem (Hartig and Zarull, 1992). The main purpose of the RAP is to allow the community within the AOC to gather relevant information from all authorities and then provide ideas regarding appropriate responses to the problems. The RAP uses an ecosystem approach and involves scientists, industry, citizens and others.

The Great Lakes Water Quality Agreement has defined 14 "beneficial uses" of water, based on changes in the chemical, physical or biological integrity which leads to use impairments of the Great Lakes system (Anderson et al., 1990). These impairments include beach closings, degradation of aesthetics and loss of fish and wildlife habitat. Five of the fourteen beneficial uses are directly related to fish. Restrictions on fish consumption, tainting of fish flavor, degradation of populations, tumors and other deformities and loss of suitable habitat are the main fish uses that are focused on (Minns et al., 1994). There are four additional uses that are indirectly related to fish and their habitat. Consequently, fish have become important targets for the assessment and restoration of the Great Lakes ecosystem.

Fish are useful organisms for a study of change in the aquatic ecosystem because they indicate both direct and indirect effects of the entire aquatic ecosystem. Fausch et al. (1990) list four reasons: (1) fish are sensitive to a variety of direct and indirect stressors, (2) fish incorporate these stressors because of their dependence on all aspects of the aquatic ecosystem for survival,

(3) fish are long lived, and therefore provide a longer term record of environmental stresses and (4) fish are widely recognized because of their economic and aesthetic importance.

Since the late 1800's, the water quality in the Cornwall area of the St. Lawrence River has been adversely affected by the contaminated effluents originating from various industrial activities in this area. These include textile manufacturing, pulp and paper mills, chemical companies, car plants and aluminum industries (Anderson et al., 1990). In addition to local sources of contaminants, the St. Lawrence River carries contaminants that originate from industrial activities throughout the Great Lakes area, in particular, from Lake Ontario. It is estimated that 90% of the water that passes through the St. Lawrence River at Cornwall originates from Lake Ontario (Anderson et al., 1990).

The area within the St. Lawrence River known as Lake St. Francis, just downstream of the City of Cornwall, Ontario and Massena, New York, was recognized by the IJC as an AOC because of its impaired water quality (Anderson et al., 1990). Problems identified in this AOC included sediments contaminated with PCB's, excess phenols and coliform bacteria in the water and high organochlorine concentrations in fish (Anderson et al., 1990).

Another important anthropogenic stressor of the natural fluvial ecosystem in this area was the construction and opening of the Moses-Saunders hydroelectric dam. When the dam became functional in 1959, 132 km^2 of land upstream of the city of Cornwall were flooded, most of which were farmland (Efford, 1975). In addition to the main dam, a total of 25 km of smaller regulatory dams were constructed in the surrounding area to help control water levels throughout the resulting reservoir, Lake St. Lawrence (Anderson et al., 1990). In addition to the flooding associated with dam construction, this time period also saw the opening of the St. Lawrence Seaway. Flow modification is one of the most widespread, but poorly understood, human disturbances of riverine environments (Bain et al., 1991).

It is reasonable to presume that the individual and combined effects of all these stressors have had a major impact on the natural fluvial ecosystem of the St. Lawrence. It is assumed that these alterations have affected all biota, including the fish at the community level.

Changes in the fish community that have probably accompanied the above mentioned stressors in this area of the St. Lawrence River have never been investigated. Patch and Busch (1984) have found that since the 1930's, a total of 99 species of fish have been identified in the international waters of the St. Lawrence River (the area between Brockville and Cornwall) in various surveys. More recent fish sampling efforts have generally been aimed at analyzing the population characteristics of local sportfish, such as yellow perch (*Perca flavescens)*, walleye (*Stizostedion vitreum*) and northern pike (*Esox lucius*) (Patch and Busch, 1984; Anderson et al., 1990; St. Lawrence RAP Plan, 1994). However, to better understand the fate of a particular sportfish species, an understanding of the entire fish community is usually necessary (Evans et al., 1987). Minnows and darters are important components of the North American fish fauna (Moyle and Cech, 1988) Information about the ecology and population characteristics of these small fish species are sparse because these species have little direct economic importance other than being sold as baitfish (Lyons, 1989).

Government sampling efforts in this area of the St. Lawrence River have concentrated on Lake St. Francis due to the presence of several chemical effluents originating from industries located in the regions of Cornwall and Massena. In general, the sampling effort devoted to the non-AOC, Lake St. Lawrence, has been restricted to some index netting (standardized nets at the same sampling sites from year to year) of sportfish species. Various studies in Lake St. Francis have looked at water quality, sediment quality, biota (benthic invertebrates and fish), wildlife and aesthetics (Anderson et al., 1990). However, in the St. Lawrence River RAP, fish communities as a whole have not been examined.

There were two main objectives to this project. First, we wanted to characterize and compare littoral fish communities both in Lake St. Lawrence, upstream of the Moses-Saunders hydroelectric dam, and in the north channel of the St. Lawrence River at the western end of Lake St. Francis, downstream of the dam. The characterization of this fish communities will provide a unique and useful database for future comparative studies. For the comparative aspect, it was hypothesized that the fish community within Lake St. Lawrence would not be as diverse or abundant as the community in Lake St. Francis because of habitat alteration associated with the dam and Seaway construction. Habitat has been found to be the primary determinant of species composition (Tonn and Magnuson, 1982; Eadie and Keast, 1984). Within a reservoir, littoral productivity is often decreased and results in changes in the relative abundance, biomass and diversity of fish and their food organisms (Geen, 1974; Petts, 1984). Also, most reservoir environments are unstable because of rapid water level fluctuations that could potentially destroy spawning beds and aquatic weed beds (Petts, 1984; Fowler, 1978). Chemical contamination could be affecting the fish community, but it is difficult to associate fish composition changes with chemical pollution without directly performing toxicity tests. The second objective was to examine if the parameters of the fish community (diversity, abundance and biomass) could be associated with particular features of the habitat. The discovery of associations could help define habitat types that could be prioritized for preservation/ conservation to help maintain an abundant and/or diverse fish community in the St. Lawrence River.

Methods

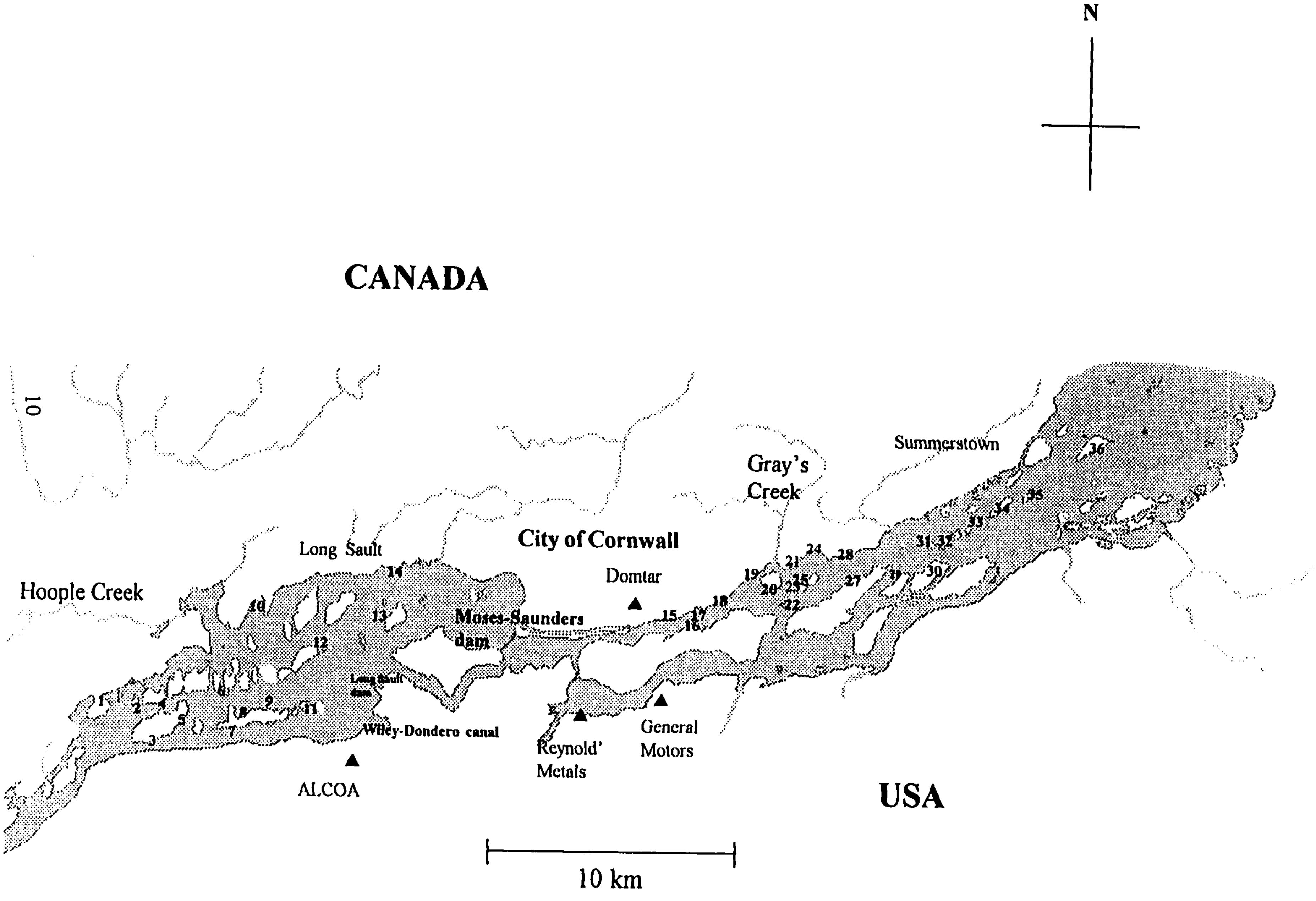
Study Area

This study took place in the St. Lawrence River near Cornwall, Ontario in the summers of 1994 (June-August) and 1995 (June and July) (Figure 1; Table 1). All sampling sites were within a 20 km radius of the city of Cornwall (74°44' W, 45°01'N) on both the Canadian and American shores of the St. Lawrence River. Sites were originally selected to cover three types of habitat - fast current areas, embayments and wetlands. Because of the sampling gear, sites were restricted mainly to embayments which covered a broad spectrum of substrate and vegetation types. There were two main sampling areas - Lake St. Lawrence (upstream) and the western portion of Lake St. Francis (downstream). The boundary between the two sampling areas was the Moses-Saunders hydroelectric dam. During the two summers, 14 upstream sites and 22 downstream sites were sampled in weekly alternance to reduce the effect of temporal variation.

Data Collection

Five seine hauls were done at each of the 36 sites, covering an area of approximately 0.06 ha per site. Within the littoral zone, bottom type, water depth, and current can change the effectiveness of seining (Hayes, 1983). For this reason, two different seining techniques were used at each sampling site. Two 30m seine hauls (mesh - 0.5cm) were done using a small motor boat. One extremity of the seine net was pulled out approximately 25-30 m from shore and was then arched back towards shore, where a second collector would pull the net into shore from the

Figure 1: Location of 1994 and 1995 sampling sites in the St. Lawrence River, near Cornwall, Ontario. Upstream and downstream sites are separated by the Moses-Saunders hydroelectric dam. See Table 1 for corresponding site names and exact locations.


N
CANADA
USA
Hoople Creek
Long Sault
City of Cornwall
Gray's Creek
Summerstown
Domtar
Moses-Saunders dam
Long Sault dam
Wiley-Dondero canal
ALCOA
Reynold' Metals
General Motors
10 km
1
2
3
4
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6
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Table 1: Location of 1994 and 1995 sampling sites in the St. Lawrence River, near Cornwall, Ontario and Massena, New York. U=upstream of dam, D=downstream of dam. Site # refers to numbers on Figure 1.

Location	Site # on Map	Latitude	Longitude	Region
Farran Provincial Park	1	75°59'48"W'	44°59'54"N	U
Bredin Island	2	74°58'30"W	44°59'24"N	U
SE Croil Isl.	3	74°58'00"W	44°58'48"N	U
NE Croil Isl.	4	74°58'12"W	44°58'54"N	U
Croil Island #3	5	74°57'30"W	44°58'24"N	U
Hoople Island	6	74°55'54"W	44°59'36"N	U
W Long Sault Isl.	7	74°56'06"W	44°58'48"N	U
Long Sault Isl. Inlet	8	74°55'54"W	44° 58'18"N	U
E Long Sault Isl.	9	74°54'00"W	44°59'00"N	U
Across From Wales	10	74°55'06"W	45°01'06"N	U
Long Sault Isl.	11	74°53'36"W	45°59'36"0N	U
Milles Roche Isl.	12	74°53'30"W	45°00'18"N	U
Sheek Island	13	74°51'06"W	45°01'00"N	U
Lakeview Heights	14	74°51'30"W	45°01"48"N	U
Below the Bridge	15	74°44'06"W	45°00'48"N	D
Cornwall Island	16	74°42'00"W	45°01'42"N	D
Windmill Point	17	74°41'54"W	45°01'00"N	D
Infront of Courtauld's	18	74°40'54"W	45°01'30"N	D
Across from Pilon Isl.	19	74°40'30"W	45°01'54"N	D
Pilon Island	20	74°439'54"W	45°01'24"N	D
Third Crab Island	21	74°39'12"W	45°01'54"N	D
W St. Regis Isl.	22	74°39'54"W	45°01'12"N	D
W Colquhoun Isl.	23	74°39'12"W	45°01'30"N	D
Farlinger's Point	24	74°39'42"W	45°01'48"N	D
E Colquhoun Isl.	25	74°38'42"W	45°01'42"N	D
Flanigan's Point	26	74°38'18"W	45°02'00"N	D
E St. Regis Isl.	27	74°37'30"W	45°01'42"N	D
Stonehouse Point	28	74°36'54"W	45°02'42"N	D
Corn Island	29	74°36'06"W	45°01'42"N	D
Goose Island	30	74°35'30"W	45°01'54"N	D
Dickerson Island	31	74°35'18"W	45°02'12"N	D
Ile du Canal Isl.	32	74°34'42"W	45°02'24"N	D
Doden Island	33	74°34'12"W	45°02'30"N	D
Clark Island	34	74°34'06"W	45°03'00"N	D
Little Hog Island	35	74°32'24"W	45°03'00"N	D
Thompson Island	36	74°31'18"W	45°04'00"N	D

boat. Three 10 m seine hauls (mesh - 0.5 cm) were done by two collectors wearing chest waders. The 10 m seine was pulled through the water, parallel to the shoreline, a distance of approximately 7 m to cover approximately 70 m^2. Captured fish were identified to species, measured (total length) and released. Fish that could not be identified in the field were fixed in 5% formaldehyde for two weeks and then preserved in 70% ethanol for subsequent identification in the lab.

For each species where more than 10 fish were caught, 75 preserved fish, from a spectrum of lengths, were measured (total length) and weighed. Length-weight regression equations (log weight = log a + b log length) were subsequently used to calculate total biomass by species for each site. For easily identified species, which were for the most part released, preserved specimens from the Canadian Museum of Nature, caught in the same area, were used to calculate the length-weight regression. Total biomass (B_i=N_i*w_i; where B_i=biomass, N_i=number and w_i=weight) per site was calculated for species where ten or more fish were caught (Appendix 1, 2).

At each fish sampling site, habitat variables (depth gradient, percent vegetation cover and percent substrate cover) were measured according to a protocol similar to the one used in Benson and Magnuson (1992). To measure the depth gradient (DepGr) the collector would walk out from shore to a 1m depth. At the 1m depth, the collector would make a visual estimate of percent aquatic vegetation cover (Veg1) by examining a 1m radius around the sample point. The collector would then walk in approximately one-quarter of the distance from the 1m depth and visually estimate the percent substrate composition within a one meter radius. Substrate types were categorized into rock (>50 cm), boulder (20-50 cm), rubble (2-20 cm), gravel (0.2-2 cm), sand (1-2 mm), silt (0.2-1 mm), clay, muck and detritus or a combination of these variables . The collector would then move one-quarter closer to shore to estimate near shore aquatic vegetation (Veg2), and one-quarter of this distance towards shore to reassess near shore substrate composition. Habitat was sampled in all five areas seined (Appendix 3).

Statistical Analysis

All fish data (including date, sampling site, sampling method, fish species, and capture method) were entered into SYSTAT® (1994). Young-of-the year (YOY) fish were eliminated from the analysis to reduce temporal sampling bias. The elimination process had two steps. First, all fish less than 22 mm in total length were eliminated. This length was chosen based on an average length of 0+ cyprinids from Scott and Crossman (1973). The second step involved eliminating YOY fish on a species specific basis, based mainly on total lengths of 0+ fishes found in Scott and Crossman (1973), unless otherwise noted in Appendix 4.

ANOVA and ANCOVA were used to assess if the biomass (g/site), species richness (# of fish species caught/site), or fish abundance (# of fish caught/site) were different upstream compared to downstream. The ANOVA was calculated for biomass (dependent variable - biomass (log transformed), independent variable - region) and fish abundance (dependent variable - fish abundance, independent variable - region). In the case of biomass, the assumption of homogeneity of variance for ANOVA was not met, but log transformation of the data remedied the problem. For species richness, an ANCOVA was performed (covariate - fish abundance. This was used to correct for the fact that as the number of fish caught increases, so does the probability of catching a new species).

To determine if fish assemblages upstream and downstream were distinct from one another, a set of exploratory multivariate analyses were done. These were aimed at finding patterns amongst sites for a series of fish community variables.

To examine if fish assemblages upstream and downstream differed in terms of fish species composition, a hierarchical cluster analysis was performed on a Jaccard's similarity coefficient matrix. This coefficient was generated from the presence-absence matrix of 37 species found at the 36 sites. Species found at only one site were eliminated from the matrix. If the resulting phenogram showed large groupings associated with each region, then it could be hypothesized that, in terms of fish species composition, upstream and downstream were different. If no groupings by region were observed, then fish species composition is probably associated with inter-site variability rather than inter-region variability.

A second cluster analysis was done to explore patterns in species abundance between regions. A Pearson correlation coefficient matrix was generated using the same 37 species from the presence-absence cluster analysis to explore the possibility of similarities between the clusters. If this analysis resulted in clusters similar to the species composition cluster analysis, it could be concluded that the similarities or differences between regions include both species composition and fish abundance.

To look at species abundance patterns at the community level amongst sites, principal components analyses (PCA) were done using abundance and relative abundance of fish species caught in 60% (22) or more of the 36 sites (Hinch et al., 1991). The objective was to examine if species abundance patterns could be detected when sites were identified "a posteriori" according to their region of origin. Elimination of rare species was done because of the disruptive effects of species with low abundance have on multivariate techniques (Gauch, 1982). Both types of abundance data were log transformed to statistically control for the numerical influence of dominant species and the schooling behavior (grouping) of fish that could contribute to high variation in fish species abundance (Kinsolving and Bain, 1993).

For habitat variables, depth gradient, deep water vegetation and near shore vegetation were averaged for each of the five seining areas at a site. The relative amount of each substrate type was also calculated for each site using the Shannon-Weiner index of diversity ($H = -\Sigma p \log_e p_i$) to obtain a variable indicative of substrate diversity. The habitat variables were also analysed using PCA. A posteriori identification of sites was done on the projections of all in sites for the first two factors of the PCA analysis to determine if there was a distinction between upstream and downstream based on a combination of habitat variables. All habitat variables were compared using MANOVA (dependent variables - habitat variables, independent variable - region) to look for specific significant differences between upstream and downstream.

Discriminate function analysis (DFA) was performed using habitat variables to generate a model that would maximize separation of upstream and downstream sites. DFA is used to predict membership in groups (the dependent variable) from a set of independent variables (Tabachnick and Fidell, 1989). The variable "rock", found at one site, was removed from the analysis because of its disruptive effects on the DFA.

Regression analyses were done to attempt to relate fish variables (species number, biomass and total abundance) to habitat variables (DepGr, Veg1, Veg2, relative abundance substrate type and Shannon-Weiner Index) for each of the 36 sites. This information will help define habitat types that support the fish community with the greatest biomass, diversity and abundance.

To determine if fish community characteristics were correlated with one or more of the habitat variables, a series of correlation analyses were performed. The scores of the first two PCA axes for fish abundance and relative fish abundance were correlated, using Pearson correlation coefficient, to the first two axes of the habitat PCA. Biomass was also correlated to factors one and two of the habitat PCA. Finally, a correlation analyses of the fish abundance PCA and the individual habitat variables were done to assess the relationships between fish assemblage structure and individual habitat variables. These correlations will help define habitats that support various types of fish communities.

Canonical correspondence analysis (CCA) was done using PC-ORD ® (1995) to create an ordination based on the fish community data which could be related to the habitat variables that were measured. This analysis creates a matrix based on a chi-square distance measure. In this matrix, the samples are weighted according to their totals. A high weight is given to species whose total abundance in the matrix is low. This emphasizes the distinctiveness of rare species. The second axis contains the environmental variables. This allows an independent assessment of the importance of the habitat variables, based on their position within the CCA with the community variables. For this analysis, all fish species were included (with the exception of YOY) in the main matrix, with the second matrix being comprised of the habitat data.

RESULTS

A total of 42 fish species representing sixteen families were caught during the summers of 1994 and 1995 at 36 sampling sites (Table 2; Appendix 5). Young-of-the-year elimination brought the number of fish caught down from 77,125 to 74,419. The bluntnose minnow (*Pimephales notatus*) made up 47% of the total catch, followed by the mimic shiner (*Notropis volucellus*) and the banded killifish (*Fundulus diaphanus*) (24% and 11% of the catch, respectively). The ten most common species made up 95% of the total number of fish caught (Table 3). These ten species (species caught in 60% or more of sites) were used for PCA analysis of fish abundance and fish relative abundance.

In the upstream area, 30 species were caught, including three species absent from the downstream samples (Table 2). Downstream, 40 species were caught, including 13 not captured in the upstream area. Most of the fish absent upstream were generally in low abundance at one or two sites downstream (Table 2). Two notable exceptions are the blacknose and blackchin shiners (*Notropis heterodon* and *N. heterolepis*). A large number (1,082 specimens) of blackchin shiners and blacknose shiners (198 specimens) were caught downstream while none were caught upstream.

Fish species richness was significantly different between upstream and downstream, with more species being caught downstream (Table 4). Fish abundance or number of fish per site was

Table 2: List of fish species caught and their occurence in the St. Lawrence River near Cornwall, Ontario in 1994 and 1995. U=upstream, D=downstream and B=both regions. Species in bold were caught in more than 60% of sampling sites.

Species		Common Name	No. of Specimens	No. of Sites (%)	Region
Ichthyomyzon unicuspis	Hubbs and Trautman	Silver Lamprey	1	2.8	D
Lepisosteus osseus	(Linnaeus)	Longnose Gar	3	5.6	B
Amia calva	Linnaeus	Bowfin	1	2.8	D
Alosa pseudoharengus	(Wilson)	Alewife	13	5.6	U
Osmerus mordax	(Mitchill)	Rainbow Smelt	6	16.7	B
Esox lucius	Linnaeus	Northern Pike	19	30.6	B
E. masquinongy	Mitchill	Muskellunge	7	5.6	B
Cyprinus carpio	Linnaeus	Carp	8	13.9	B
Phoxinus eos	(Cope)	Northern Red Belly Dace	2	5.6	D
Chrosomus neogaeus	(Cope)	Finescale Dace	2	2.8	D
Exoglossum maxillingua	(Le Sueur)	Cutlips Minnow	33	25.0	B
Notemigonus crysoleucas	**(Mitchill)**	**Golden Shiner**	**1963**	**61.1**	**B**
Luxilus cornutus	(Mitchill)	Common Shiner	9	8.3	B
Notropis atherinoides	Rafinesque	Emerald Shiner	68	19.4	B
N. heterodon	(Cope)	Blackchin Shiner	1079	50.0	D
N. heterolepis	Eigenmann & Eigenmann	Blacknose Shiner	198	13.9	D
N. hudsonius	**(Clinton)**	**Spottail Shiner**	**3348**	**91.7**	**B**
N. volucellus*	**(Cope)**	**Mimic Shiner**	**17494**	**77.8**	**B**
Pimephales notatus	**(Rafinesque)**	**Bluntnose Minnow**	**34719**	**97.2**	**B**
P. promelas	Rafinesque	Fathead Minnow	2	5.6	D
Semotilus corporalis	(Mitchill)	Fallfish	360	**61.1**	B
S. atromaculatus	(Mitchill)	Creek Chub	33	2.8	U
Catostomus commersoni	(Lacépède)	White Sucker	789	**77.8**	B
Moxostoma erythrurum	(Rafinesque)	Golden Redhorse	35	19.4	B
M. valenciennesi	Jordan	Greater Redhorse	10	8.3	D
Amerius nebulosus	(Le Sueur)	Brown Bullhead	73	22.2	B
Fundulus diaphanus	**(Le Sueur)**	**Banded Killifish**	**7945**	**83.3**	**B**
Labidesthes sicculus	(Cope)	Brook Silverside	26	19.4	B
Culaea inconstans	(Kirtland)	Brook Stickleback	33	13.9	D
Gasterosteus aculeatus	Linnaeus	Three Spine Stickleback	6	5.6	D
Percopsis omiscomaycus	(Walbaum)	Trout-Perch	1	2.8	D
Ambloplites rupestris	**(Rafinesque)**	**Rock Bass**	**225**	**63.9**	**B**
Lepomis gibbosus	(Linnaeus)	Pumpkinseed	541	44.4	B
Micropterus dolomieui	Lacépède	Small Mouth Bass	207	41.7	B
M. salmoides	(Lacépède)	Large Mouth Bass	43	2.8	D
Pomoxis nigromaculatus	(Le Sueur)	Black Crappie	6	8.3	B
Etheostoma exile	(Girard)	Iowa Darter	286	38.9	B
E. olmstedi	**Storer**	**Tesselated Darter**	**2655**	**97.2**	**B**
Perca flavescens	**(Mitchill)**	**Yellow Perch**	**1421**	**88.9**	**B**
Percina caprodes	(Rafinesque)	Logperch	742	55.6	B
Stizostedion vitreum	(Mitchill)	Walleye	4	5.6	U
Cottus bairdi	Girard	Mottled Sculpin	3	8.3	D
TOTAL			74419		

**Notropis volucellus and N. straminaeus (Cope) combined*

Table 3: Abundance and relative abundance of the species caught in 60% or more of sites upstream and downstream of the Moses-Saunders hydroelectric dam. Numbers do not include young of the year fish.

	Upstream (N=14)		**Downstream (N=22)**	
Species	**Abundance**	**Relative Abundance**	**Abundance**	**Relative Abundance**
Bluntnose Minnow	16,689	0.832	18,028	0.332
Fallfish	139	0.007	221	0.004
Golden Shiner	98	0.005	1,865	0.034
Banded Killifish	76	0.004	7,869	0.145
Mimic Shiner	246	0.012	17,248	0.317
Rock Bass	32	0.002	193	0.004
Spottail Shiner	716	0.036	2,632	0.048
Tesselated Darter	385	0.019	2,270	0.042
White Sucker	149	0.007	640	0.012
Yellow Perch	337	0.017	1,044	0.019
Total	18,867	0.941	52,010	0.957

Table 4: Fish variables measured including number of fish species caught, fish abundance and biomass upstream and downstream of the Moses-Saunders hydroelectric dam. Data were analysed using ANOVA (abundance and biomass) and ANCOVA (number of species). Values reported are mean±SEM (standard error of mean). Upstream N=14, downstream N=22. *0.01<p<0.05, n.s. indicates no significant difference between regions.

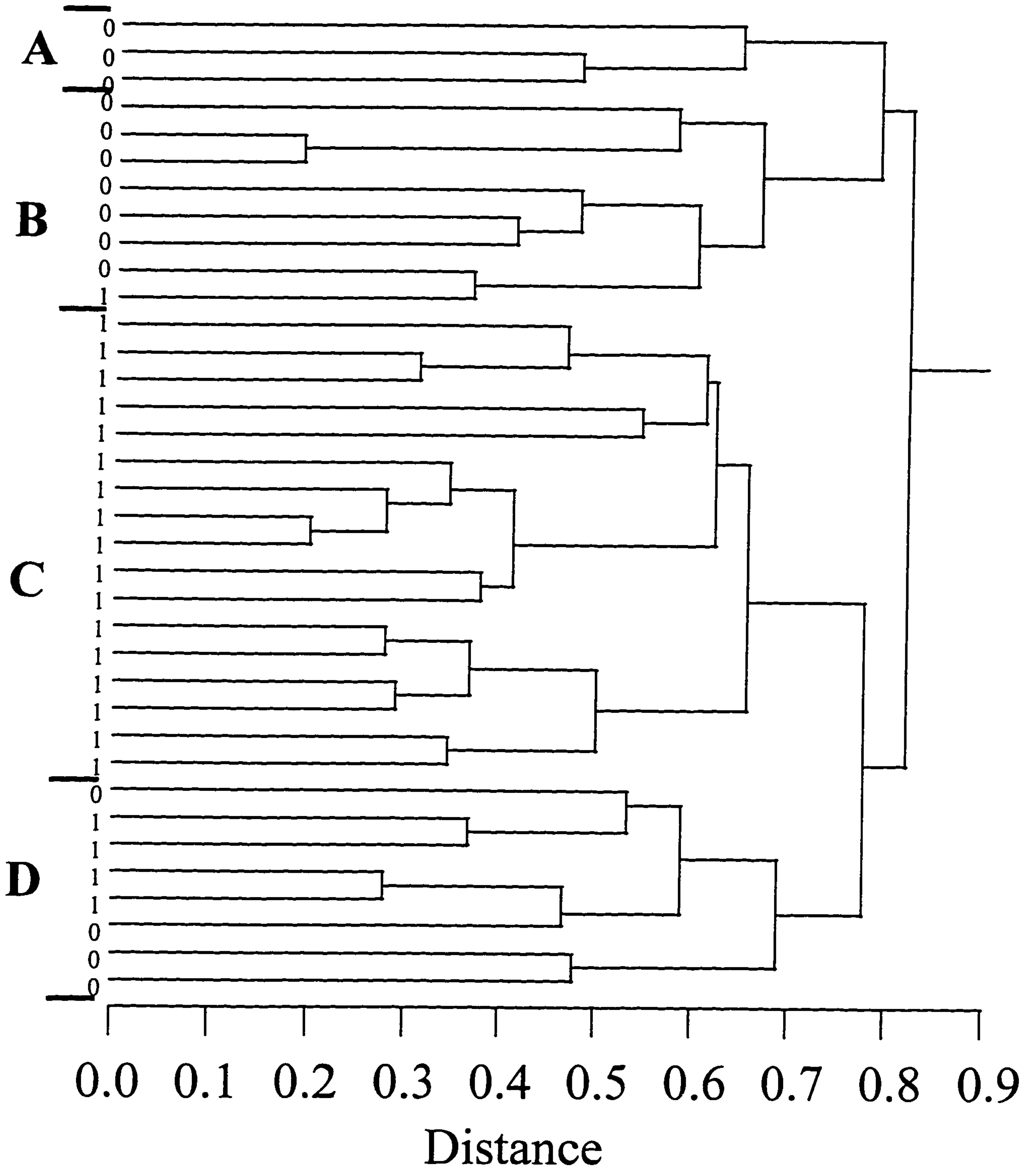
	Total	**Mean/site±SEM**
UPSTREAM		
# of Species	30	11.07±0.95*
Abundance	20 056	1432.57±411.01$^{n.s.}$
Biomass (g)	44 330	3166.49±814.69*
DOWNSTREAM		
# of Species	40	14.59±0.80
Abundance	54 363	2471.05±644.27
Biomass (g)	124 900	5680.50±955.70

not significantly different between upstream and downstream, but the biomass per site (log transformed) was significantly higher downstream.

The hierarchical cluster analysis of the presence-absence matrix of fish species revealed large clusters associated with upstream and downstream regions (Figure 2). The analytical procedure separated the sites into two large clusters, which can be further separted into four sub-clusters. When regions (upstream or downstream) were used to identify sites, 10 of the 14 upstream sites clustered together with one downstream site (in clusters A & B). The third cluster (C) contained 17 of 22 downstream sites. Sites in the fourth cluster (D) had a mixture of upstream and downstream sites. In sites of cluster A & B, smallmouth bass (*Micropterus dolomieui*) were captured but the blackchin shiner, blacknose shiner, golden shiner (*Notemigonus crysoleucas*) and mimic shiner were not captured. Cluster C is characterized by the absence of smallmouth bass, and the presence of the above-mentioned shiners. Cluster D lacked the species of cluster C, with the exception of the mimic shiner. Smallmouth bass were also rare in sites of cluster D. The hierarchical cluster analysis using fish abundance did not show any distinct regional clustering (Appendix 6).

The first two axes of the PCA of log transformed fish abundance accounted for 38.7% and 14.4% of the variance, respectively (Figure 3). The mimic shiner, banded killifish and golden shiner had the highest component loading on the first axis (Table 5). This creates a gradient along the axis with these three species having the greatest influence on the positioning of sites on the first PCA axis. This PCA shows definite clustering of downstream sites on the

Figure 2: Cluster analysis of presence and absence of fish species upstream and downstream sites in the St. Lawrence River, near Cornwall, Ontario. Data analysed using a hierarchial cluster analysis, complete linkage, Pearson distance. Fish species caught at only one site were eliminated from the analysis. 0 = upstream, 1=downstream. A, B, C and D represent major clusters in the analysis.


A
0
0
0
B
0
0
0
0
0
0
0
1
C
1
1
1
1
1
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1
1
1
1
1
1
1
1
1
1
1
D
0
1
1
1
1
0
0
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Distance

Figure 3: Graph of the first two axes of the fish abundance PCA done on the upstream area (filled circles) and downstream area (filled triangles) of the St. Lawrence River at Cornwall. Data analysed included fish species caught in 60% or more of sampling sites. Factor (1) accounts for 38.7% of total variance. Factor (2) accounts for 14.4% of total variance. Species name and (component loading) of fish having the greatest effect on the PCA labelled on factors 1 and 2.

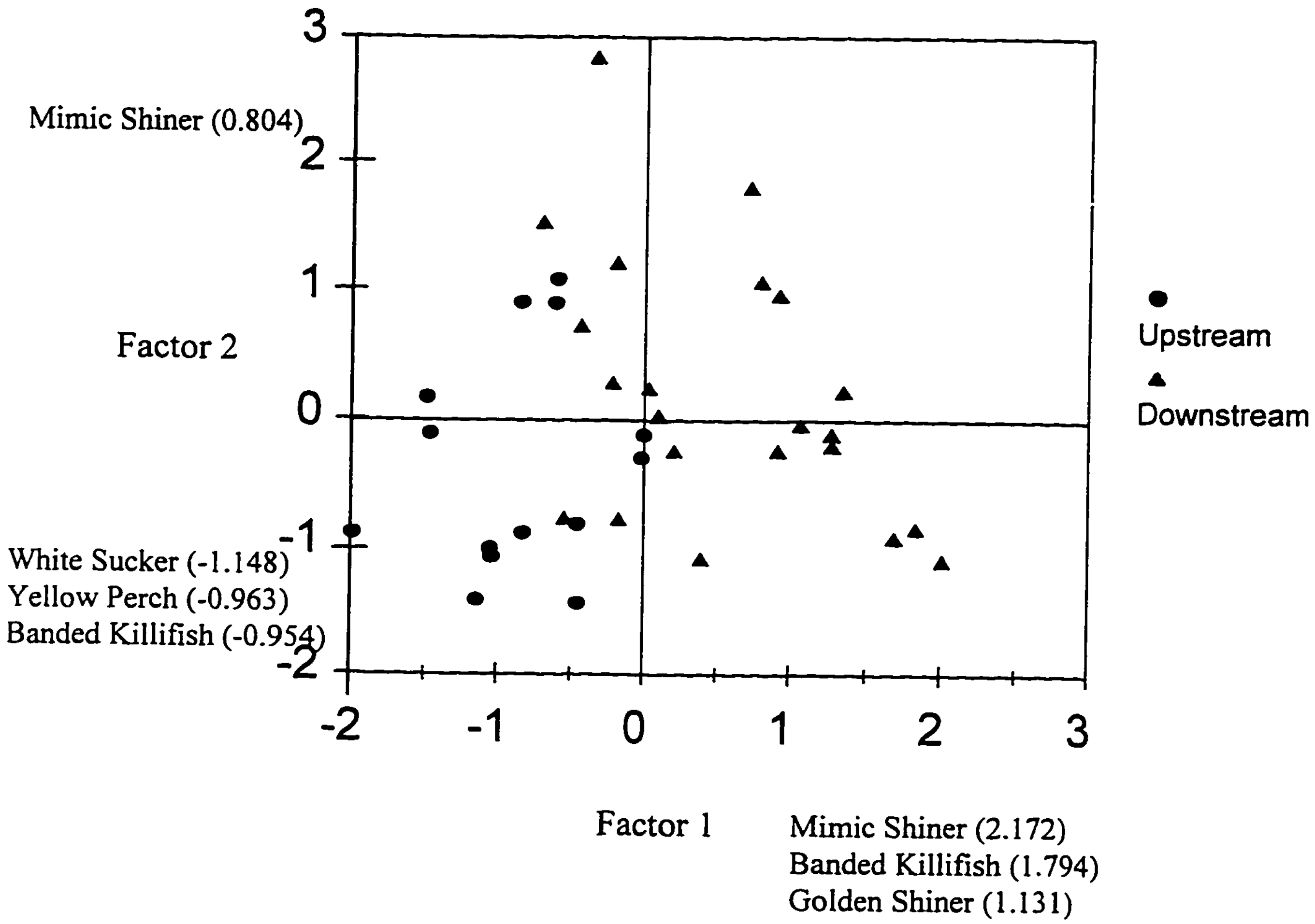

3
Mimic Shiner (0.804)
2
1
Factor 2
0
-1
White Sucker (-1.148)
Yellow Perch (-0.963)
Banded Killifish (-0.954)
-2
-2
-1
0
1
2
3
Factor 1
Mimic Shiner (2.172)
Banded Killifish (1.794)
Golden Shiner (1.131)
● Upstream
▲ Downstream

Table 5: Component loadings and variance explained by factors one and two of the PCA of abundance and relative abundance of fish using species caught in 60% or more of the sites during 1994 and 1995 in the St. Lawrence River, near Cornwall, Ontario. Underlined numbers indicate species with the highest component loadings in the analysis. N=36.

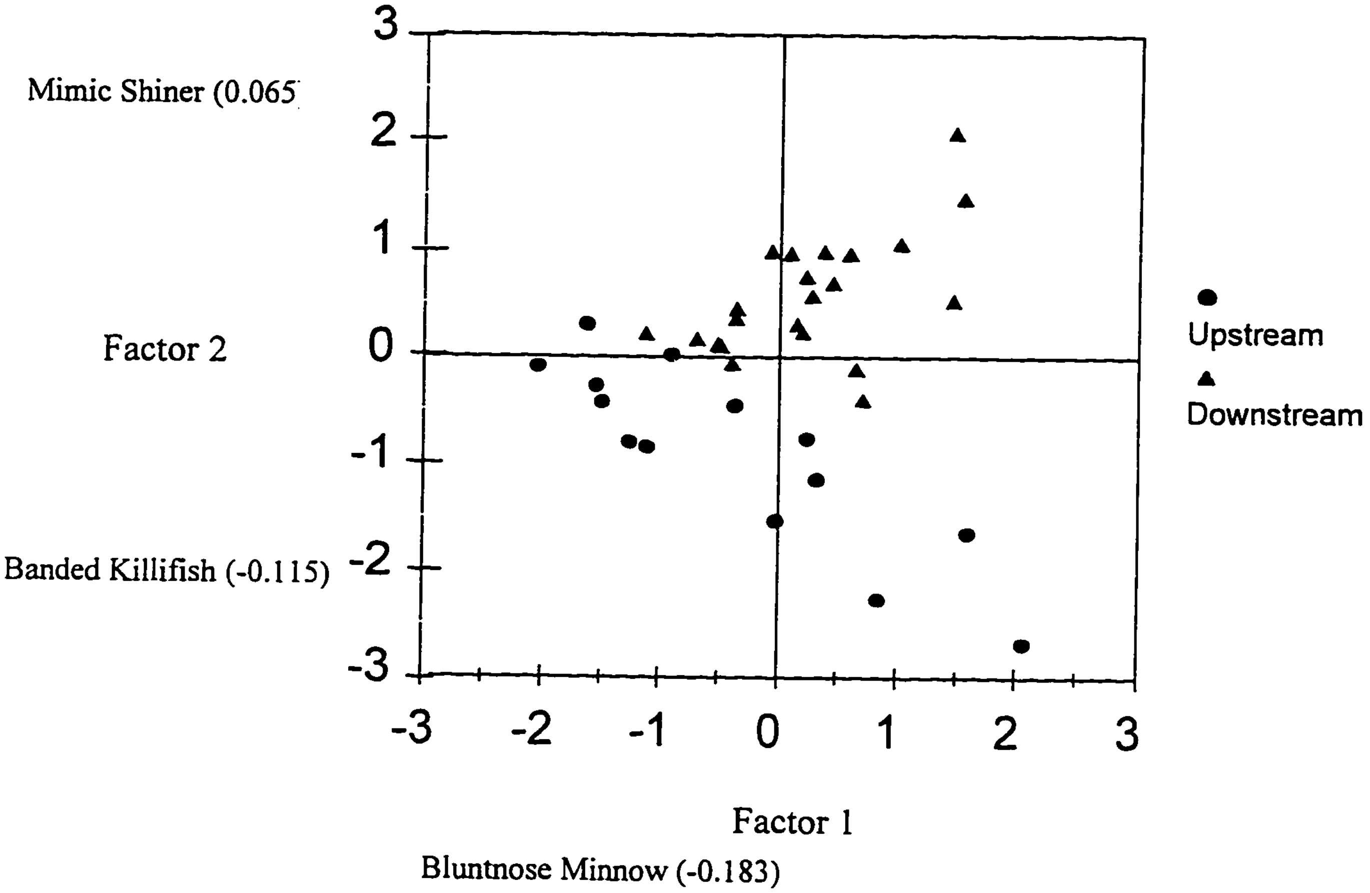
	Abundance		**Relative Abundance**	
SPECIES	Factor 1	Factor 2	Factor 1	Factor 2
Bluntnose Minnow	1.01	-0.235	-0.183	0.004
Fallfish	0.226	0.184	0.004	0.004
Golden Shiner	1.131	0.402	0	0.006
Banded Killifish	1.794	-0.954	0.037	-0.115
Mimic Shiner	2.172	0.804	0.071	0.065
Rock Bass	0.464	-0.508	-0.001	-0.001
Spottail Shiner	1.064	0.644	0.019	0.016
Tesselated Darter	0.883	0.021	0.038	0
White Sucker	0.453	-1.148	0.004	-0.007
Yellow Perch	0.252	-0.963	0.014	0
Total Variance Explained %	38.7	14.421	48.742	20.641

right hand portion of the first axis, while the upstream sites cluster on the left hand side indicating an absence of the above three species in the upstream sites. The second axis components weighed positively on the mimic shiner, and negatively on the white sucker (*Catostomus commersoni*), yellow perch and banded killifish. Within the second factor, there are no groupings between upstream and downstream sites. The downstream sites are distributed evenly throughout the second axis, while the upstream sites are generally grouped along the negative scale (lower left corner). This indicates a tendency for a lower abundance of the white sucker, yellow perch and banded killifish in the upstream area.

The first axis of the PCA for relative fish abundance accounted for 48.7% of the total variance in the data (Figure 4). Interestingly, the only species that had a high component loading on this axis was the bluntnose minnow (Table 5). The bluntnose minnow had a high relative abundance both upstream and downstream (Table 3). The second axis accounted for 20.6% of the total variation. The highest component loading on the second axis was with the banded killifish (negative) and mimic shiner (positive). Within the second factor, groupings of upstream and downstream sites are visible. This axis indicates that a high abundance of banded killifish is associated with a low abundance of mimic shiners. Therefore, although there were fewer banded killifish (76 specimens) caught upstream compared to the mimic shiner, banded killifish were caught at more sites.

Date (including year) of capture was added on to the PCA. No temporal pattern of overall fish abundance or relative fish abundance was detected either within years or between

Figure 4: Graph of the first two axes of the PCA of fish relative abundance upstream (filled circles) and downstream (filled triangles) of the Moses-Saunders hydroelectric dam in the St. Lawrence River at Cornwall, Ontario. Data analysed using fish species caught in 60% or more of sampling sites. Factor (1) accounts for 48.7% of total variance. Factor (2) accounts for 20.6% of total variance. Species name and (component loading) of fish having the greatest effect on the PCA labelled on factors 1 and 2.


Mimic Shiner (0.065
Factor 2
Banded Killifish (-0.115)
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
Factor 1
Bluntnose Minnow (-0.183)
● Upstream
▲ Downstream

years. Thus, temporal variations are not influencing the fish community patterns that were found (Appendix 7).

PCA was also used to explore patterns, a posteriori, of upstream and downstream sites based on habitat variables (Figure 5). The first axis did not show distinct groupings of upstream and downstream sites although there is a tendency for downstream sites to be on the right side of the plot and the upstream sites on the left. This indicates that downstream there was a higher percentage of rubble, gravel and nearshore vegetation, while upstream was characterized by muck, clay, detritus and the depth gradient. The first PCA factor accounted for 20.4% of the total variance. This axis could be referred to as the "substrate axis". The second habitat PCA axis accounted for 19.4% of the variance and had the highest component loadings (Table 6) on nearshore vegetation, deep water vegetation and sand positively compared to boulder , gravel and the Shannon-Weiner index . This could be considered the "vegetation axis". There are no distinct clusters of upstream or downstream sites within the PCA. In general however, downstream sites are much more dispersed throughout the graph, while the upstream sites are, for the most part, clumped in the lower left portion of the PCA. This suggests a greater homogeneity of habitat upstream, while there is a spectrum of different habitat types downstream.

A DFA classificatory analysis was used to determine whether or not upstream habitat could be distinguished from downstream habitat. The analysis resulted in 89% of sites grouped correctly, with 86% (19 of 22) downstream sites being grouped correctly and 93% (13 of 14)

Figure 5: Graph of the first two axes of the PCA done on habitat variables upstream (filled circles) and downstream (filled triangles) of the Moses-Saunders hydroelectric dam at Cornwall, Ontario. Data analysed using mean depth gradient, percentage aquatic vegetation cover, and relative amounts of substrate. Factor (1) (the substrate axis) accounts for 20.4% of total variance. Factor (2) (the vegetation axis) accounts for 19.4% of total variance. Environmental variable and (component loading) labelled of variables having the greatest effect on the PCA.

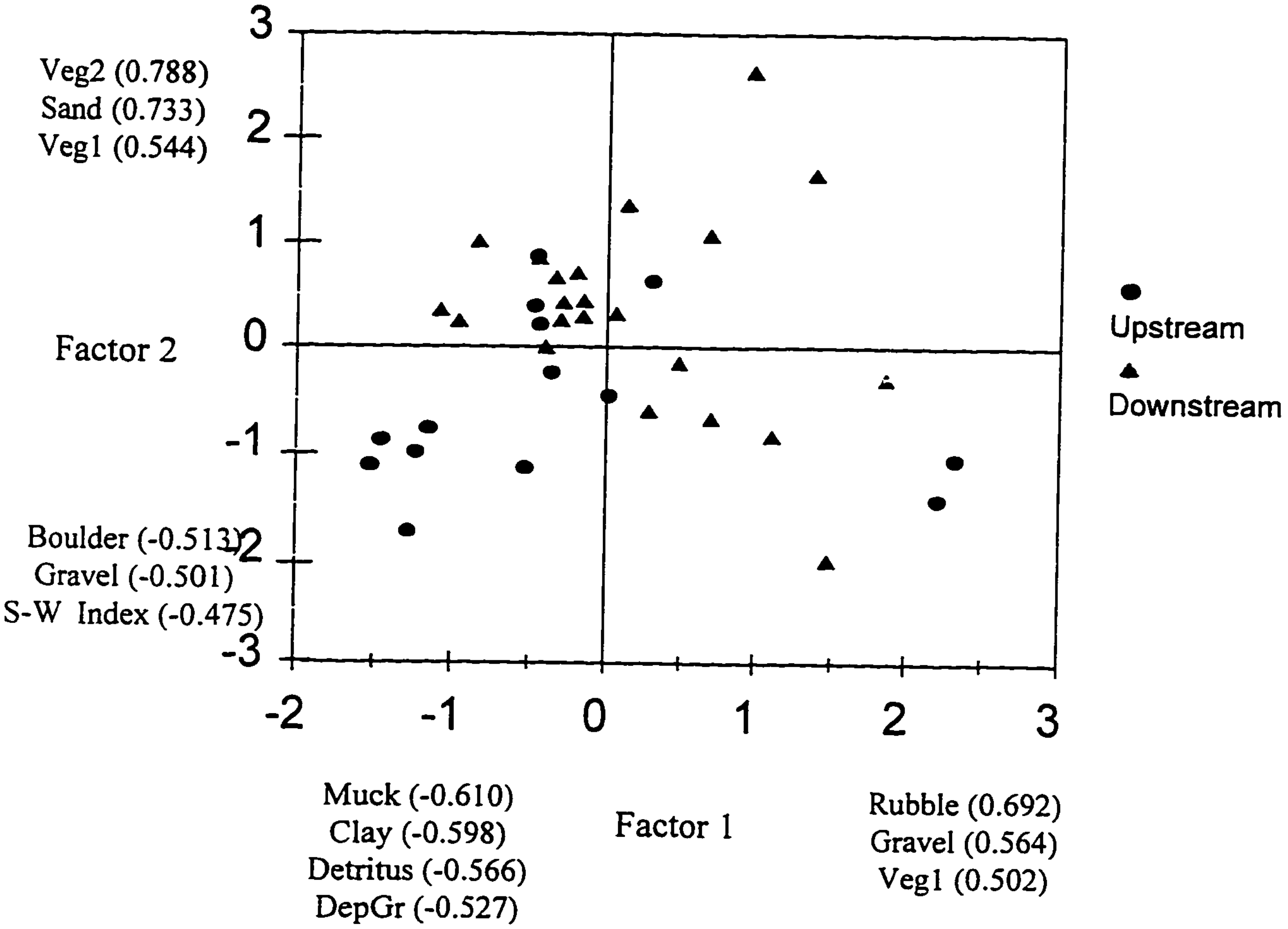

Veg2 (0.788)
Sand (0.733)
Veg1 (0.544)
Factor 2
Boulder (-0.513)
Gravel (-0.501)
S-W Index (-0.475)
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
Muck (-0.610)
Clay (-0.598)
Detritus (-0.566)
DepGr (-0.527)
Factor 1
Rubble (0.692)
Gravel (0.564)
Veg1 (0.502)
● Upstream
▲ Downstream

Table 6: PCA component loadings and total explained variance for factors one and two of the habitat variables measured during the 1994 and 1995 sampling of the St. Lawrence River, near Cornwall, Ontario. Underlined numbers represent variables with the highest component loadings in the analysis. N=36.

HABITAT VARIABLE	Factor 1	Factor 2
Depth Gradient	-0.527	0.419
Veg1	0.502	0.544
Veg2	0.255	0.788
Rock	0.055	0.231
Boulder	0.363	-0.513
Rubble	0.692	0.056
Gravel	0.564	-0.501
Sand	-0.242	0.733
Silt	0.002	0.094
Clay	-0.598	-0.271
Muck	-0.61	-0.121
Detritus	-0.566	-0.07
S-W Index	-0.14	-0.475
Total Variance Explained %	20.431	19.433

upstream sites being correctly classified. For the DFA, the highest component loadings were on all substrate values - boulder (-3.712), clay (4.306) and detritus (3.637).

A MANOVA based on all habitat variables indicated a significant difference between upstream and downstream sites (Hotelling-Lawley Trace = 1650.170, F-statistic = 2792.595, p=0.000). Comparing the habitat variables independently using ANOVA, a significant difference was found for Veg1, Veg2, boulder and gravel (Table 7) with the vegetation variables being significantly higher downstream and the substrate variables significantly higher upstream.

Linear regressions were calculated to determine if variation of any of the fish variables (species number, biomass, and total abundance) could be related to variation in individual habitat variables (Table 8). Only a few significant relationships were detected. Species number was significantly related to muck. Fish biomass was significantly related to depth gradient and gravel. A multiple regression using depth gradient and gravel as independent variables resulted in a non-significant p-value (0.07). A significant relationship was also found between total fish abundance and depth gradient and clay. This indicates that in areas with a clay substrate and gradual slope, a higher fish abundance can be found. Combining clay and depth gradient in a multiple regression analysis gives a highly significant p-value (0.001) and improves the regression (R^2=0.382). All of these significant regressions resulted in positive linear relationships between the variables.

Table 7: Comparisons of upstream and downstream habitat variables in the St. Lawrence River, near Cornwall, Ontario. Substrate variables represent a relative amount of substrate. Data was analysed using MANOVA. Values are reported as mean ± SEM (Standard Error of Mean). *p<0.05, **p<0.01, ***p<0.001.

Habitat Variable	**Upstream (n=14)**	**Downstream (n=22)**
Depth Gradient (m)	14.762±1.772	20.354±2.425
Veg1 (%)	27.171±5.553**	50.191±5.909
Veg 2 (%)	16.171±3.518***	50.500±5.101
Rock	0.000±0.000	0.003±0.003
Boulder	0.144±0.030*	0.081±0.015
Rubble	0.263±0.039	0.258±0.036
Gravel	0.176±0.045**	0.087±0.018
Sand	0.274±0.045	0.365±0.038
Silt	0.012±0.008	0.033±0.021
Clay	0.026±0.017	0.043±0.021
Muck	0.095±0.053	0.110±0.032
Detritus	0.004±0.003	0.008±0.004
Shannon-Weiner Index	0.566±0.023	0.543±0.019

Table 8: Regression analyses between fish variables (abundance, biomass and species number) to individual habitat variables from the St. Lawrence River, near Cornwall, Ontario. Data was analysed using linear regression. Numbers in bold emphasize significant linear relationships. N=36.

	Fish Abundance			Biomass			Species Number		
Habitat Variable	**p-value**	**R^2**	**F-ratio**	**p-value**	**R^2**	**F-ratio**	**p-value**	**R^2**	**F-ratio**
DepGr	**0.007**	**0.193**	**8.124**	**0.033**	**0.127**	**4.941**	0.38	0.023	0.792
Veg1	0.779	0.002	0.08	0.671	0.005	0.184	0.712	0.004	0.139
Veg2	0.554	0.01	0.356	0.716	0.004	0.135	0.64	0.007	0.223
Rock	0.784	0.002	0.079	0.959	0	0.003	0.959	0	0.003
Boulder	0.996	0.002	0	0.101	0.077	2.844	0.106	0.075	2.76
Rubble	0.092	0.024	0.82	0.115	0.072	2.623	0.646	0.006	0.215
Gravel	0.372	0.081	3.004	**0.043**	**0.115**	**4.405**	0.114	0.072	2.626
Sand	0.61	0.008	0.265	0.438	0.018	0.615	0.934	0	0.007
Silt	0.434	0.018	0.626	0.218	0.044	1.572	0.681	0.005	0.172
Clay	**0.025**	**0.139**	**5.498**	0.963	0	0.002	0.788	0.002	0.073
Muck	0.324	0.029	1.002	0.084	0.085	3.176	**0.033**	**0.127**	**4.961**
Detritus	0.65	0.006	0.21	0.069	0.094	3.522	0.227	0.043	1.513
S-W Index	0.495	0.014	0.476	0.723	0.004	0.127	0.266	0.036	1.278

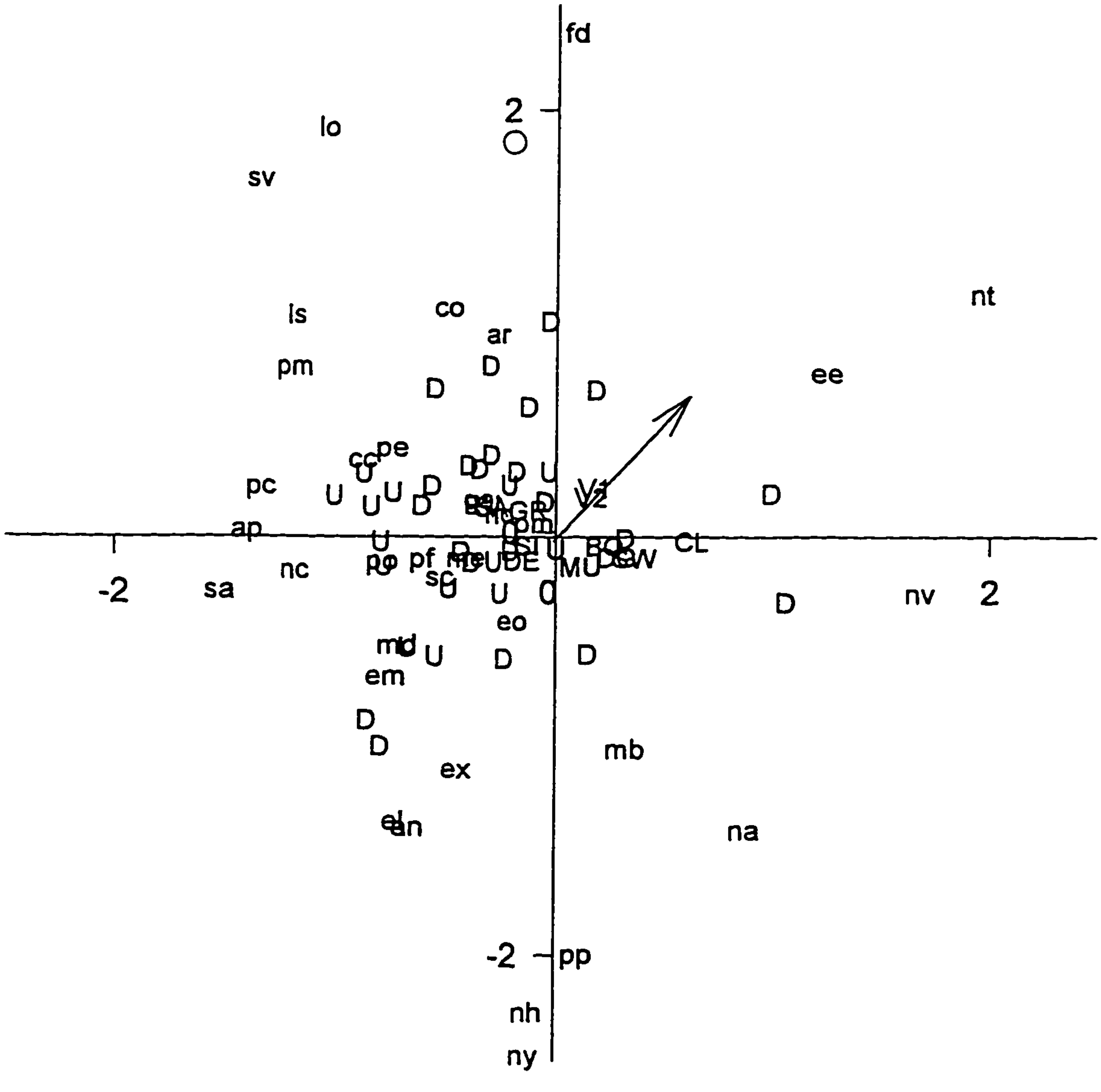
The first habitat PCA factor, the substrate axis, was negatively correlated with the first factor of fish abundance (p=0.014) and biomass (p=0.016). This indicates that in areas with high relative amounts of clay, detritus and muck, a high biomass was found. The second factor of habitat, the vegetation axis, was negatively correlated with the second factor of fish abundance (p=0.016) and the second factor of fish relative abundance (p=0.000). In areas of boulder and gravel, a higher abundance of mimic shiners was found and in areas with high amounts of vegetation and sand, the white sucker, yellow perch and banded killifish were found. A positive correlation was observed between the second habitat factor and the first fish abundance factor (p=0.006). The mimic shiner, banded killifish and golden shiner all were correlated to areas with high amounts of vegetation and sand.

Correlation analyses were done between the first two PCA factors of fish abundance and relative fish abundance with the individual habitat variables in order to assess the relationships between fish assemblage structure and habitat parameters (Table 9). Nine of the thirteen variables were significant with one or more of the PCA factors. The habitat variables that were not correlated to the fish PCA factors were rubble, silt and detritus. Many different environmental variables are making up the habitat which the fish community is utilizing. The habitat variables with the highest F-values were depth gradient, Veg1, sand and the Shannon-Weiner Index. These variables are probably the most important when considering what makes up habitat suitable for fish because they have the strongest relationships with the fish variables.

Table 9: Correlation analysis between the first two axes of fish abundance and fish relative abundance with individual habitat variables of the St. Lawrence River, near Cornwall, Ontario. Variables in bold represent significant factors. N=36.

PCA Factor	Habitat Variable	P-value	F-ratio	R^2
Abundance (1)	**Depth Gradient**	**0.001**	**12.727**	**0.272**
	Veg1	0.474	0.524	0.015
	Veg2	**0.047**	**4.268**	**0.112**
	Rock	**0.047**	**4.268**	**0.112**
	Boulder	**0.041**	**4.513**	**0.117**
	Rubble	0.162	2.040	0.057
	Gravel	**0.012**	**7.121**	**0.173**
	Sand	0.189	1.794	0.050
	Silt	0.926	0.009	0.000
	Clay	0.140	2.284	0.063
	Muck	**0.052**	**4.057**	**0.107**
	Detritus	0.731	0.120	0.004
	S-W Index	0.860	0.032	0.001
Abundance (2)	DepGr	0.866	0.029	0.001
	Veg1	**0.002**	**11.197**	**0.248**
	Veg2	**0.017**	**6.279**	**0.156**
	Rock	0.282	1.194	0.034
	Boulder	0.937	0.006	0.000
	Rubble	0.926	0.009	0.000
	Gravel	0.309	1.065	0.030
	Sand	**0.033**	**4.970**	**0.128**
	Silt	0.569	0.331	0.010
	Clay	0.155	0.059	2.114
	Muck	0.583	0.307	0.009
	Detritus	0.955	0.003	0.000
	S-W Index	**0.052**	**4.042**	**0.052**
Relative Abundance (1)	DepGr	0.154	2.121	0.059
	Veg1	0.726	0.125	0.004
	Veg2	0.950	0.004	0.000
	Rock	0.457	0.566	0.016
	Boulder	0.599	0.282	0.008
	Rubble	0.470	0.533	0.015
	Gravel	0.823	0.051	0.002
	Sand	0.878	0.024	0.001
	Silt	0.191	1.784	0.050
	Clay	**0.028**	**5.247**	**0.134**
	Muck	0.983	0.000	0.000
	Detritus	0.177	1.899	0.053
	S-W Index	0.771	0.086	0.003
Relative Abundance (2)	DepGr	0.727	0.124	0.004
	Veg1	**0.018**	**6.183**	**0.154**
	Veg2	**0.036**	**4.774**	**0.123**
	Rock	0.519	0.424	0.012
	Boulder	0.260	1.315	0.037
	Rubble	0.565	0.338	0.010
	Gravel	0.820	0.053	0.002
	Sand	**0.000**	**15.296**	**0.310**
	Silt	0.707	0.143	0.004
	Clay	**0.021**	**5.850**	**0.147**
	Muck	0.087	3.106	0.084
	Detritus	0.410	0.694	0.020
	S-W Index	**0.002**	**10.730**	0.240

Figure 6: Canonical correspondence analysis including fish species (lower case letters) and habitat variables (capital letters) from the St. Lawrence River, upstream and downstream of the Moses-Saunders hydroelectric dam near Cornwall, Ontario. U=upstream and D=downstream. Codes for fish species and environmental variables can be found in Appendix 8.



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The CCA analysis of upstream and downstream sites based on fish abundance and habitat variables did not show any distinct clustering of upstream and downstream sites (Figure 6; Appendix 8). The upstream sites are located mainly on the left hand portion of the CCA, while the downstream sites are dispersed throughout the entire CCA space. This indicates a heterogeneity for both fish and environmental variables in the downstream sites while the upstream sites are more homogeneous. The rarest species are located farthest from the central axis, while the more common ones are closest to the centroid. The environmental variables were found in each of the four portions of the CCA. The site and species which were closest to an individual environmental variable had the greatest effect on that site and/or species.

DISCUSSION:

Species Diversity

The upstream fish community had a significantly lower species diversity than the downstream community. Thirteen fish species caught downstream were not caught upstream. Nine of the thirteen species downstream caught only downstream could be considered rare, based on the fact that less than ten specimens were caught (Table 2). According to the same criteria, only one rare species was caught upstream (walleye).

A question arises when considering species rarity - is the species truly rare in the system, or is it rare only in the littoral zone? Many of the species considered rare in this study, such as the trout-perch, walleye, longnose gar, mottled sculpin and rainbow smelt are most likely rare in the littoral zone at the time of capture. These species either move inshore at night (trout-perch, longnose gar), can only survive in cold water (mottled sculpin) or are sensitive to light so remain in deeper water during the day (walleye, rainbow smelt) (Scott and Crossman, 1973). Other species, such as the red belly dace, finescale dace and fathead minnow which prefer acidic waters (Scott and Crossman, 1973) may be absent in a system such as the St. Lawrence River since this water not considered acidic (Anderson et al., 1990). Other rare species, such as the common shiner, are generally considered stream fish (Scott and Crossman, 1973) and therefore would not be common in a large river system, such as the St. Lawrence River. The rarity of lamprey species, such as the silver lamprey, may reflect the fact that these species are difficult to capture unless attached to another fish.

Sampling bias could also make a species appear to be rare in a system. Species such as the bowfin, muskie and black crappie are normally found in dense aquatic vegetation (Scott and Crossman, 1973). In areas of aquatic vegetation, the seine net had a tendency to roll onto itself or overtop the weed bed, thus reducing the efficiency of catching fish. Also, one species (common carp) was large enough to jump out of the net. This species was obviously well established in the study area, especially in Lake St. Lawrence (personal observation). The positive correlation between species number and muck, clay and detritus may also be attributed to sampling bias as these substrates have a fine particle size which are easily suspended in the water column making it difficult for the fish to see the net and avoid capture.

One species absent upstream, but abundant downstream (1079 specimens) was the blackchin shiner (Table 2). This species may be extirpated in Lake St. Lawrence. The blackchin shiner is presently on the New York State special concern list, which is a list of species that are not protected by law, but there is concern for its continued welfare in New York State (Patch and Busch, 1984). This species was captured in this portion of the St. Lawrence River during sampling efforts in 1930-31 (Table 10) (Carlson, 1996). Carlson (1996) found this species approximately 100 km upstream of Lake St. Lawrence near Brockville, Ontario, and also noted its absence from Lake St. Lawrence. He proposed that the absence of the blackchin shiner (as well as other black line shiners) was related to a lack of suitable habitat, namely aquatic vegetation. A study of fish species composition changes of Lake Mendota, Wisconsin found that the blackchin shiner (as well as the banded killifish) was abundant in this lake in the early 1900's, but noted its disappearance by the 1970's because of its intolerance of environmental

Table 10: Comparison of species caught in a 1930-1931 survey of the St. Lawrence River from Chippewa Point to Massena, New York (Carlson, 1996) to fish species caught upstream and downstream of the Moses-Saunders hydroelectric dam (1995-1996). Fish species caught only upstream or only downstream included in the table. Yes means the fish species was caught in the survey, No means it was not.

Species	**1930-1931**	**Upstream**	**Downstream**
Blackchin Shiner	Yes	No	Yes
Finescale Dace	Yes	No	Yes
Largemouth Bass	Yes	No	Yes
Mottled Sculpin	Yes	No	Yes
Silver Lamprey	Yes	No	Yes
Three-Spine Stickleback	Yes	No	Yes
Blacknose Shiner	No	No	Yes
Bowfin	No	No	Yes
Brook Stickleback	No	No	Yes
Fathead Minnow	No	No	Yes
Greater Redhorse	No	No	Yes
Northern Red Belly Dace	No	No	Yes
Trout-Perch	No	No	Yes
Creek Chub	Yes	Yes	No
Walleye	Yes	Yes	No
Alewife	No	Yes	No

degradation, especially loss of vegetation (Lyons, 1989). The result of the CCA placed the blackchin shiner in close proximity to both of the vegetation variables (Figure 6) which further supports the importance of aquatic vegetation for this species.

Two other rare species that were not used in the overall analysis of data are worth commenting on. First, two juvenile chinook salmon (*Onchorhynchus tshawytscha*) were captured with a 10m seine on 7 and 20 June 1994 on the north shore of the St. Lawrence River (45°02'00"N; 74°38'03"W and 45°01'30"N; 74°40'54"W). These specimens are the first evidence of successful chinook salmon spawning in the St. Lawrence River (Ribey and Chapleau, 1996). Second, a chestnut lamprey (*Ichthyomyzon castaneus*) was captured on 3 August 1994 in the north portion of the St. Lawrence River (45°01'42"N; 74°38'42"W) in a trap net that was set as part of another study. This specimen is the first record of this species in the St. Lawrence River, as well as a new specimen to Ontario (Renaud et al., 1996).

Fish communities in areas with unstable environments are characterized by low species diversity (Kuslan, 1976; Mahon and Balon, 1977; Horwitz, 1978). The annual water fluctuation upstream in Lake St. Lawrence is generally around 200 cm (OMNR, 1987). Downstream, Lake St. Francis has a more constant water level, with an approximate annual water fluctuation of 30 cm (OMNR, 1987). A gradient of increasing diversity is often created downstream from a dam where fluctuations are minimal and shoreline fish communities can be more diverse, as well as abundant, because of the constant water level (Kinsolving and Bain, 1993). The unstable environment upstream may not be suitable for some species, thus contributing to a lower species diversity relative to downstream.

Diversity in fish communities has been associated with complex habitats (increased substrate and vegetation diversity) in lakes (Tonn and Magnuson, 1982; Eadie and Keast, 1984; Eadie et al., 1988) and streams (Gorman and Karr, 1978). A positive relationship between resource diversity and species diversity has been demonstrated for terrestrial species as well (Eadie and Keast, 1984). In areas with fewer fish species and less habitat diversity, generalist species tend to dominate the fish community (Kelso and Johnson, 1991). In the habitat PCA (Figure 5) and CCA (Figure 6), the clustering of upstream sites and indiscriminate distribution of downstream sites showed that the upstream habitat was more homogeneous, while the downstream habitat was heterogeneous. Fish species diversity has been related to habitat heterogeneity (Tonn and Magnuson, 1982).

The habitat downstream provides diverse substratum and abundant aquatic vegetation for benthic invertebrates and areas for fish spawning beds (Moyle and Cech, 1988). More productive habitats allow for greater dietary specialization, therefore more species (Tonn and Magnuson, 1982). The bluntnose minnow was the most abundant fish in the upstream region. This species is considered as a habitat generalist (Scott and Crossman, 1973), thus the homogeneity of the upstream habitat may play a role in the success of this species.

Species Composition

To determine if there were differences in fish species composition between upstream and downstream, a cluster analysis based on presence/absence of fish species was done (Figure 2). The cluster analysis separated most upstream sites from downstream sites. This was based on the rarity of mimic shiners, banded killifish, golden shiners, the absence of blackchin and blacknose shiners upstream and the presence of these fish species downstream. These results suggest that it is mainly the differences in the presence or absence of cyprinids that determine the fish species composition in the littoral zone of the St. Lawrence River, and are therefore important indicator species for this area.

There was only one downstream site (East St. Regis Island) in the second cluster (B) (Figure 2). The habitat data from this site were compared to nearby sites to determine if habitat differences were responsible for the differences in species composition. However, the habitat was similar to a nearby site (West St. Regis Island) thus, habitat is probably not playing a role in the difference in species composition at this site, but could be a factor in the intra-regional differences that were found.

A cluster analysis of 19 northern Ontario lakes using presence/absence of fish species found that lakes tended to group in watersheds (Kelso and Johnson, 1991). In this study we sampled two areas in close proximity, within the same watershed and we detected distinct fish communities. Statistically, it is possible that the result of a cluster analysis is related to the type of clustering executed and provides clusters that are not natural or biologically significant (Jackson and Harvey, 1989). However, the distinct regional clusters that were observed in the present study make it likely that species composition differences exist between the two areas, and that these differences supersede the inter-site differences.

Species Abundance

The PCA of overall fish abundance (Figure 3) showed distinct upstream and downstream communities based on the high component loadings of the mimic shiner, banded killifish and golden shiner on the first axis. The combined abundance of these three species distinguishes the downstream community from the upstream community. Differences in habitat are playing a major role in determining why the abundance patterns are different.

Scott and Crossman (1973) stated that the mimic shiner, banded killifish and golden shiner require aquatic macrophytes for spawning habitat, as well as refuge from predators. The ANOVA of habitat variables (Table 4) found a significantly higher percentage of aquatic vegetation cover downstream, while the upstream sites had a significantly higher amount of boulder and gravel substrate. It has been found that as plant density increases, so do the numbers of smaller fish (Barnett and Schneider, 1974). Aquatic vegetation increases littoral zone productivity by providing structural complexity within the littoral zone (Ploskey, 1986; Randall et al., 1996). Vegetation also provides cover which decreases predator/prey encounters (Aboul Hosn and Downing, 1994) and structure for invertebrate growth which then creates a productive feeding area (Randall et al., 1996). The water level fluctuations upstream could create problems for littoral zone fish species by exposing spawning beds or desiccating nearshore aquatic vegetation, thus reducing suitable productive habitat for littoral zone fish.

The first axis of the PCA of fish relative abundance (Figure 4) did not provide conclusive results at the community level due to the high relative abundance of the bluntnose minnow throughout the study area. The second axis of this PCA showed some separation between upstream and downstream sites. The downstream sites were separated positively from the upstream sites based on the high component loading of the mimic shiner and negatively based on the high component loading of the banded killifish. Fewer banded killifish were caught upstream (76 specimens at 8 sites) compared to the mimic shiner (246 specimens at 8 sites).

The Pearson correlation coefficients (Table 9) gave an indication of the type of habitat that the most abundant fish species were utilizing. The mimic shiner was correlated with vegetation in the analyses, which was not surprising considering its apparent need for vegetation to survive (Scott and Crossman, 1973, Coad, 1995). The banded killifish was correlated with many habitat variables including muck, clay, vegetation and sand. The white sucker and yellow perch were correlated to vegetation and sand. Higher numbers of all of these fish species were caught downstream, which again indicates that habitat differences are probably a major factor in the differences in the fish community.

Habitat has been found to be the basis of many biological communities (Schoener, 1974). The destruction of habitat associated with the construction of the Moses-Saunders hydroelectric dam appears to have had a negative effect on the upstream fish community in the St. Lawrence River near Cornwall. Six of the thirteen species that were absent upstream in this study, were present in this area of the St. Lawrence River in the 1930's, before the construction of the dam (Table 10) (Carlson, 1996).

Damming creates an environmental disturbance that immediately changes a lotic system into a lentic system (Yount and Niemi, 1990). Direct effects of flooding include changes in water velocity, water quality, habitat (including silt deposition), access to spawning areas and migration patterns (Fowler, 1978; Allan et al., 1991). Indirect changes include changes in food supply (decrease in the biomass of benthic invertebrates and disruption of the natural drift of planktivores), changes in channel morphology and destruction of wetlands (Petts, 1984). In Lake Ontario, physical stresses such as water change flows from hydroelectric development and dredging have induced the most heavily stressed habitat (Busch and Lary, 1996). An overview of damming projects in western Canada concluded that littoral zone production in reservoirs is often low (Geen, 1974). This low reservoir production is probably related to the lack of aquatic vegetation (submergent and emergent), which appears to be the case in this study.

Correlations were found between nine out of thirteen habitat variables with the first two PCA factor of fish abundance and fish relative abundance (Table 9). The three variables that were not correlated to a PCA factor (rubble, silt and detritus) therefore may not be as biologically significant as the other variables. It is suggested that in future studies habitat variables, especially vegetation, gravel and sand (which had the highest F-ratios) be focused on. As well, fish abundance was positively related to depth gradient and clay, which shows that these habitat variables are contributing to a higher overall fish abundance.

Fish Biomass

Littoral zone biomass was found to be significantly higher downstream compared to upstream. When biomass was correlated to the second habitat PCA (vegetation) , a negative correlation was found. A lower biomass was found in vegetated areas. This finding contradicts what would be expected. Keast (1978) found fish biomass was highest in vegetated areas of an Ontario lake. As well, Randall et al. (1996) used a fish production index, which is a based on fish abundance and size, and found fish production was highest in littoral sites with macrophyte beds than in areas where macrophytes were more sporadic. Moyle and Cech (1988) stated that when there is a limited food supply, lower growth rates are often found.

Aquatic vegetation provides cover and a food resource (benthic invertebrates) (Aboul Hosn and Downing, 1994; Eadie and Keast, 1984), so it would be expected that a high density of fish (therefore a potentially higher biomass) would be found in an aquatic weedbeed. The low biomass in vegetated areas may be explained by sampling difficulties in weeds associated with the seine net. A higher biomass was found in areas with muck, detritus and clay. In these areas, fine particle size of the substrate allows for easy suspension of particles into the water column.

This lowers water clarity which makes the probability of catching fish increase, because fish cannot see the net.

CONCLUSIONS

The first objective of this study was to characterize and compare the fish communities upstream and downstream of the Moses-Saunders hydroelectric dam. The examination of the littoral fish communities in the St.. Lawrence River near Cornwall has provided baseline data for future comparative studies. As well, differences between the littoral zone fishes, such as significantly higher species diversity and biomass downstream of the dam, have been recognized with the upstream fish community in apparent need of rehabilitation efforts because of the lower fish species diversity, lower biomass and fewer number of fish caught. Fish community characteristics were related to various habitat variables using multivariate analysis, regression analysis and correlation analysis. The lack of a suitable (i.e.. aquatic weed beds) and a diverse habitat appears to be the greatest factor contributing to the differences in fish community diversity and biomass in Lake St. Lawrence. It appears that the unstable reservoir environment has had an effect on both the fish community and the habitat. Although the biology of some fish species, such as photosensitivity and temperature requirements, and the sampling method in the littoral zone may have created some bias towards some species, the differences in habitat complexity and water fluctuations upstream and downstream are probably playing a major role in the difference in species richness between both regions.

The lack of suitable habitat associated with the construction of the Moses-Saunders hydroelectric dam and the St. Lawrence Seaway appears to be one factor that has affected the fish communities in Lake St. Lawrence. It has been generally recognized that the construction of the dam and seaway have impacted the fish community due to habitat destruction, water level changes and current changes (Anderson et al., 1990). The flooding associated with the damming destroyed shoals, wetlands, islands and the shoreline while at the same time created new fish habitat areas (Patch and Busch, 1984).

A further factor which may be affecting the fish community structure in this area is chemical contamination. As water enters a reservoir, it slows down and loses its capacity to carry suspended solids (Fowler, 1978). Upstream, Lake St. Lawrence is the first sedimentation basin for contaminants carried downstream from Lake Ontario. The area downstream of the Moses-Saunders dam receives pollutants directly from local industry (General Motors, Domtar, ALCOA, Reynolds etc.). Recent studies in the same upstream and downstream location, have shown the white sucker population had significantly higher amounts of both PAH's (polycyclic aromatic hydrocarbons), aldrins, and mercury upstream compared to downstream (Ridgway, 1996; Lalonde, 1996). Since the white sucker is a bottom feeding species, it is continually exposed to organic and inorganic pollutants found in sediments. The sediment contamination would have an affect on all levels of the fish community, which could indirectly affect the fish community structure by creating year class failures, poor growth or unsuccessful reproduction (Allan et al., 1991). This could also be a factor that has altered the fish community, although it is difficult to associate chemical contamination with changes at the community level (Allan et al., 1991).

Fish and their habitat requirements are a primary target within the Great Lakes Water Quality Agreement (GLWQA), as well as with the U.S. Fish and Wildlife Service (USFWS) for restoration and preservation (Minns et al., 1994; Karr, 1992). For fish management, an understanding of the interactions between fish and their habitat is necessary to make any management decisions. Two habitat variables that have been found to support diverse and abundant fish communities are substratum type and vegetation abundance. The bottom substrate is important for benthic invertebrate abundance, as well for fish cover and spawning sites. As well, aquatic vegetation supports a benthic community and provides cover for fish. For these reasons, diverse habitats are expected to support a diverse fish community (Eadie and Keast, 1984).

FUTURE CONSIDERATIONS:

Considering these results, rehabilitation efforts should focus on Lake St. Lawrence. It is obvious that the system has not recovered from the flooding after 37 years, so it is difficult to presume that more time for recovery would begin to remedy the problems that are associated with the flooded land. The lack of aquatic vegetation, which provides spawning habitat, cover, and a substrate for benthic invertebrates, appears to be one of the major factors that is associated with the habitat problems in Lake St. Lawrence. But, before introducing aquatic vegetation physically to the upstream environment, future studies need to be done to assess the success that this introduction could bring. For example, it is not known how well various aquatic plants could adapt to the conditions in Lake St. Lawrence. It is not a "natural" river, so it is difficult to say at this point if the substrate that is present would even support this vegetation. If vegetation is not there now, it is probable it will never establish itself. Another option to weedbeds is placing rock rip-rap structures in the littoral zone. These areas provide cover, as well as substrate for some invertebrates. This type of structure would not be dependent on water level fluctuations, so would be an excellent alternative to vegetation. Iit would be necessary to find out if colonization of both invertebrates and fish would occur in these man-made structures compared to areas that are presently in the aquatic ecosystem.

If the weed beds did grow successfully, and fish or invertebrates did not colonize the area, further investigations could be done on the effects of chemical pollutants on both fish and invertebrates that are presently absent in Lake St. Lawrence and present downstream of the

Moses-Saunders hydroelectric dam. This could be done in the laboratory using LC50's or LD50's on these species, and finding out what the tolerance to various pollutants, especially PAH's, aldrins and mercury, are in order to assess if the differences in chemical degradation in the two sampling areas could be a factor contributing to the differences in the fish community.

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Appendix 1: Biomass conversion table for species where ten or more specimens were caught in the St. Lawrence River, near Cornwall, Ontario. * indicates species measured and weighed from the collection at the Canadian Museum of Nature. ** is taken from Ridgway, 1996.

	CONSTANT	**SLOPE**	**R^2**	**STANDARD ERROR OF SLOPE**	**# OF CASES**
*Ambloplites rupestris**	-4.64	2.97	0.99	0.05	75
*Amerius nebulosus**	-5.11	3.1	1	0.06	71
*Alosa pseudharengus**	-6.01	3.35	0.91	0.14	75
*Culaea inconstans**	-4.19	2.52	0.85	0.05	75
*Catostomus commersoni***	-5.22	3.11	1	0.07	271
Esox lucius	-4.65	2.78	0.88	0.13	75
*Exoglossum maxillingua**	-5.58	3.31	0.99	0.05	75
Etheostoma olmstedi	-5.47	3.18	0.98	0.08	75
Fundulus diaphanus	-5.62	3.34	0.99	0.07	75
*Lepomis gibbosus**	-5.16	3.24	1	0.05	75
*Labidesthes sicculus**	-5.42	3.01	0.97	0.08	75
*Moxostoma erythrurum**	-5.35	3.17	1	0.05	74
*Micropterus salmoides**	-4.81	2.94	0.99	0.05	75
*M. dolomieui**	-5.02	3.05	1	0.07	12
Notemigonus crysoleucas	-6.16	3.55	0.99	0.06	75
*Notropis atherinoides**	-5.67	3.26	0.99	0.04	75
N. heterodon	-5.77	3.36	0.99	0.05	75
N. hudsonius	-5.72	3.31	0.99	0.06	75
*N. heterolepis**	-5.29	3.07	0.95	0.07	75
N. volucellus	-6.21	3.66	0.99	0.05	75
Perca flavescens	-5.32	3.18	1	0.04	75
Pimphales notatus	-5.64	3.32	0.99	0.06	75
Percina caprodes	-4.42	2.63	0.99	0.05	75
*Semotilus atromaculatus**	-4.7	2.85	0.99	0.06	74
S.corporalis	-5.14	3.02	1	0.05	75

Appendix 2: Biomass caluculations ($B_i=N_i*w_i$, where B_i= biomass, N_i= number, and w_i=weight) for 36 sites upstream and downstream of the Moses-Saunders hydroelectric dam, near Cornwall, Ontario. All calculations done in grams. See Appendix 1 for conversion calculations for each species.

SITE	# of cases	Minimum (g)	Maximum (g)	Mean (g)	Standard Deviation	Biomass (g)
UPSTREAM						
Bredin Isl.	143	0.25	275.73	6.89	24.47	984.7
Croil #3	5,439	0.03	275.75	1.02	8.76	6,020.97
ELong Sault	87	0.21	188.17	4.22	21.33	366.97
Farran Park	18	0.21	9.22	1.92	2.65	34.06
Hoople Isl.	2,781	0.07	42.71	0.45	0.98	1,257.01
Lakeview H.	141	0.18	1,450.44	15.62	124.55	2,202.7
Long #3	1,810	0.1	303.64	0.62	7.13	1,114.96
Long #4	961	0.06	932.33	7.84	48.96	7,536.16
Mille Roche	130	0.18	63.13	5.23	10.21	679.25
NE Croil	1,896	0.02	1,110.54	2.31	26.62	4,377.86
SE Croil	954	0.03	611.32	10.32	34.49	9,849.1
Sheek Isl.	2,371	0.13	180.65	1.31	5.87	3,094.16
Wales Isl.	345	0.09	706.38	3.41	38.2	1,177.83
WLong Sault	2,622	0.07	1,187.01	2.15	23.53	5,634.68
DOWNSTREAM						
Clark Isl.	617	0.1	156.91	3.34	14.37	2,116.93
Corn Isl.	5,473	0.04	470.09	2.57	14.45	14,065.61
Cornwall Isl.	402	0.07	138.04	2.74	8.25	1,101.48
Court. Cot.	1,409	0.06	458.68	1.82	13.39	2,564.38
3rd Crab Isl.	611	0.11	202.78	2.54	10.95	1,548.89
Dickerson	1,977	0.06	113.44	1.65	8.8	3,267.98
Doden Isl.	5,136	0.07	11.14	0.85	1.16	4,350.19
E Colq. Isl.	994	0.12	233.53	6.72	18.16	6,674.71
E St. Regis	544	0.11	177.81	1.78	8.94	966.14
Farlinger's	313	0.05	227.88	30.42	47.54	9,522.4
Flannigan's	1,540	0.05	128.67	1.22	6	1,871.1
Goose Isl.	947	0.09	414.06	6.7	28.76	6,341.11
Hog Isl.	1,975	0.06	116.94	2.45	7.89	4,834.8
Ile du Canal	1,344	0.1	278.82	3.34	18.39	4,488.96
Pilon Isl.	3,424	0.1	262.62	1.68	6.27	5,728.35
Stone Pt.	7,890	0.05	822.45	0.77	10.12	6,035.85
Thompson	12,941	0.05	182.94	0.43	3.86	5,564.63
UnderBridge	1,552	0.1	383.43	2.75	12.32	4,261.79
W Colq. Isl	1,754	0.09	431.68	9.47	24.97	16,613.89
Windmill Pt.	1,354	0.11	1,760.12	10.74	61.85	14,536.54
W Pilon Isl.	208	0.11	67.89	3.68	11.58	764.82
W St. Regis	1,601	0.07	370.34	4.84	17.47	7,750.44

Appendix 3: Averages of environmental variables (as a percentage unless otherwise noted) from 36 sites upstream and downstream of the Moses-Saunders hydroelectric dam near Cornwall, Ontario. Region 0=upstream, 1=downstream.

Date	Site Name	Region	Depth Gradient (m)	Vegetation1 (deep)	Vegetation2 (shallow)	Rock	Boulder	Rubble	Gravel	Sand	Silt	Clav	Muck	Detritus
June2195	Bredin	0	14.29	14.00	14.00	0.00	7.00	27.50	9.00	33.50	0.00	18.00	4.00	0.00
June2895	Croil3	0	23.28	3.40	41.00	0.00	6.00	2.50	20.00	58.50	0.00	0.00	27.00	4.00
June294	Farran	0	7.84	19.00	3.00	0.00	13.50	20.50	43.50	22.50	0.00	0.00	0.00	0.00
June194	Hoop	0	12.50	13.00	10.00	0.00	22.00	35.00	18.00	9.00	0.00	0.00	16.00	0.00
June1394	Lake	0	24.33	21.00	36.00	0.00	20.00	20.00	10.00	40.00	10.00	0.00	0.00	0.00
July1994	Long2	0	26.37	76.00	24.00	0.00	215.00	380.00	75.00	270.00	0.00	0.00	6.00	0.00
June2795	Long3	0	9.79	54.00	2.40	0.00	140.00	430.00	330.00	100.00	0.00	0.00	0.00	0.00
June2795	Long4	0	20.37	0.00	6.00	0.00	10.00	42.00	10.00	198.00	0.00	0.00	73.00	1.00
July594	Milles	0	9.72	21.00	25.00	0.00	390.00	200.00	290.00	110.00	0.00	0.00	0.00	0.00
Aug994	NECroil	0	7.93	33.00	11.00	0.00	305.00	280.00	260.00	110.00	0.00	0.00	0.00	0.00
Aug1094	SECroil	0	8.49	24.00	0.00	0.00	90.00	570.00	240.00	100.00	0.00	0.00	0.00	0.00
June 2995	Sheek	0	18.68	22.00	32.00	0.00	0.00	150.00	275.00	510.00	2.50	0.00	4.00	0.00
May2594	Wales	0	8.74	28.00	12.00	0.00	50.00	240.00	60.00	420.00	5.00	18.00	0.00	0.00
July2094	WLong	0	14.33	52.00	10.00	0.00	135.00	340.00	95.00	390.00	0.00	0.00	3.00	1.00
MIN			**7.84**	**0.00**	**0.00**	**0.00**	**0.00**	**2.50**	**9.00**	**9.00**	**0.00**	**0.00**	**0.00**	**0.00**
MAX			**26.37**	**76.00**	**41.00**	**0.00**	**390.00**	**570.00**	**330.00**	**510.00**	**10.00**	**18.00**	**73.00**	**4.00**
AVG			**14.76**	**27.17**	**16.17**	**0.00**	**100.25**	**195.54**	**123.96**	**169.39**	**1.25**	**2.57**	**9.50**	**0.43**
June2095	Clark	1	25.29	31.00	37.00	0.00	8.00	9.00	5.00	65.00	0.00	0.00	13.00	0.00
June1395	Corn	1	54.07	31.00	40.00	0.00	7.50	18.50	1.00	63.00	5.00	0.00	5.00	0.00
Aug1794	Cornwal	1	19.39	70.00	57.00	0.00	18.00	12.50	9.00	50.50	0.00	0.00	10.00	0.00
Aug1594	CourtCot	1	7.62	68.00	64.00	0.00	19.00	23.00	21.00	32.00	0.00	0.00	5.00	0.00
June895	Crab3	1	9.94	55.00	68.00	0.00	11.00	51.00	15.50	22.50	0.00	0.00	0.00	0.00
June2394	Dicker	1	14.18	61.00	41.00	0.00	2.00	41.00	16.00	24.00	0.00	0.00	19.00	0.00
June1495	Doden	1	13.96	51.00	40.00	0.00	2.00	39.00	4.00	54.00	0.00	0.00	0.00	1.00
Aug994	EColq	1	16.76	69.00	75.00	0.00	7.50	29.50	1.00	62.00	0.00	0.00	0.00	0.00
July2794	EStReg	1	16.46	97.00	90.00	0.00	16.00	39.00	4.00	41.00	0.00	0.00	0.00	0.00
June894	FarPt	1	13.89	7.00	24.00	0.00	7.50	29.50	3.00	17.50	42.50	0.00	0.00	0.00
June694	Flanpt	1	15.19	17.00	33.00	0.00	7.00	36.50	0.00	48.50	8.00	0.00	0.00	0.00
June1595	Goose	1	26.08	10.20	7.00	0.00	2.00	23.00	4.50	30.50	0.00	32.50	0.00	7.50
June2894	Hog	1	38.22	96.00	67.00	0.00	2.00	13.00	29.50	55.50	0.00	0.00	0.00	0.00
June1495	IleCan	1	10.26	50.00	78.00	60.00	0.00	41.50	20.00	30.50	0.00	0.00	10.00	2.00
June795	Pilon	1	29.77	9.00	23.00	0.00	0.00	55.00	50.00	393.00	0.00	16.20	34.00	0.00
June695	StonePt	1	26.66	18.00	13.00	0.00	120.00	100.00	10.00	20.00	0.00	25.00	48.50	1.50
June2994	Thomp	1	28.64	78.00	71.00	0.00	190.00	130.00	150.00	330.00	0.00	20.00	0.00	0.00
June2195	UBridge	1	16.09	42.00	37.00	0.00	200.00	40.00	180.00	190.00	0.00	0.00	39.00	0.00
June1295	WColq	1	25.73	41.00	44.00	0.00	125.00	170.00	80.00	475.00	0.00	0.00	15.00	0.00
June2195	Windmill	1	5.30	59.00	50.00	0.00	50.00	60.00	100.00	200.00	0.00	0.00	34.00	5.00
June2094	WPilon	1	8.82	54.00	56.00	0.00	0.00	700.00	200.00	100.00	0.00	0.00	0.00	0.00
July2694	WStReg	1	22.45	90.00	96.00	0.00	0.00	360.00	0.00	365.00	17.50	0.00	10.00	0.00
MIN			**5.30**	**7.00**	**7.00**	**0.00**	**0.00**	**9.00**	**0.00**	**17.50**	**0.00**	**0.00**	**0.00**	**0.00**
MAX			**54.07**	**97.00**	**96.00**	**60.00**	**200.00**	**700.00**	**200.00**	**475.00**	**42.50**	**32.50**	**48.50**	**7.50**
AVG			**20.22**	**50.19**	**50.50**	**2.73**	**36.11**	**91.86**	**41.07**	**121.34**	**3.32**	**4.26**	**11.02**	**0.77**

Appendix 4: Total lengths (TL) in mm used to eliminate young-of-the-year fish from overall analysis of fish caught in the St. Lawrence River upstream and downstream of the Moses-Saunders hydroelectric dam, near Cornwall, Ontario.

SPECIES	**TL (mm)**	**SOURCE**
Perca flavescens	< 80	Scott and Crossman, 1973
Catostomus commersoni	< 60	Ridgway, 1996
Ambloplites rupestris	< 38	Scott and Crossman, 1973
Lepomis gibbosus	< 35	Scott and Crossman, 1973
Esox lucius	< 80	Scott and Crossman, 1973
Micropterus salmoides	< 38	Scott and Crossman, 1973
M. dolomieui	< 38	Scott and Crossman, 1973
Amerius nebulosus	< 60	Scott and Crossman, 1973
Moxostoma erythrurum	< 64	Scott and Crossman, 1973
All Species	< 22	Scott and Crossman, 1973

Appendix 5 Fish species and number caught (excluding young-of-the-year) from 36 sampling sites upstream and downstream of the Moses-Saunders hydroelectric dam near Cornwall, Ontario Region 0=upstream, 1=downstream

Site	Region	*Amia calva*	*Amerius nebulosus*	*Alosa pseudoharengus*	*Ambloplites rupestris*	*Cottus bairdi*	*Cyprinus carpio*	*Catostomus commersoni*	*Culaea inconstans*	*Chrosomus neogaeus*	*Etheostoma exile*	*Esox lucius*
Bredin	0	0	0	0	3	0	0	0	0	0	0	1
Croil3	0	0	1	0	3	0	0	0	0	0	0	0
Farran	0	0	0	0	0	0	0	2	0	0	0	0
Hoop	0	0	0	0	1	0	0	0	0	0	0	0
Lake	0	0	0		0	0	0	1	0	0	0	1
Long2	0	0	0	0	0	0	0	1	0	0	0	0
Long3	0	0	0	0	0	0	0	0	0	0	0	0
Long4	0	0	16	0	0	0	0	5	0	0	0	4
Milles	0	0	0	0	0	0	0	5	0	0	0	0
NECroil	0	0	0	4	3	0	0	36	0	0	7	2
SECroil	0	0	0	9	0	0	1	52	0	0	0	0
Sheek	0	0	0	0	1	0	2	0	0	0	0	1
Wales	0	0	25	0	1	0	3	2	0	0	0	0
WLong	0	0	0	0	20	0	0	45	0	0	0	0
Clark	1	0	0	0	0	1	0	12	0	0	0	0
Corn	1	0	2	0	5	0	0	21	0	2	5	0
Cornwal	1	0	0	0	21	0	0	6	6	0	0	1
CourtCot	1	0	0	0	4	0	0	31	0	0	0	1
Crab3	1	0	0	0	0	0	0	1	0	0	0	0
Dicker	1	0	0	0	3	0	0	5	2	0	4	0
Doden	1	0	0	0	10	0	0	8	0	0	1	0
EColq	1	0	0	0	22	0	0	85	2	0	1	1
EStReg	1	0	0	0	4	0	0	11	0	0	0	0
FarPt	1	0	0	0	0	0	0	0	0	0	9	0
Flanpt	1	0	1	0	0	1	0	11	0	0	13	0
Goose	1	1	1	0	3	0	0	9	0	0	0	1
Hog	1	0	0	0	2	0	0	79	5	0	5	0
IleCan	1	0	0	0	15	0	0	1	0	0	4	0
Pilon	1	0	0	0	0	0	0	8	0	0	0	1
StonePt	1	0	0	0	10	0	0	10	0	0	36	0
Thomp	1	0	0	0	8	0	0	0	0	0	172	0
UBridge	1	0	0	0	3	0	1	60	0	0	1	0
WColq	1	0	0	0	8	0	0	137	0	0	0	0
Windmill	1	0	25	0	5	0	1	0	0	0	0	5
WPilon	1	0	0	0	0	1	0	3	0	0	27	0
WStReg	1	0	2	0	70	0	0	142	18	0	1	0
Total		1	73	13	225	3	8	789	33	2	286	19

Appendix 5 (continued)

Esox masquinongy	*Exoglossum maxillingua*	*Etheostoma olmstedi*	*Fundulus diaphanus*	*Gasterosteus aculeatus*	*Icthyomyzon unicuspis*	*Lepomis gibbosus*	*Lepisosteus osseus*	*Labidesthes sicculus*	*Micropterus dolomieui*
0	0	40	0	0	0	0	0	0	5
0	0	0	35	0	0	4	0	0	9
0	0	16	0	0	0	0	0	0	0
0	0	12	0	0	0	0	0	1	0
0	0	26	0	0	0	0	0	0	1
0	0	3	10	0	0	0	0	0	54
0	0	4	1	0	0	0	0	11	1
0	6	29	9	0	0	110	0	0	0
0	0	6	0	0	0	0	0	0	0
5	0	76	4	0	0	11	0	0	68
0	0	61	2	0	0	1	0	4	7
0	0	51	14	0	0	0	0	0	3
0	0	33	0	0	0	1	0	0	0
0	0	28	1	0	0	2	2	0	11
0	0	70	310	0	0	0	0	0	0
0	1	509	41	0	0	114	0	0	0
2	0	11	20	0	0	9	0	0	21
0	1	11	13	0	0	0	0	0	6
0	0	70	125	0	0	0	0	0	0
0	0	83	338	0	0	0	0	0	0
0	0	145	1786	0	0	0	0	0	0
0	0	17	415	0	0	0	1	4	3
0	1	41	127	0	0	0	0	0	8
0	0	21	16	0	1	69	0	0	0
0	0	167	564	0	0	9	0	3	0
0	0	14	9	0	0	34	0	0	0
0	0	64	1205	1	0	0	0	0	0
0	0	17	17	0	0	0	0	0	0
0	5	107	375	0	0	0	0	0	0
0	0	251	116	0	0	4	0	0	0
0	0	165	2029	0	0	10	0	0	0
0	5	409	29	5	0	1	0	1	2
0	3	73	77	0	0	0	0	0	0
0	7	9	35	0	0	152	0	2	0
0	0	2	4	0	0	0	0	0	0
0	4	14	218	0	0	10	0	0	8
7	33	2655	7945	6	1	541	3	26	207

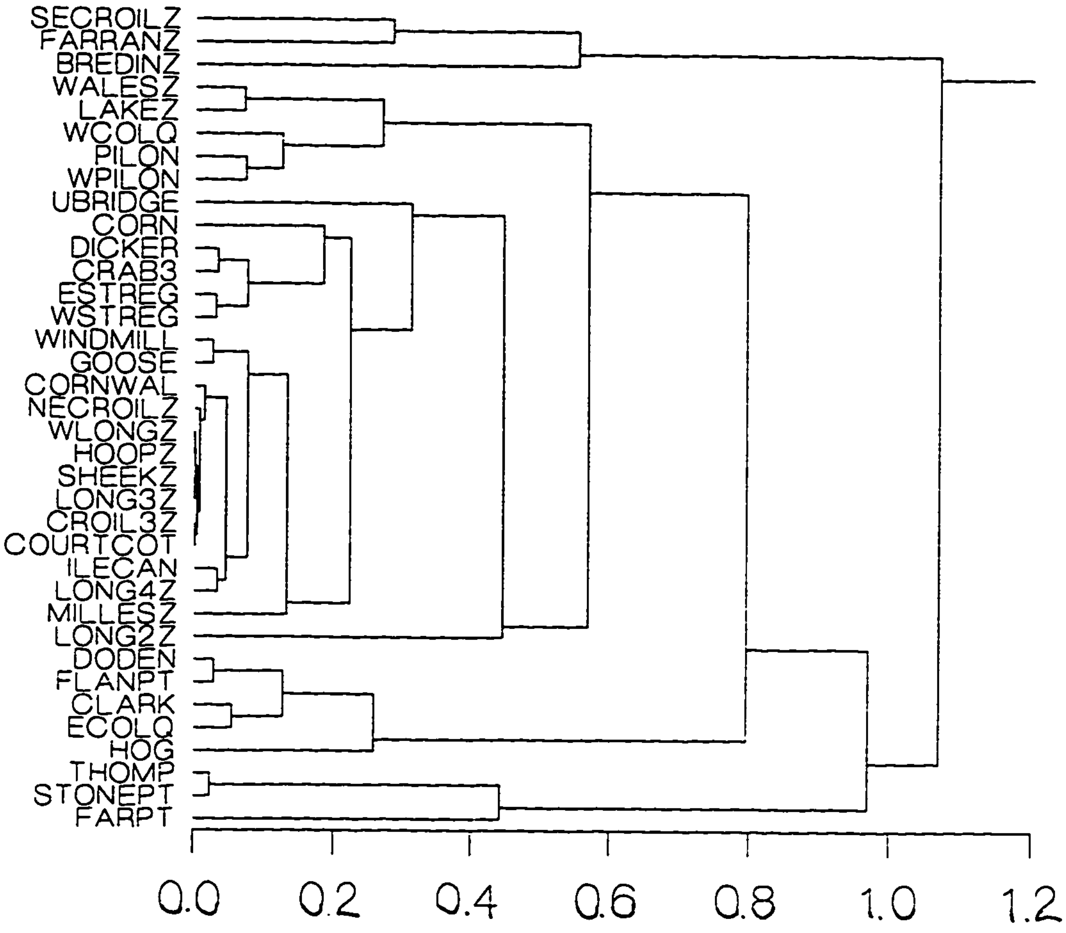
Appendix 5 (continued)

Moxostoma erythrurum	*Micropterus salmoides*	*Moxostoma valenciennsi*	*Notropis atherinoides*	*Luxilus cornutus*	*Notemigonus crysoleucas*	*Notropis heterodon*	*Notropis heterolepis*	*Notropis hudsonius*	*Notropis volucellus*	*Osmerus mordax*
8	0	0	0	0	0	0	0	27	9	0
0	0	0	0	0	0	0	0	2	210	0
0	0	0	2	0	0	0	0	2	0	0
0	0	0	0	1	3	0	0	161	10	1
0	0	0	0	1	0	0	0	45	4	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	1	6	0
5	0	0	1	0	54	0	0	116	4	1
0	0	0	0	0	0	0	0	2	1	0
0	0	0	0	0	15	0	0	2	0	0
0	0	0	0	0	0	0	0	32	0	0
2	0	0	0	0	0	0	0	35	2	0
0	0	0	0	0	24	0	0	190	0	0
0	0	0	0	0	1	0	0	101	0	0
0	0	0	0	0	0	0	0	5	4	0
1	0	0	4	0	1102	453	1	206	567	0
0	0	0	0	0	15	0	0	0	5	0
0	0	0	0	0	0	0	1	22	100	0
0	0	0	0	0	0	1	0	63	42	0
0	0	0	4	0	78	32	0	67	278	0
1	0	0	0	0	8	95	1	289	72	1
0	0	0	0	0	0	3	0	1	0	0
0	0	0	0	0	0	22	0	0	0	0
0	0	0	0	0	13	24	0	15	66	0
0	0	0	0	7	53	5	1	58	48	0
0	0	0	0	0	122	49	0	12	12	1
0	0	0	0	0	1	1	0	201	28	1
0	0	1	0	0	2	7	0	173	134	0
0	0	0	0	0	0	0	0	746	696	0
0	0	3	37	0	31	109	0	200	6147	1
0	0	0	0	0	270	118	194	7	8618	0
15	0	6	18	0	48	2	0	99	170	0
3	0	0	2	0	0	3	0	425	181	0
0	43	0	0	0	109	143	0	4	2	0
0	0	0	0	0	2	2	0	31	32	0
0	0	0	0	0	11	10	0	8	46	0
35	43	10	68	9	1963	1079	198	3348	17494	6

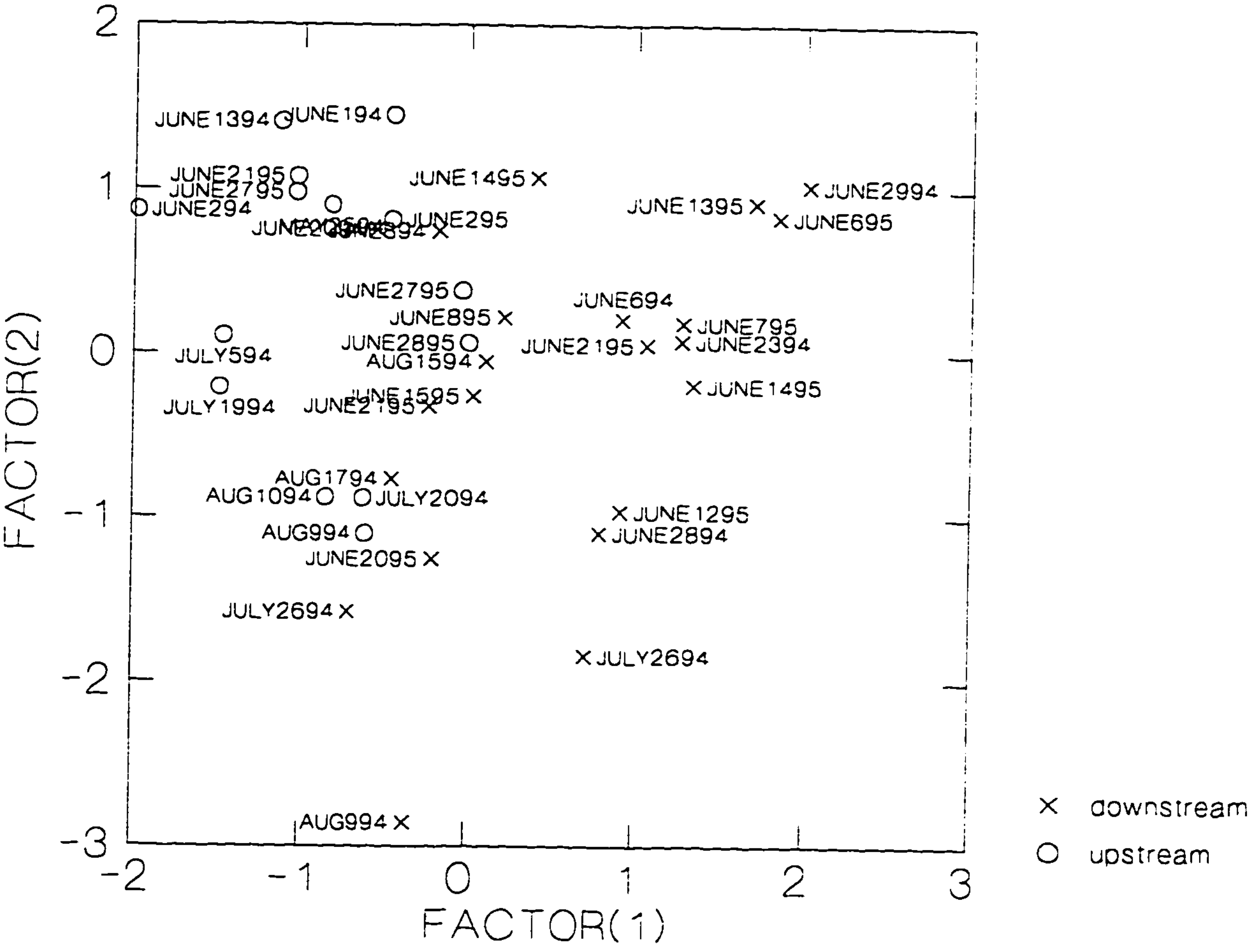
Appendix 5 (continued)

Percina caprodes	*Phoxinus eos*	*Perca flavescens*	*Pomoxis nigromaculatus*	*Pimephales notatus*	*Percopsis omiscomaycus*	*Pimephales promelas*	*Semotilus atromaculatus*	*Semotilus corporalis*	*Stizostedion vitreum*	Total
15	0	17	0	10	0	0	0	12	0	147
0	0	26	0	5149	0	0	0	0	0	5439
20	0	0	0	0	0	0	0	0	0	42
12	0	5	0	2580	0	0	0	6	0	2793
0	0	0	0	61	0	0	0	0	0	140
1	0	4	0	68	0	0	0	0	0	141
1	0	0	0	1783	0	0	0	1	0	1810
1	0	36	0	559	0	0	0	7	1	964
21	0	18	0	65	0	0	0	12	0	130
119	0	41	0	1589	0	0	0	0	0	1982
421	0	171	0	189	0	0	0	41	0	991
1	0	0	0	2211	0	0	0	54	3	2380
2	0	10	0	149	0	0	0	0	0	440
81	0	49	1	2276	0	0	33	6	0	2657
0	0	34	0	182	0	0	0	0	0	618
0	0	10	0	2415	0	1	0	9	0	5469
0	0	22	1	267	0	0	0	2	0	409
0	0	6	0	1239	0	0	0	3	0	1438
0	0	16	0	292	0	0	0	1	0	611
1	1	32	0	1053	0	0	0	0	0	1981
0	0	2	0	2717	0	0	0	2	0	5138
0	0	141	0	372	0	0	0	0	0	1068
1	0	12	0	330	0	0	0	0	0	557
0	0	58	0	22	0	0	0	0	0	314
0	0	1	0	607	1	0	0	0	0	1550
0	0	122	0	558	0	0	0	1	0	949
26	0	15	0	342	0	0	0	1	0	1977
4	0	2	0	962	0	0	0	5	0	1344
0	0	40	0	1445	0	1	0	1	0	3425
0	0	25	0	892	0	0	0	33	0	7905
0	0	1	0	1351	0	0	0	1	0	12944
3	1	57	0	515	0	0	0	146	0	1597
1	0	257	0	576	0	0	0	10	0	1756
1	0	70	4	742	0	0	0	1	0	1360
0	0	12	0	92	0	0	0	1	0	209
10	0	109	0	1057	0	0	0	4	0	1742
742	2	1421	6	34719	1	2	33	360	4	74419

Appendix 6: Cluster analysis of fish abundance of both upstream and downstream sites in the St. Lawrence River, near Cornwall, Ontario. Data analysed using hierarchial cluster analysis, complete linkage, Pearson distance. Fish species caught in only one site were eliminated from the analysis. 0=upstream and 1=downstream.


SECROILZ
FARRANZ
BREDINZ
WALESZ
LAKEZ
WCOLQ
PILON
WPILON
UBRIDGE
CORN
DICKER
CRAB3
ESTREG
WSTREG
WINDMILL
GOOSE
CORNWAL
NECROILZ
WLONGZ
HOOPZ
SHEEKZ
LONG3Z
CROIL3Z
COURTCOT
ILECAN
LONG4Z
MILLESZ
LONG2Z
DODEN
FLANPT
CLARK
ECOLQ
HOG
THOMP
STONEPT
FARPT
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Distance

Appendix 7: Graph of the first two axes of the fish abundance PCA, with date labelled, done on the upstream area (0's) and downstream area (X's) of the St. Lawrence River, near Cornwall, Ontario. Analysis include fish species caught in more than 60% of sampling sites. Factor (1) accounts for 38.7% of total variance. Factor (2) accounts for 14.4% of total variance.


FACTOR(2)
FACTOR(1)
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
JUNE1394
JUNE194
JUNE2195
JUNE2795
JUNE294
JUNE1495
JUNE295
JUNE1395
JUNE2994
JUNE695
JUNE2795
JUNE694
JUNE895
JUNE795
JUNE2394
JULY594
JUNE2895
JUNE2195
AUG1594
JUNE1495
JULY1994
JUNE1595
AUG1794
AUG1094
JULY2094
JUNE1295
AUG994
JUNE2894
JUNE2095
JULY2694
JULY2694
AUG994
× downstream
○ upstream

Appendix 8: Codes for both fish species and environmental variables used for CCA analysis (Figure 6) of the St. Lawrence River near Cornwall, Ontario. See Table 2 for scientific name.

SPECIES	CCA CODE	ENVIRONMENTAL VARIABLE	CCA CODE
Bowfin	ac	Depth Gradient	DG
Brown Bullhead	an	Vegetation 1	V1
Alewife	ap	Vegetation 2	V2
Rock Bass	ar	Boulder	BO
Mottled Sculpin	cb	Rubble	RU
Carp	cc	Gravel	GR
Brook Stickleback	ci	Sand	SA
Finescale Dace	cn	Silt	SI
White Sucker	co	Clay	CL
Iowa Darter	ee	Muck	MU
Northern Pike	el	Detritus	DE
Muskellunge	em	S-W Index	SW
Tesselated Darter	eo		
Cutlips Minnow	ex		
Banded Killifish	fd		
Three Spine Stickleback	ga		
Silver Lamprey	iu		
Pumpkinseed	lg		
Longnose Gar	lo		
Brook Silverside	ls		
Greater Redhorse	mb		
Small Mouth Bass	md		
Golden Redhorse	me		
Large Mouth Bass	ms		
Emerald Shiner	na		
Common Shiner	nc		
Spottail Shiner	nd		
Blacknose Shiner	nh		
Blackchin Shiner	nt		
Mimic Shiner	nv		
Golden Shiner	ny		
Rainbow Smelt	om		
Logperch	pc		
Northern Red Belly Dace	pe		
Yellow Perch	pf		
Trout-Perch	pm		
Black Crappie	pn		
Bluntnose Minnow	po		
Fathead Minnow	pp		
Creek Chub	sa		
Fallfish	sc		
Walleye	sv		