INVESTIGATING THE FISH COMMUNITY OF THE RIDEAU RIVER, ONTARIO, WITH RESPECT TO HISTORICAL CHANGES AND CURRENT LAND-USE PRACTICES

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Abstract

Agricultural and urban development incites change in aquatic ecosystems. It is generally hypothesized that change due to agricultural and urban development modifies the aquatic habitat characteristics, which ultimately affect the fish communities. The first objective of this study was to describe the appearance and disappearance of fish species within the Rideau River. Scientific literature, museum archives, newspaper articles, historical atlases, municipal reports, and anecdotal reports were consulted to reconstruct the past 120 years of the fish community. The results indicated that the diversity of fish species increased as a result of fish introductions, through increased boat traffic, fish stocking, transient species, baitfish introductions, live-well dumping and the introduction of exotics. The second objective of this study was to determine whether diversity and abundance of fish in the Rideau River could be attributed to agricultural, urban, or forested land-use type. In order to determine this, the fish community was intensively sampled in each of the three habitat types utilizing various sampling gear (trapnets, seines, backpack electrofisher). Over 9000 fish belonging to 33 species were captured between mid-July through mid-September 1998 and 1999. It was found that fewer species were captured in urban areas as compared to agricultural or forested areas and that the abundance of fish was higher in agricultural areas. Also, land-use was correlated with habitat characteristics and habitat characteristics were correlated with fish community diversity and abundance.

Résumé

Le développement agricole et urbain provoque des changements au niveau des écosystèmes aquatiques. Il est généralement postulé que ces changements entraînent des modifications au niveau des caractéristiques de l'habitat aquatique qui, ultimement, affectent les communautés de poissons. Le but de cette étude était de documenter l'apparition et la disparition des espèces de poissons dans le système de la Rivière Rideau et fournir des explications possibles pour expliquer les changements dans la diversité des poissons au cours de cette période. Afin de reconstituer les communautés ichtyennes au cours des 120 dernières années, nous avons puisé dans les archives de musée ainsi que dans la littérature. Les résultats indiquent que la diversité des espèces de poissons a augmenté suite à l'apparition du traffic maritime, l'introduction de nouvelles espèces, l'utilisation de poissons d'appât, l'introduction d'espèces exotiques, et l'apparition d'espèces transitoires. L'objectif de notre étude était d'examiner si la variabilité au niveau de la diversité, de la distribution, de l'abondance et de la biomasse des poissons de la rivière Rideau pouvait être attribuée au fait que la rivière coule en milieu agricole, urbain ou forestier. Afin de vérifier ceci, nous avons fait un échantillonnage ichtyologique intensif de chacun des trois types d'habitat en utilisant divers engins de pêche (verveux, seine et pêche électrique). Plus de 9,000 poissons appartenant à 33 espèces ont été capturés. Les résultats indiquent que le nombre moyen d'espèces capturées par station d'échantillonnage en mileu urbain est nettement inférieur à celui obtenu en milieu agricole ou forestier. L'abondance est cependant plus élevée en milieu agricole que dans les deux autres milieux. En plus, les résultats démontrent que le milieu est associé avec le type d'habitat, et que le type d'habitat est associé avec la diversité et l'abondance.

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Chapter 1. Over one hundred years of change within the fish community of the Rideau River, Ontario, Canada.

1.0. Introduction

The Rideau River forms part of the Rideau Canal Waterway, a 202 km chain of lakes and rivers that connect Lake Ontario, Kingston, to the Ottawa River, Ottawa (Fig. 1). Upper Rideau Lake is the highest point along the Rideau Canal Waterway, from which water flows downstream towards both Kingston and Ottawa. The water flows downstream towards Kingston through 14 locks, descending 50 m in elevation. The canal also flows downstream towards Ottawa through 33 locks, descending 83 m in elevation (Dimension 1977*). The Rideau River itself spans 100 km flowing along manicured parks, abandoned fields, beaches, forests, dairy farms, cornfields, cottages, housing developments, and shopping malls between Smiths Falls and Ottawa. The river provides aesthetic and recreational areas reknown for their excellent sportfishing and boating, and their historical and ecological significance (Parks Canada, 1996).

The Rideau River flows through the St. Lawrence Lowlands. The Lowlands are composed of limestone bedrock with a thin overlying layer (<5 m) of stony, sandy, carbonate rich till and brunisol soils (Marshall *et al.* 1979, Kettles and Shilts 1987, Schut and Wilson 1987). The buffering capacity of the limestone and till in addition to the high levels of detritus in the soils, makes the lands along the Rideau River ideal for agriculture (Brady 1990).

The forests along the Rideau River are dominated by sugar maple, *Acer saccharum* and beech, *Fagus grandifolia*, with redmaple, *Acer rubrum*, basswood, *Tilia americana*, white ash, *Fraxinus americana*, yellow birch, *Betula allegheniensis,* and white oak, *Quercus alba* (Dimension 1977*).

The lakes and rivers forming the Rideau River drainage basin were created from the meltwaters from the Labrador sector of the Laurentide ice sheet which covered Ontario and Quebec during the Wisconsonian period, 80 000-10 000 years before present. The ice sheet started to recede 15 000 years before present, creating several freshwater rivers and lakes.

Marine water moved onto the St. Lawrence lowlands 10 000-9 000 years ago replacing the freshwater lakes and rivers with the Champlain Sea (Mandrak and Crossman 1992). As the glacier continued to melt, the northern portion of the Champlain Sea was inundated with fresh water and renamed Lake Lampsilis in recognition of the freshwater clam species that inhabited this northern shore (Hooper 1996). The marine waters eventually receded, eliminating the Champlain Sea and leaving behind the freshwater lakes and rivers that are known today. The fish species currently residing in the Rideau River inhabited refugia to the south and east of the Laurentide ice sheet throughout the Wisconsonian period. The Mississippi Valley refugium, the largest refugium south of the ice sheet, was home to all native Rideau River species except three, American eel, *Anguilla rostrata*, tessellated darter, *Etheostoma olmstedi*, and alewife, *Alosa pseudoharengus,* which immigrated from the Atlantic Coastal refugium (Mandrak and Crossman 1992).

The Rideau River has a daily average summer temperature between 22-24°C (P. Hamilton, personal communication). Temperature is one of many factors that influence the types of fish that inhabit a waterbody. Warmwater systems have an average daily summer temperature above 24-26°C and are dominated by cyprinids, catostomids, centrarchids, and percids. Coldwater systems have an average daily summer temperature below 22°C and are dominated by salmonids and cottids (Lyons *et al.* 1996). The Rideau River falls in-between these two temperature regimes and has characteristics of both warmwater and coldwater systems.

The Rideau River is an interesting river to study because it has been subject to human perturbation ever since early settlers arrived in the Ottawa Valley in the early 1800s. The rich mixed-wood forests supported a thriving forestry industry and the alluvial soils bordering the Rideau River were ideal for cash crops and dairy farming. After the war of 1812, the Rideau River became an alternate link between Kingston and Ottawa, enabling Canadians to avoid confrontation with Americans along the St. Lawrence River (National Capital Commission 1998). The construction of the Rideau Canal took place during 1826 – 1832 and improved the link between the two cities. Prior to the construction of the Rideau Canal, the natural outlet of the Rideau River at the confluence of the Ottawa River was

Rideau Falls, a 15 m drop forming an impassable barrier to the movement of fishes from the Ottawa River to the Rideau River. However, the construction of locks along the length of the waterway made access possible from both the Ottawa River and the St. Lawrence River. The movement of the alewife, *Alosa pseudoharengus* (Coad 1983) and the freshwater drum, *Aplodinotus grunniens* (Phelps *et al.* 2000a) into the Rideau River demonstrates that movement of fishes from other watercourses is possible.

The objective of this chapter was to describe the similarities and differences between the current Rideau River fish community and past fish communities re-constructed from 120 years of historical records. The Rideau River landscape has changed since the early 1800s. Forests have been cleared for agricultural and urban development. These land-use changes impact aquatic habitat characteristics through increased erosion, pollution, dredging, and water level fluctuations, which ultimately affect fish communities (Tonn and Magnuson 1982, Lenat and Crawford 1994, Smith 1994, Wang et al. 1997, Osborne 1998). Studies that have considered historical data provide baseline knowledge to which present and future environmental characteristics can be compared and knowledge of past conditions guide the direction and degree of rehabilitation efforts. Also, an understanding of how past activities influenced the environment may provide the impetus for human behavioral changes that will prevent future environmental degradation (Bray 1996, Steedman et al. 1996).

Similar historical studies have been conducted elsewhere in Ontario. Kelso *et al.* (1996) reconstructed the fish community in the Great Lakes between 1870 and 1990. Several long-term changes in the fish community were observed: There was a shift from the dominance of large long-lived species to short-lived species; there was a shift from fish populations with constant size and age structure to fluctuating populations; species that were associated with diverse shorelines are now less common than species that are associated with less-structured open water environments; and there was a shift from fish species preferred by humans as food to those that were not.

Evans *et al.* (1996) used historical data to link land-use to the loss of fish habitat through phosphorus loading, phytoplankton production, and biological oxygen demand in Lake

Simcoe, Ontario. The history of human land-use and aquatic ecosystem change was related to the loss of cold-water fish habitat. This study assisted with the development of management strategies for Lake Simcoe.

Scott Gibson and Nick Mandrack also used historical data to reconstruct the fish community along the Trent/Severn Canal, Ontario between 1970 and 1999. Their objective was to determine if the fish community shifted from a cool/cold water community to a warm-water community due to the development and construction of dams and locks along the length of the system (Scott Gibson personal communication).

1.2. Methods

During the summers of 1998 and 1999, surveys of the fish community within the Rideau River and its tributaries were conducted as part of a three-year multidisciplinary study, the Rideau River Biodiversity Project (RRBP), involving the Canadian Museum of Nature, the Rideau Valley Conservation Authority, and the University of Ottawa.

During the summer of 1998, between mid-July through mid-September, a total of 14 sites were sampled between Downtown Ottawa at Rideau Falls and Smiths Falls (Table 1). Each site spanned approximately 500 m of shoreline and was selected based on land-use in the adjoining areas, accessibility, and suitability for the sampling gear. The distance between sites was at least 500 m. Qualitative and quantitative data were collected on habitat characteristics such as water depth, water temperature, bank height, water clarity, substrate type, and the abundance and diversity of aquatic and riparian vegetation according to the methodologies suggested by Gorman and Karr (1978), Meador *et al.* (1993), and Simonson *et al.* (1994). The substrate was classified according to Meador *et al.* (1993) (Table 2). The plant species were identified using Newmaster *et al.* (1997) and grouped as in Table 3.

Five sites were sampled in the urban area between Rideau Falls and Mooney's Bay, Ottawa. Five agricultural sites and four forested sites were sampled between Mooney's Bay and Merrickville (Fig. 2). At each site, a trap net and two sizes of hoop/fyke nets were set perpendicular to the current for 24 hours [a] .Two 30m boat seines[b] and 1200 seconds of DC backpack electrofishing[c] were also used to capture fish at each site. A variety of sampling equipment was used at each site to ensure that all sizes of fish were captured. Since each gear type has a bias towards a certain size of fish, using a variety of gear types reduces the sampling bias (Hinch *et al.* 1991). Trapnets tend to catch the large-bodied sportfish and suckers. Seining catches small-bodied fish such as juveniles and minnows. Electrofishing catches fish that hide under rocks or inhabit weedy or rocky areas that are difficult to sample with other methods.

All fish were identified to species using Scott and Crossman (1973), McAllister and Coad (1974), Bernatchez and Giroux (1991), and Coad's (2000) unpublished key. Fork and total length (mm), as well as weight (g), were measured, if appropriate, on each captured fish. The general health of each fish and the presence of morphological abnormalities or parasites were also recorded. Fishes were released at the same location they were captured immediately after recording data. All captured fishes were released, except for a representative sample of smallmouth bass, *Micropterus dolomieu*, found to exhibit morphological deformities and outwardly normal specimens of smallmouth bass for comparative purposes. A sample of black crappie, *Pomoxis nigromaculatus*, to be used in a growth study, as well as any fish that could not be identified in the field were also kept. Unreleased fishes were deposited in the Canadian Museum of Nature, Ottawa [Accession no. 1999-4].

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[a] Trapnet: 1.83 m^3 box, a multifilament stretched mesh size of 6.4 cm, and a 25 m x 1.83 m lead.
Small hoop/fyke net: 9.1m x 0.9 m lead, mesh size 6mm, and rings 76 cm in diameter.
Large hoop/fyke net: 1.20 m^3 box, a multifilament stretched mesh size of 6.4 cm, and a 15 m x 1.20 m lead.
[b] Boat seine: 30m long with a bag operated from a boat and weighed down by chains to prevent rolling, stretch mesh size 6 mm.
[c] Smith-Root DC backpack electrofisher.

During the last two weeks of July 1999, three tributaries of the Rideau River were sampled: the Jock River, Kemptville Creek, and Steven Creek. These tributaries were chosen because they are the largest tributaries of the Rideau River, ensuring sufficient depth for the sampling gear. Also, they flow through both agricultural and forested land-use types and the confluences of these tributaries are distributed along the length of the Rideau River between downtown Ottawa at Rideau Falls and Merrickville. Three sites were sampled along each tributary: At the confluence of the tributary and the Rideau River, as close to the source of the tributary as could be navigated, and approximately mid-way between these two sites (Fig. 2). Each site spanned approximately 500 m of shoreline and was selected based on land use in the adjoining areas, accessibility, and suitability for the sampling gear. The distance between sites was at least 500 m. The habitat was described at each site using the same method as for the Rideau River. The fishing gear used at each site included a 10-m seine net, 1200 seconds of DC-electrofishing and eight unbaited minnow traps.

Past fish communities were re-constructed from scientific literature, museum archives from the Canadian Museum of Nature, Ottawa, and the Royal Ontario Museum, Toronto, newspaper articles, historical atlases, municipal reports, and anecdotal reports. Data from the Ontario Ministry of Natural Resources Fish Species Distribution Data System (FSDDS), a province-wide database with records of capture for the Rideau River spanning 1914-1987, are also included. Data from all of these sources were pooled together and used to describe the fish community over time. Scientific literature formed the basis of the early records between 1883 and 1983. Newspaper articles were helpful in determining stocked species and dates in the 1940s and 1950s. Municipal reports were the predominant source of information from the 1980s and 1990s within the Regional Municipality of Ottawa-Carleton (RMOC) and the City of Gloucester. Additional information was obtained from anecdotal reports from members of the Ottawa branch of Muskies Canada. The anecdotal reports demonstrate the importance of involving the public in this type of scientific inquiry. These reports were substantiated using museum records.

1.3. Results

The Rideau River Biodiversity Project survey forms the most comprehensive study of the fish community to date. Prior studies were limited to portions of the river or focused on sportfish species. This whole river, entire community approach ensured that the resulting catch was representative of the Rideau River fish community. As a result of this survey, in 1998, 6904 fish from 30 species representing 10 families were captured along the length of the Rideau River between Smiths Falls and Ottawa (Table 4; Appendix 1, Appendix 7). Two captures were first records for the Rideau River: A freshwater drum, *Aplodinotus grunniens,* (Phelps *et al.* 2000a), and a tadpole madtom, *Noturus gyrinus* (Phelps *et al.* 2000b).

According to literature records and technical reports, (Small 1883; Prince *et al.* 1906; Halkett 1906, 1908; Dymond 1939; McAllister and Coad 1974; Coad 1983, 1987; City of Gloucester 1991*, 1992* and RMOC 1995a*, 1995b*, 1996a*, 1996b*, 1998*), as well as unpublished sources (FSDDS database, Ontario Ministry of Natural Resources), 56 fish species (including the introduced brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss,* and common carp *Cyprinus carpio*) belonging to 19 families have been reported in the Rideau River and Canal (Appendix 2). The first record of a tadpole madtom (Phelps *et al.* 2000b), considered along with the first record of a freshwater drum (Phelps *et al.* 2000a), and that of the exotic oscar, *Astronotus ocellatus* (Renaud and Phelps 1999), recently captured within the Rideau River, increased the total number of fish species reported in the Rideau River and Canal to 59 species belonging to 20 families. For comparison, 64 species representing 21 families of fish have been reported for the Ottawa River (Dymond 1939, McAllister and Coad 1974, Coad 1987).

Twenty-eight of the 58 species of fish known to have resided in the Rideau River / Canal over the past 120 years, were not captured during the 1998 sampling season (Table 4). These "missing" fish initiated the 1999 sampling season in three major tributaries to the Rideau River: Kemptville Creek, Jock River and Steven Creek. As a result of this survey, 2099 fish were captured representing 26 species from 9 families (Table 5, Appendix 3). In Kemptville Creek, 748 fish were captured representing 22 species. In the Jock River, 1097 fish representing 17 species were captured. In Steven Creek, 254 fish representing 18 species were captured. Three species of fish were captured in the tributaries to the Rideau River that were not captured in the River proper during 1998. These were the central mudminnow, *Umbra limi*, captured in Kemptville Creek and Steven Creek, the rosyface shiner, *Notropis rubellus*, captured in all three tributaries, and the mimic shiner, *Notropis volucellus*, captured in the Jock River only.

Figures 3 and 4 summarize all known documented records (published and unpublished) of capture within the Rideau River and Canal between Smiths Falls and Ottawa. The dark squares represent all known records of capture for a given year. This means that a dark square may represent one specimen or hundreds. The lack of a dark square does not necessarily mean that the fish were not present; there may not have been sampling conducted at that time. For example, during the 1940s no sampling was conducted due to World War II. Figure 3 shows all known literature records of capture for the lamprey family, Petromyzontidae, the gar family, Lepisosteidae, the freshwater eel family, Anguillidae, the herring family, Clupeidae, the salmon and trout family, Salmonidae, the pike family, Esocidae, the mudminnow family, Umbridae, and the minnow family, Cyprinidae, in the Rideau River / Canal.

Alewife *Alosa pseudoharengus*, silver lamprey *Ichthyomyzon unicuspis*, longnose gar *Lepisosteus osseus*, burbot *Lota lota*, and American eel *Anguilla rostrata* are medium to large-bodied fish that were captured infrequently within the Rideau River and are thought to be transient species. These hearty fish are able to travel large distances and tolerate a variety of environmental conditions enabling them to survive the warm polluted waters of the locks. Transient species were only captured occasionally because they had not established reproducing populations in the Rideau River. These species may have entered the Rideau River through the locks at either the Ottawa River or the St. Lawrence River. In the case of the parasitic silver lamprey, it likely entered the Rideau attached to a host fish. The alewife was first reported to be in the Rideau Canal at Hogs Back in 1983 (Coad 1983) and has been captured with increased regularity since this time (Coad 1987, City of Gloucester 1992, and RMOC 1996a,b).

Rainbow trout *Oncorhynchus mykiss,* and brown trout *Salmo trutta*, were released into the Rideau River during the 1937 Ottawa Exhibition (Ottawa Citizen 1937). These fish no longer reside in the Rideau River due to angling pressure and unsuitable habitat characteristics. Rainbow trout prefer cooler water below 21°C, brown trout prefer water below 24°C, and both species prefer a gravel or boulder substrate (Scott and Crossman 1973).

Muskellunge, *Esox masquinongy,* are shown to have resided in the Rideau River since 1880 and were restocked during the 1940s and 1960s. Muskies Canada has closely monitored muskellunge in the Rideau River since 1990 (H. Wachelka: personal communication). An analysis of the trends within the muskie population is yet to be completed by Muskies Canada. Northern pike *Esox lucius,* were stocked in the Rideau River during the early 1940s and have been present in the Rideau River ever since.

There are documented records of central mudminnow, *Umbra limi*, inhabiting the Rideau River during the 1880s. They were sporadically captured between the 1940s and the 1980s. No specimens have been reported since 1983, although, several were captured in the tributaries to the Rideau River, Kemptville Creek and Steven Creek during the 1999 sampling season. This fish is usually found in lakes, streams and bogs (McAllister and Coad 1974).

Common shiner, *Luxilus cornutus*, golden shiner, *Notemigonus crysoleucas*, and spottail shiner, *Notropis hudsonius* have been captured in the Rideau River since the 1940s. Emerald shiner, *Notropis atherinoides*, blackchin shiner, *Notropis heterodon*, and blacknose shiner, *Notropis heterolepis* have been captured since the 1960s. These species are ideally suited to the Rideau River since they prefer habitats with some vegetation, clear water, still to medium current, and sandy, silty substrate (Scott and Crossman 1973, McAllister and Coad 1974). Common carp have thrived in the Rideau River since they were first reported during the late 1950s.

Several dace and minnow species have gone undetected in the Rideau River for several years. Longnose dace was last captured in 1995 by the Regional Municipality of Ottawa Carleton (RMOC). Pearl dace, *Margariscus margarita*, finescale dace, *Phoxinus neogaeus*, and northern redbelly dace, *Phoxinus eos* have not been identified in the Rideau River since 1974 (Coad 1987). Dace species are usually found in small clear steams with moderately flowing water (McAllister and Coad 1974). Rosyface shiners, *Notropis rubellus*, have not been captured in the Rideau River since 1983, although they were captured in all three tributaries sampled during the 1999 sampling season. A mimic shiner, *Notropis volucellus*, was captured in the Rideau River in 1992 by the City of Gloucester and in 1996 by RMOC, and it was captured in the Jock River during the 1999 sampling season. Creek chub, *Semotilus atromaculatus*, fathead minnow, *Pimephales promelas*, and brassy minnow, *Hybognathus hankinsoni* have not been captured in the Rideau River since 1992. These fish are also usually attributed to small streams. There is one record of a sand shiner, *Notropis stramineus* being captured in the Rideau River by the OMNR in 1968. This species is usually found in sandy-bottomed streams or along sandy beaches in lakes, which does not make the Rideau River an ideal habitat (McAllister and Coad 1974).

Figure 4 illustrates the presence of the sucker family, Catostomidae, the bullhead catfishes, Ictaluridae, the trout-perch family, Percopsidae, the codfishes, Gadidae, the killifish family, Fundulidae, the silversides, Atherinidae, the sticklebacks, Gasterosteidae, the sculpin family, Cottidae, the sunfish family, Centrarchidae, the perch family, Percidae, and the drum family, Sciaenidae, within the Rideau River.

The catostomids seem to thrive in the Rideau River. White sucker, *Catostomus commersoni*, silver redhorse, *Moxostoma anisurum*, and shorthead redhorse, *Moxostoma macrolepidotum* have been captured regularly since the 1940s. These large fish prefer large streams and rivers with slow current and sandy substrate (Scott and Crosssman 1973). White suckers are also tolerant of turbid water (Portt *et al.* 1999). The greater redhorse, *Moxostoma valenciennesi* has been less regularly captured since the late 1950s. This fish is sensitive to habitat disturbance and turbidity (Portt *et al.* 1999).

The ictalurids have had a less predictable history. A tadpole madtom, *Noturus gyrinus*, the smallest member of the family Ictaluridae in Canada, was captured for the first time in the Rideau River during the 1998 sampling season. This fish was captured halfway between Burritts Rapids and Becketts Landing (45° 00' 40''N, 75° 44' 40''W). It was likely that this fish migrated into the Rideau River from Kemptville Creek, a tributary of the Rideau River located 10 km downstream from its site of capture, a significant distance for a small sedentary fish with a limited home range (Phelps *et al.* 2000b). Specimens of the channel catfish, *Ictalurus punctatus* were captured in 1992 (City of Gloucester), 1994 and 1996 (RMOC 1995b, 1996b). It is likely that the channel catfish is a transient species because this fish was infrequently captured and it is a hardy fish that is able to swim great distances (Scott and Crossman 1973).

There are only two documented records of capture for the stonecat, *Noturus flavus*, in the Rideau River, an OMNR capture in 1965 (FSDDS) and McAllister and Coad (1974). This elusive fish lives under rocks in the riffle areas of fast flowing streams, making it very difficult to capture and restricting this fish to only a few localities within the Rideau River (McAllister and Coad 1974). Possible riffle areas where it might still occur include the western side of Long Island, downtown Ottawa between the Bronson and Bank St. bridges, or below the 417/Queensway bridge, downtown Ottawa.

Yellow bullhead, *Ameiurus natalis* have not been reported in the Rideau River since late 1974. This might be because of the difficulty in distinguishing this fish from the brown bullhead. The yellow bullhead may in fact be more common than the data indicate. The brown bullhead can be distinguished from the yellow bullhead by the presence of dark chin barbels, serrated pectoral spines and 19-23 anal fin rays. The yellow bullhead has white barbels, smooth pectoral spines and 24-26 anal fin rays (Scott and Crossman 1973, McAllister and Coad 1974).

Sunfish, Centrarchidae, are extremely abundant within the Rideau River / Canal system. Sunfish, except for bass species, are omnivorous, habitat generalists that are able to tolerate a wide variety of environmental conditions and are known to thrive in degraded areas (Tonn and Magnuson 1982, Karr 1981, Lyons *et al.* 1996). All six species of Centrarchidae reported in the Rideau River have been present since the 1940s, with documented records of largemouth bass and smallmouth bass residing in the river since the 1880s. Largemouth bass, *Micropterus salmoides* and smallmouth bass, *Micropterus dolomieu*, were stocked in the Rideau River, predominantly Upper Rideau Lake, during the 1940s until the early 1970s to improve the quality of angling in the Rideau River (Ken Harris, personal communication).

Members of the Percidae have also resided in the Rideau River since the early 1900s. Walleye, *Stizostedion vitreum*, are native to the Rideau River, although they were regularly stocked during the 1940s due to angling pressure (Ottawa Citizen, June 18, 1947). Sauger, *Stizostedion canadense*, are not common within the Rideau River. This fish may be a transient species as sauger prefer deep, dark, flowing waters of the Ottawa River or the St. Lawrence. The tesselated darter, *Etheostoma olmstedi*, is the most abundant darter in the Rideau River and it has been captured frequently since the late 1950s. They are most commonly found in large rivers. The Iowa darter, *Etheostoma exile* has been sporadically captured in the Rideau River, it was last captured in 1995. This fish prefers bays in rivers and small lakes with still water and a sand or mud bottom (Scott and Crossman 1973, McAllister and Coad 1974). Literature records show that the johnny darter, *Etheostoma nigrum* was captured in the Rideau River in 1939, but then went undetected until 1991 and has since been captured regularly. . Logperch, *Percina caprodes* and yellow perch, *Perca flavescens* have been regularly captured in the Rideau River, since the 1880's and 1900's respectively.

A freshwater drum, *Aplodinotus grunniens*, was captured in the Rideau River during the 1998 sampling season, between the Bank Street and Bronson Street bridges, Ottawa, Ontario, (45° 23' 12''N, 75° 41' 09''W). This is the first reported capture of a freshwater drum within the Rideau River (Phelps *et al.* 2000a). This fish species is the only freshwater representative of the Sciaenidae in North America (Barney 1926; Robins *et al.* 1991). The freshwater drum is likely a transient species as it may have entered the Rideau River through the locks from either the Ottawa River or the St.Lawrence River.

The trout-perch, *Percopsis omiscomaycus,* has gone undetected within the Rideau River for at least 10 years. The habitat preferences for this fish are the deeper portions of lakes, making the Rideau River a marginal habitat for this species (McAllister and Coad 1974). Mottled sculpin, *Cottus bairdi,* was first reported in the Rideau River in the 1900s. There were no further documented captures of this fish until the 1960s, when it was captured regularly until the 1980s. After the 1980s, this fish disappeared from the Rideau River literature again until the 1990s. The mottled sculpin is an uncommon, elusive fish that is difficult to capture because it hides under rocks, which requires diligent sampling. It is likely that this fish was not reported within the Rideau River literature because sampling techniques more suitable for capturing sportfish were used at the time.

Brook silversides, *Labidesthes sicculus,* have been captured regularly in the Rideau River since the 1930s and banded killifish, *Fundulus diaphanous,* have been documented since the 1960s. Brook stickleback, *Culaea inconstans,* have been sporadically captured in the Rideau River since the late 1950s. These fish are known to prefer small slow streams (McAllister and Coad 1974).

1.4. Discussion

It is only possible to guess at the composition of the pre-canal (1826-1832) fish community, as our earliest documented records begin more than fifty years after its construction. During the late 1800's, fisheries statistics were reported by county and not by waterbody. This, combined with the reporting method of number of barrels or pounds of sportfish removed from the region, not waterbody, make it difficult to reconstruct the fish community with any degree of detail. The fish reported to reside in the Rideau River during this era include muskellunge, walleye, bass, carp, suckers and catfish. Although it is difficult to quantitatively describe the fish community, it is known that extremely high fishing pressure was negatively impacting the fish community. During 1899, the state of the Rideau River fish community was described by the Ontario Fisheries Branch as "…fair, but nothing like it was a few years earlier" (Dymond 1939). This resulted in the prohibition of the sale and export of all sportfish from 1900 until 1903.

As the city of Ottawa grew, the Rideau River became more polluted as residents discharged their wastes directly into the river. A letter written to the editor of the Ottawa Citizen described the level of pollution in the Rideau River as "deplorable" (Ottawa Citizen, May 29, 1918). Non-native rainbow trout and brown trout were released into the Rideau River at the 1937 Ottawa Exhibition. Again in 1941, 3600 brown trout fingerlings were released into the river (Ottawa Citizen 1941). Newspaper articles from the 1940s and 1950s detailed the extensive restocking that occurred along the length of the Rideau River in order to improve the quality of sportfishing in the region. Walleye eggs, muskellunge fry, as well as adult and fingerling smallmouth and largemouth bass were stocked in the Rideau and Jock Rivers annually during the 1940s (Ottawa Citizen, September 10, 1941; March 15, 1945; June 18, 1947; 1955). Norman Patrick stated in a newspaper article from 1955 (Ottawa Citizen) that the Rideau River "has been planted with every species of fish ever raised in provincial hatcheries, a situation verging on the ridiculous". The general belief at the time was that the fish stocks were decreasing solely due to angling pressure, which could be remediated by restocking. The impacts of pollution and siltation were not considered.

During the 1960s and 1970s, increased economic activity led to rapid population growth and increased development along the Rideau River. Increased harbour construction and waterway modification were undertaken along the Great Lakes to improve seaway transport. This development affected the Rideau River fish community through the introduction of exotic species. During the 1980s and 1990s, urban populations stabilized and rural communities declined. These changes, in addition to an increase in environmental awareness have resulted in improved water quality (Kelso *et al.* 1996).

At first glance, it appears that the diversity of fish species within the Rideau River has decreased over the past 120 years, as 28 of the 58 species ever captured in the river were not captured during the 1998 sampling season (Table 4). However, several of the 28 "missing species" may not be truly missing from the Rideau River because they may be transient species from the Ottawa River or St. Lawrence River that never developed reproducing populations in the Rideau River. Of these 28 missing species, seven could be designated as transient species including alewife, channel catfish, silver lamprey, longnose gar, burbot, American eel, and sauger.

Two other missing species of fish, the rainbow trout and brown trout, were released into the Rideau River in 1937 at the Ottawa Exhibition and became extirpated from the Rideau River shortly after. These fish were not be able to reproduce in the Rideau River due to angling pressure and sub-optimal habitat characteristics.

Of the 19 remaining "missing species", rosyface shiners, longnose dace, johnny darter and stonecats prefer faster flowing water and are more commonly found in the riffle areas of small streams. The Rideau River is generally a slow moving and densely vegetated river, which is not an ideal habitat for these fishes. It is not surprising then, that these species have not been regularly or recently captured within the Rideau River. During the 1999 sampling season, rosyface shiners were captured in the Jock River, Steven Creek and Kemptville Creek, tributaries to the Rideau River. Several other missing species are more suited to slow quiet streams or lakes rather than rivers. These fishes include the central mudminnow, northern redbelly dace, finescale dace, brassy minnow, sand shiner, fathead minnow, creek chub, trout-perch and brook stickleback. The elimination of species with habitat preferences different from those found in the Rideau River decrease the number of "missing species" to six: the eastern silvery minnow, pearl dace, mimic shiner, yellow bullhead, shorthead redhorse and Iowa darter.

Eastern silvery minnows were captured in the Rideau River between 1957 and 1995. This fish is known to inhabit vegetated streams and large rivers where the current is slow to medium with varied substrate types (Lane *et al.* 1996a, McAllister and Coad 1974). Eastern silvery minnows spawn in vegetation over silt and clay (Lane *et al.* 1996b). Their YOY inhabit these same areas. It seems that this fish species would be ideally suited to the Rideau River environment. There are several possible reasons why this species is no longer captured in the Rideau River. McAllister and Coad (1974) suggested that eastern silvery minnows are sensitive to turbidity and siltation, although Portt *et al.* (1999) listed the sensitivity of this species as unknown. Urban and agricultural development or fluctuating water levels may have increased the turbidity of the water above levels the minnow could tolerate. Eastern silvery minnows have unique spawning habits; these spring-spawning fish have non-adhesive eggs that are released directly onto the bottom amid vegetation. Minnows more commonly release adhesive eggs onto algae or vegetation. Eastern silvery minnow eggs may be more susceptible to the spring water level fluctuations or predation by exotics such as common carp that nose along the bottom substrate of the shoreline. It is also possible that mis-identification in the field underestimated the abundance of this species.

Both the pearl dace and the mimic shiner prefer medium-sized streams, but have been known to inhabit rivers (McAllister and Coad 1974). These species prefer areas with little current and a moderate amount of vegetation (Lane 1996a). There are only two documented records of capture of the pearl dace in the Rideau River, during 1960 and 1974 and only two documented records of the mimic shiner, during 1992 and 1996. It is possible that these fish strayed into the Rideau River from the tributaries. During the 1999 sampling season, mimic shiners were captured in the Jock River. It is also possible that mis-identification has led to an underestimation of the abundance of these species.

There are two documented records of capture for the yellow bullhead, during 1957 and 1974. These turbidity tolerant fish are known to inhabit the shallow vegetated backwaters of lakes and rivers in areas with boulder, gravel, silt, or clay substrate. As only two records of capture exist for each of these three species, it is unlikely that they have established reproducing populations in the Rideau River. These specimens may have strayed into the Rideau River from the tributaries. They may also have been transferred as a result of anglers using live bait, or dumping live wells.

The shorthead redhorse has not been captured in the Rideau River since 1996. The first documented record of capture of this species was in 1939. After this, there was nothing documented until the 1960s when several specimens were collected. The next record of capture was not until 1985. Since this time, specimens have been captured in 1992, 1995, and finally 1996. These fish are known to live in the pools and runs of rivers with rubble and gravel substrate and spawn in shallow riffles over rubble and gravel (Lane 1996a, c, Portt *et* *al*. 1999, McAllister and Coad 1974). The Rideau River may not flow fast enough for optimal spawning, which might explain why so few adults, juveniles, or YOY were captured in the Rideau River. Other impacts such as urban and agricultural development, fluctuating water levels, the introduction of exotic species, and interactions with predatory fish species may have limited the populations of this species. The mis-identification of redhorse species in the field by may also have underestimated the abundance of this species.

Lastly, the Iowa darter has not been captured in the Rideau River since 1995. The first record of capture was in 1959. Since this time, specimens have been captured in 1968, 1974, and 1985. These fish are known to prefer bays with little current in rivers with gravel and sand substrate (McAllister and Coad 1974). They spawn in areas with gravel and sand substrate amongst vegetation and algae (Lane 1996b). Iowa darters are intolerant to turbidity (Portt 1999). Development, fluctuating water levels, the introduction of exotic species, and interactions with predatory fish species may influence the populations of this species. Mis-identification in the field may also contribute to an underestimation of species number.

When the number of fish species captured in the Rideau River was compared among years, the diversity of fish species in the Rideau River was shown to increase. Records of fifteen species captured in the Rideau River between 1880-1920 were mostly sportfish. Common shiners were the only minnow documented in the literature at this time, since it was a commonly used baitfish. Between 1920 and 1940, 32 species of Rideau River fish were documented in the literature. Dymond (1939) wrote the first comprehensive review of the fishes of the Ottawa region, including fish species other than sportfish. Between 1960-1980, 46 species were identified and between 1980-1998, 48 species were identified. The large increase in the number of species captured between the 1940's and the 1960's was partly due to more frequent sampling efforts and a shift from the reporting of sport fish species to the reporting of the entire fish community. However, anthropogenic factors also played a role: The introduction of exotics, increased boat traffic, fish stocking, transient species, baitfish introductions, and live-well dumping have all contributed to the diversity of fish captured in the Rideau River. Many of these introduced species have not established stable populations, which are demonstrated by sporadic records of capture over the years. It is not known whether these introductions will adversely affect the native fish fauna of the Rideau River through the competition for resources, predation, or the introduction of disease. Nevertheless, native fish species with established populations and habitat preferences that coincide with the habitat characteristics of the Rideau River have been consistently captured over the years. With further sampling every few years using a variety of gear types, the status of the native fish species may be monitored and the development of any newly establishing reproducing species may be identified.

Several aspects of the Rideau River fish community have remained unchanged over the past 120 years, in contrast to the long-term changes that occurred in the Great Lakes (Kelso *et al.* 1996). In the Great Lakes there was a shift from the dominance of large long-lived species to short-lived species; from fish populations with constant size and age structure to fluctuating populations; from species that were associated with diverse shorelines to species that are associated with less-structured open water environments; and from fish species preferred by humans as food to those that were not. The Rideau River fish community has not undergone a shift from the dominance of long-lived species to short-lived species, nor a shift from fish species preferred by humans as food to those that are not. The Rideau River fish community has continued to be dominated by sunfish species. The long-lived fish species such as muskellunge and bass continue to inhabit the Rideau River as shown by the regular records of capture described in the literature. Also, a shift from species that were associated with diverse shorelines to species that were associated with less-structured, open water was not observed. Unlike a lake, the Rideau River does not have large expanses of open water or the fish species associated with them. It was not possible to determine if there was a long-term shift from fish populations with constant size and age structure to fluctuating population sizes because the historical data consisted of presence / absence information not abundance.

1.5. Conclusion

The Rideau River fish community has been reconstructed from 120 years of historical records in order to compare the similarities and differences between the current fish community and past accounts. The fish community has continued to be dominated by sunfish species and the long-lived fish species such as muskellunge and bass continue to inhabit the Rideau River as shown by the regular records of capture described in the literature. The differences seen in the fish community over the past 120 years are primarily due to increases in the number of species captured. This is a result of the introduction of transient and exotic species. For several species, there are no records of capture in the Rideau River for over five years. The Rideau River may not be an ideal habitat for these fish or anthropogenic disturbances such as water level fluctuations or excessive turbidity may make the Rideau River an unsuitable habitat for their survival.

Fig. 1:
Map of the Rideau River in eastern Ontario, Kingston to Ottawa. The dashed line indicates the divide between the Rideau and Cataraqui rivers, which together form the Rideau River Canal System.

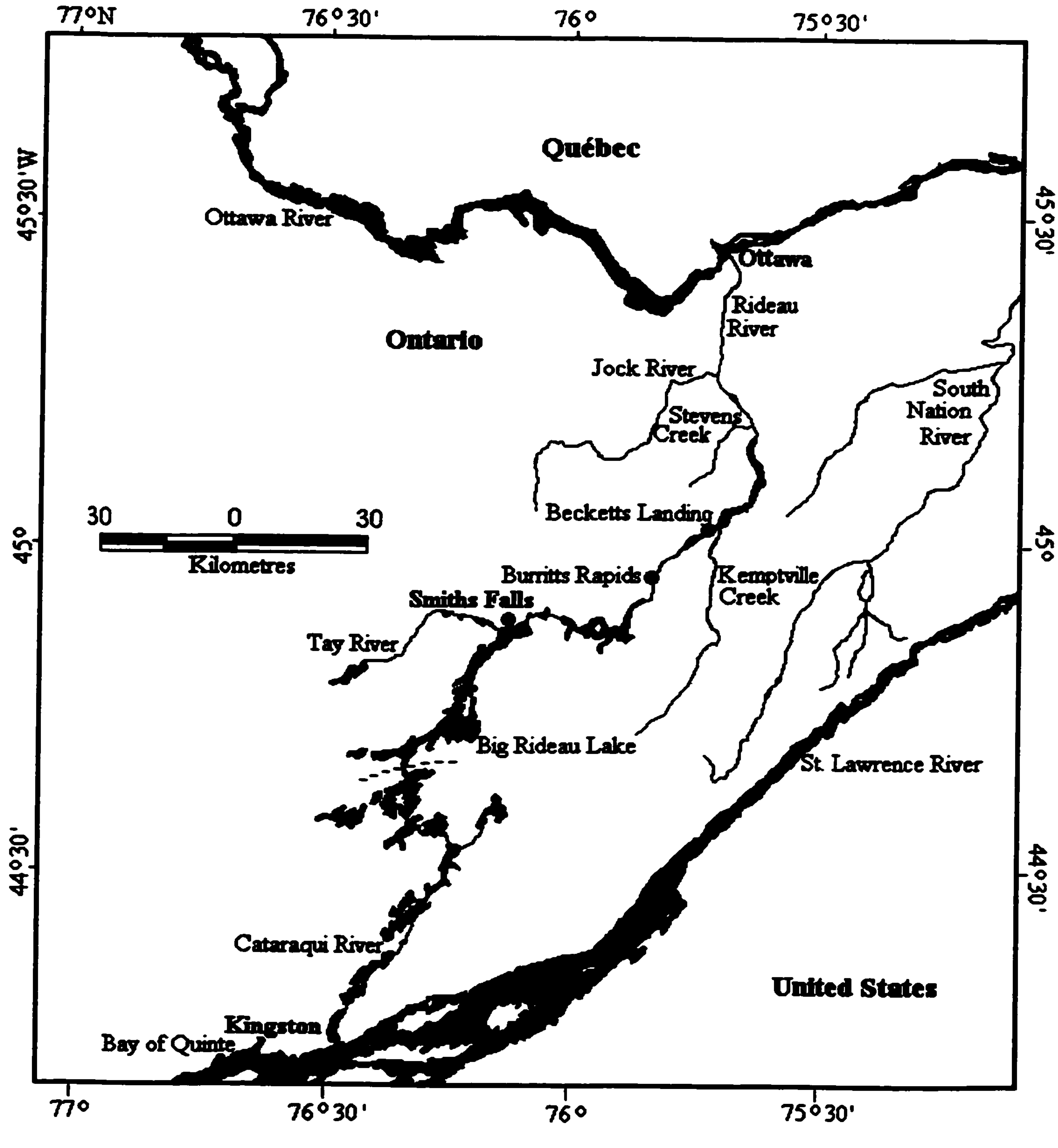

77°N
76°30'
76°
75°30'
45°30'W
45°
44°30'
45°30'
45°
44°30'
Québec
Ottawa River
Ottawa
Rideau River
Ontario
Jock River
Stevens Creek
South Nation River
Becketts Landing
30
0
30
Kilometres
Burritts Rapids
Kemptville Creek
Smiths Falls
Tay River
Big Rideau Lake
St. Lawrence River
Cataraqui River
United States
Kingston
Bay of Quinte
77°
76°30'
76°
75°30'

Fig. 2:
Map of the Rideau River, Smiths Falls to Ottawa. The white triangles indicate the sites along the Rideau River that were sampled during the 1998 sampling season. The black triangles indicate the sites that were sampled in the tributaries to the Rideau River during the 1999 sampling season.


30
0
30
Kilometres
Québec
Ottawa
Rideau
River
Ontario
Jock River
Stevens
Creek
Becketts Landing
Burritts Rapids
Smiths Falls
Kemptville
Creek

Fig. 3:
All known documented records (published and unpublished) of capture for the lamprey family, Petromyzontidae, the gar family, Lepisosteidae, the freshwater eel family, Anguillidae, the herring family, Clupeidae, the salmon and trout family, Salmonidae, the pike family, Esocidae, the mudminnow family, Umbridae, and the minnow family, Cyprinidae, captured in the Rideau River between Smiths Falls and Ottawa. The dark squares represent all known records of capture for a given year.

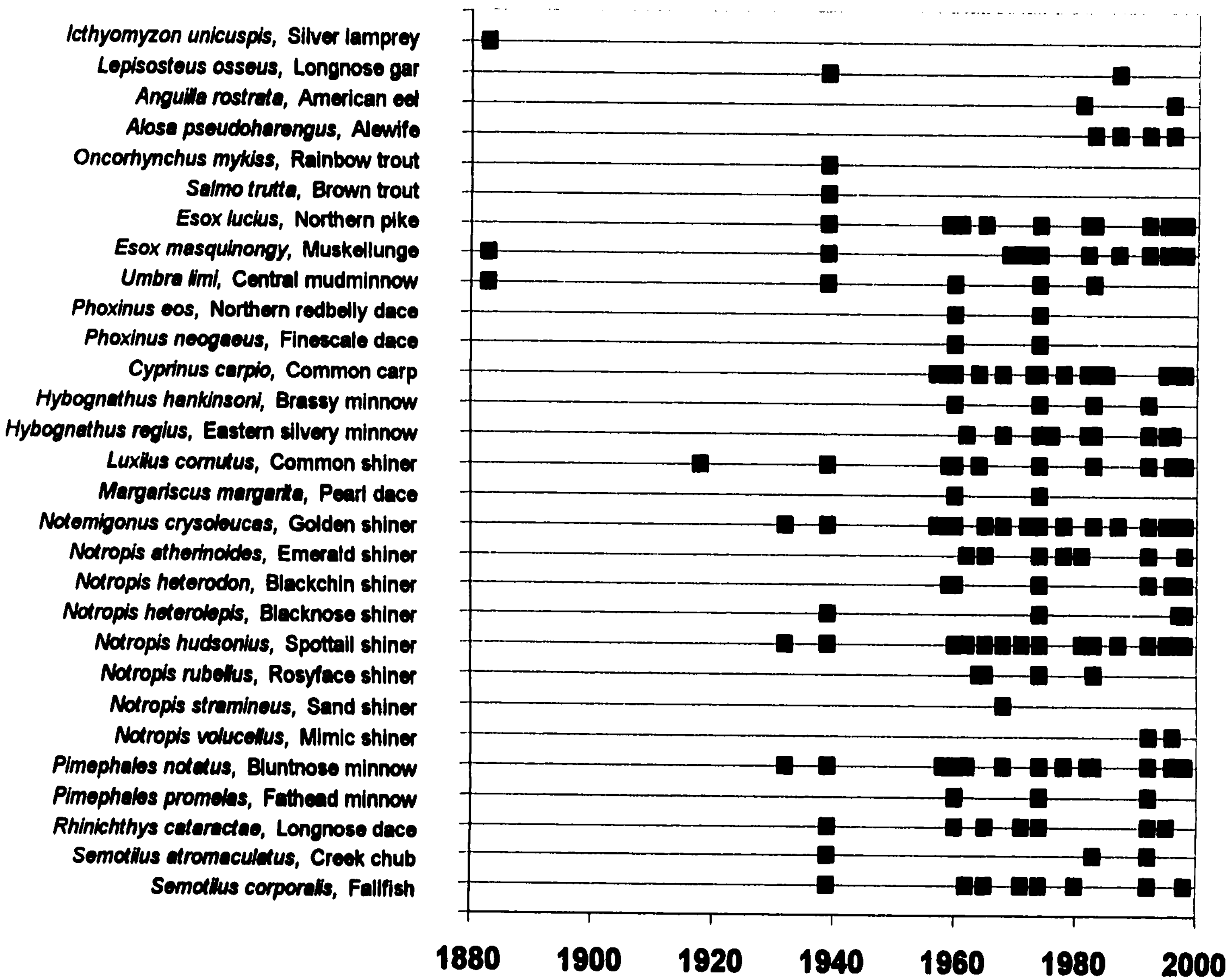

Icthyomyzon unicuspis, Silver lamprey
Lepisosteus osseus, Longnose gar
Anguilla rostrata, American eel
Alosa pseudoharengus, Alewife
Oncorhynchus mykiss, Rainbow trout
Salmo trutta, Brown trout
Esox lucius, Northern pike
Esox masquinongy, Muskellunge
Umbra limi, Central mudminnow
Phoxinus eos, Northern redbelly dace
Phoxinus neogaeus, Finescale dace
Cyprinus carpio, Common carp
Hybognathus hankinsoni, Brassy minnow
Hybognathus regius, Eastern silvery minnow
Luxilus cornutus, Common shiner
Margariscus margarita, Pearl dace
Notemigonus crysoleucas, Golden shiner
Notropis atherinoides, Emerald shiner
Notropis heterodon, Blackchin shiner
Notropis heterolepis, Blacknose shiner
Notropis hudsonius, Spottail shiner
Notropis rubellus, Rosyface shiner
Notropis stramineus, Sand shiner
Notropis volucellus, Mimic shiner
Pimephales notatus, Bluntnose minnow
Pimephales promelas, Fathead minnow
Rhinichthys cataractae, Longnose dace
Semotilus atromaculatus, Creek chub
Semotilus corporalis, Fallfish
1880
1900
1920
1940
1960
1980
2000

Fig. 4:
All known documented records (published and unpublished) of capture for the sucker family, Catostomidae, the bullhead catfishes, the Ictaluridae, the trout-perch family, Percopsidae, the codfishes, Gadidae, the killifish family, Fundulidae, the silversides, Atherinidae, the sticklebacks, Gasterosteidae, the sculpin family, Cottidae, the sunfish family, Centrarchidae, the perch family, Percidae, and the drum family, Sciaenidae, captured in the Rideau River between Smiths Falls and Ottawa. The dark squares represent all known records of capture for a given year.

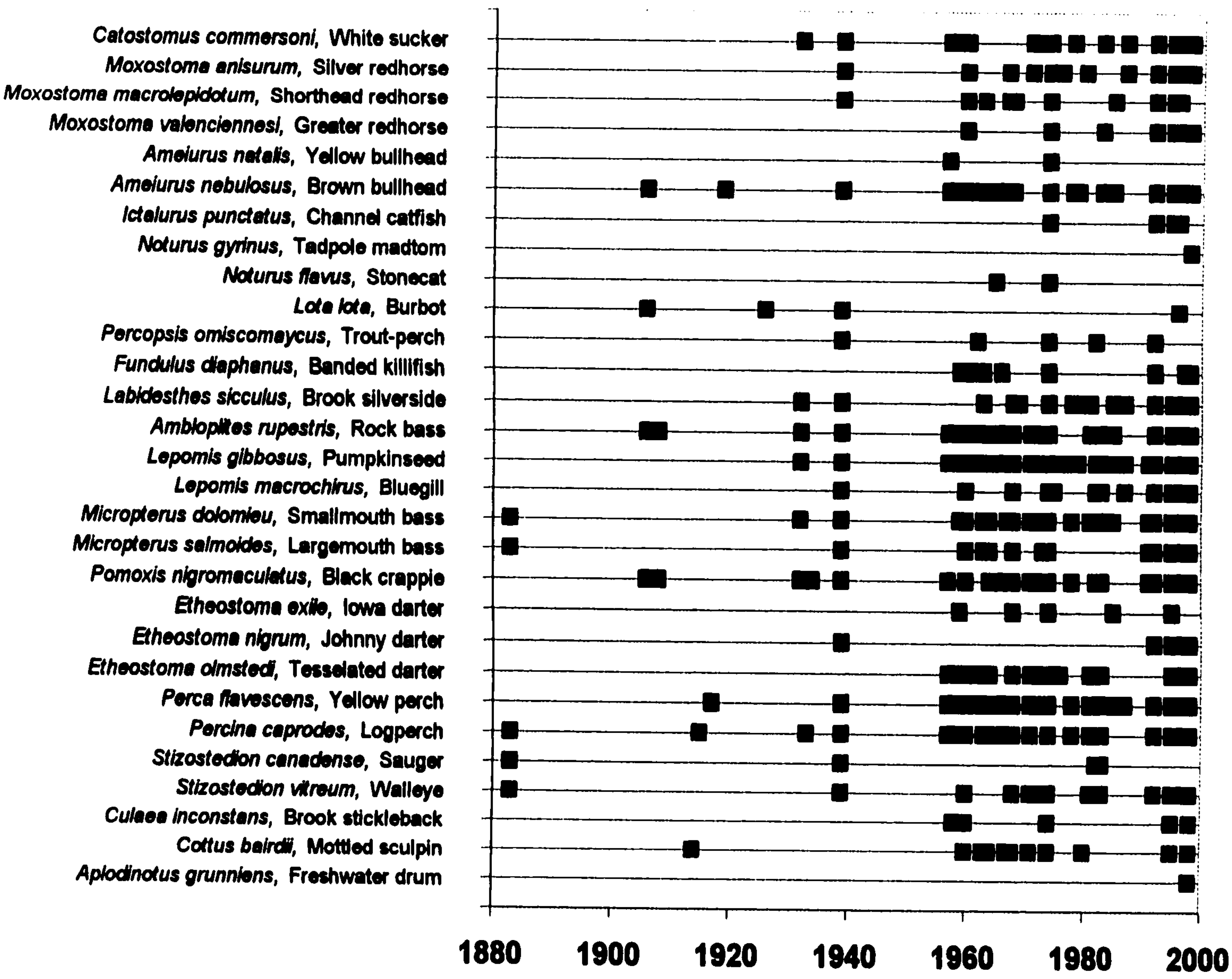

Catostomus commersoni, White sucker
Moxostoma anisurum, Silver redhorse
Moxostoma macrolepidotum, Shorthead redhorse
Moxostoma valenciennesi, Greater redhorse
Ameiurus natalis, Yellow bullhead
Ameiurus nebulosus, Brown bullhead
Ictalurus punctatus, Channel catfish
Noturus gyrinus, Tadpole madtom
Noturus flavus, Stonecat
Lota lota, Burbot
Percopsis omiscomaycus, Trout-perch
Fundulus diaphanus, Banded killifish
Labidesthes sicculus, Brook silverside
Ambloplites rupestris, Rock bass
Lepomis gibbosus, Pumpkinseed
Lepomis macrochirus, Bluegill
Micropterus dolomieu, Smallmouth bass
Micropterus salmoides, Largemouth bass
Pomoxis nigromaculatus, Black crappie
Etheostoma exile, Iowa darter
Etheostoma nigrum, Johnny darter
Etheostoma olmstedi, Tesselated darter
Perca flavescens, Yellow perch
Percina caprodes, Logperch
Stizostedion canadense, Sauger
Stizostedion vitreum, Walleye
Culaea inconstans, Brook stickleback
Cottus bairdii, Mottled sculpin
Aplodinotus grunniens, Freshwater drum
1880
1900
1920
1940
1960
1980
2000

Table 1.

Locations of sampling sites along the Rideau River sampled during 1998 and the locations of sampling sites located along the Jock River, Steven Creek and Kemptville Creek sampled during 1999. The N values are buoy numbers. Latitude and longitude were obtained from a hand-held GPS unit.

Site	Reach	Description	Landuse	Latitude (N)	Longitude (W)
1	Downtown	City Hall	urban	45° 26' 14"	75° 41' 34"
2	Downtown	South of St.Patricks St.Bridge	urban	45° 26' 16"	75° 41' 35"
3	Carleton U	West of Bank St.Bridge	urban	45° 23' 12"	75° 41' 09"
4	Carleton U	West of Bronson St.Bridge	urban	45° 23' 13"	75° 41' 04"
5	Mooneys Bay	Downstream of Blacks Rapids	urban	45° 19' 42"	75° 42' 01"
6	Eccolands	Rideau Glen, upstream of N44	agriculture	45° 18' 09"	75° 41' 51"
7	Rideau River Provincial Park	Across from Park	forested	45° 03' 14"	75° 40' 11"
8	Muldoon	N207, downstream from the Catchall	forested	45° 00' 58"	75° 43' 50"
9	Merrickville	N337, upstream from bird sanctuary	forested	44° 53' 47"	75° 52' 44"
10	Merrickville	N320, bird sanctuary	forested	44° 54' 43"	75° 52' 03"
11	Muldoon	N183, upstream of Libby Island	agriculture	45° 01' 30"	75° 42' 28"
12	Muldoon	N211, upstream from the Catchall	agriculture	45° 00' 36"	75° 44' 31"
13	Burritts Rapids	Upstream from N250	agriculture	44° 58' 20"	75° 49' 00"
14	Burritts Rapids	Upstream from Rideau Creek, N253	agriculture	44° 57' 35"	75° 44' 36"
JR1	Jock River	Confluence with Rideau	urban	45° 15' 40"	75° 42' 30"
JR2	Jock River	Bow of Jock Park	agriculture	45° 15' 15"	75° 48' 30"
JR3	Jock River	Richmond	cottages	45° 11' 15"	75° 49' 50"
SC1	Steven Creek	Confluence with Rideau	urban	45° 08' 50"	75° 38' 40"
SC2	Steven Creek	North Gower	urban	45° 07' 45"	75° 42' 45"
SC3	Steven Creek	At Hwy 4	agriculture	45° 08' 20"	75° 44' 10"
KC1	Kemptville Creek	Confluence with Rideau	cottages	45° 03' 20"	75° 39' 15"
KC2	Kemptville Creek	Halfway between Kemptville and confluence	urban	45° 02' 45"	75° 39' 15"
KC3	Kemptville Creek	Kemptville	urban	45° 01' 15"	75° 38' 30"

Table 2:
Substrate type classifications based on particle size. The descriptions were used to determine particle size in the field. Adapted from Meador *et al.* (1993).

Substrate Type	Description	Particle Size
Bedrock	continuous rock surface	
Boulder	round stones or slabs	>25 cm in length or diameter
Rubble	stones	5 cm - 25 cm diameter
Gravel	smaller stones	0.2 cm - 5 cm diameter
Sand	feels gritty when rubbed between fingers	0.05 mm - 2.0 mm diameter
Clay	feels smooth, greasy, or sticky	<0.05 mm diameter
Detritus	un-decomposed organic matter	
Large wood debris	tree stumps, logs, sticks	

Table 3:
Aquatic plants identified in the Rideau River, Jock River, Kemptville Creek, and Steven Creek. Vegetation was grouped by taxonomic family to facilitate the identification of aquatic plant species in the field. The common and scientific names are the plant species that are included in each grouping. Note that sedges and rushes are grouped together and that all species of algae are grouped together for this analysis although they are not in the same taxonomic family.

Grouping	Common Name	Scientific Name
Vallisneria	tape grass / wild celery	*Vallisneria americana*
Milfoil	milfoil	*Myriophyllum spp.*
Potamogeton	pondweed	*Potamogeton spp.*
Coontail	coontail	*Ceratophyllum demersum*
Elodea	common waterweed	*Elodea canadensis*
Lily	yellow pond lily	*Nuphar variegatum*
	white water lily	*Nymphaea odorata*
Cattail	common cattail	*Typha latifolia*
Arrowhead	broad-leafed arrowhead	*Sagittaria latifolia*
Rushes	rushes	*Juncus spp.*
	sedges	*Carex spp.*
Loosestrife	purple loosestrife	*Lythrum salicaire*
Algae	all species found within river	
Duckweed	duckweed, watermeal	*Lemna spp.*
		Spirodela spp.
		Wolffia spp.

Table 4:
List of fish species reported in the Rideau River and Canal according to literature records (technical reports and unpublished sources), since 1883. * Indicates species captured during the 1998 field season. [T] Indicates species that have not been captured in the Rideau River or Canal for at least ten years. Scientific names according to Robins *et al.* (1991).

Family	Scientific Name	Family	Scientific Name
Petromyzontidae	*Ichthyomyzon unicuspis*[T]	Catostomidae	*Catostomus commersoni* *
Lepisosteidae	*Lepisosteus osseus*[T]		*Moxostoma anisurum* *
Anguillidae	*Anguilla rostrata*		*Moxostoma macrolepidotum*
Clupeidae	*Alosa pseudoharengus*		*Moxostoma valenciennesi* *
Salmonidae	*Oncorhynchus mykiss*[T]	Ictaluridae	*Ameiurus natalis*[T]
	Salmo trutta[T]		*Ameiurus nebulosus* *
Esocidae	*Esox lucius* *		*Ictalurus punctatus*
	Esox masquinongy *		*Noturus gyrinus* *
Umbridae	*Umbra limi*[T]		*Noturus flavus*[T]
Cyprinidae	*Cyprinus carpio* *	Gadidae	*Lota lota*[T]
	Hybognathus hankinsoni	Percopsidae	*Percopsis omiscomaycus*
	Hybognathus regius	Cyprinodontidae	*Fundulus diaphanus* *
	Luxilus cornutus *	Atherinidae	*Labidesthes sicculus* *
	Margariscus margarita[T]	Gasterosteidae	*Culaea inconstans*
	Notemigonus crysoleucas *	Centrarchidae	*Ambloplites rupestris* *
	Notropis atherinoides *		*Lepomis gibbosus* *
	*Notropis heterodon**		*Lepomis macrochirus* *
	Notropis heterolepis *		*Micropterus dolomieu* *
	Notropis hudsonius *		*Micropterus salmoides* *
	Notropis rubellus[T]		*Pomoxis nigromaculatus* *
	Notropis stramineus[T]	Percidae	*Etheostoma exile*
	Notropis volucellus		*Etheostoma nigrum*
	Phoxinus eos[T]		*Etheostoma olmstedi* *
	Phoxinus neogaeus[T]		*Perca flavescens* *
	Pimephales notatus *		*Percina caprodes* *
	Pimephales promelas		*Stizostedion canadense*[T]
	Rhinichthys cataractae		*Stizostedion vitreum* *
	Semotilus atromaculatus	Sciaenidae	*Aplodinotus grunniens* *
	Semotilus corporalis *	Cottidae	*Cottus bairdi* *

Table 5:
List of fish species captured during the 1999 field season in the Jock River, Kemptville Creek and Stevens Creek. A ✔ indicates that the species is present. Scientific names according to Robins et al. 1991.

Family	Scientific Name	Jock River	Steven Creek	Kemptville Creek
Esocidae	*Esox lucius*	✔	✔	✔
	Esox masquinongy	✔		
Umbridae	*Umbra limi*		✔	✔
Cyprinidae	*Luxilus cornutus*	✔	✔	✔
	Notropis heterodon	✔		✔
	Notropis heterolepis		✔	✔
	Notropis hudsonius	✔		
	Notropis rubellus	✔	✔	✔
	Notropis volucellus	✔		
	Pimephales notatus	✔	✔	✔
	Semotilus corporalis			✔
Catostomidae	*Catostomus commersoni*		✔	✔
	Moxostoma anisurum			✔
Ictaluridae	*Ameiurus nebulosus*		✔	✔
	Noturus gyrinus		✔	✔
Cyprinodontidae	*Fundulus diaphanus*	✔	✔	✔
Atherinidae	*Labidesthes sicculus*	✔	✔	✔
Centrarchidae	*Ambloplites rupestris*	✔	✔	✔
	Lepomis gibbosus	✔	✔	✔
	Lepomis macrochirus	✔	✔	✔
	Micropterus dolomieu	✔	✔	✔
	Micropterus salmoides			✔
	Pomoxis nigromaculatus	✔	✔	✔
Percidae	*Etheostoma olmstedi*	✔	✔	
	Perca flavescens		✔	✔
	Percina caprodes	✔		✔

Chapter 2. Investigating the relationship between the Rideau River fish community and the aquatic habitat characteristics associated with land use.

2.1. Introduction

Threats to the biodiversity of North American freshwater fishes were described by Miller *et al.* in 1989 and coined "the sinister sextet" in 1991 by M. E. Soulé. These threats include habitat loss and degradation, the introduction of exotics, overexploitation, secondary extinctions (a loss of a species as a result of a loss of another species), chemical and organic pollution, and climate change (Allan and Flecker 1993). Recent ecological perturbations are the result of urbanization and agricultural development. In urban areas, construction of pavement reduces the permeability of the watershed, increasing surface run-off (Wang *et al.* 1997). During a rain event within the forested portions of the Rideau River watershed, trees take up 65% of the rainwater, 15% becomes surface water run-off, and 20% runs into the ground. In urban areas, surface water run-off increases to 45% (M. Trudeau, Regional Municipality of Ottawa Carleton, personal communication.). The removal of riparian vegetation results in increased shoreline erosion and suspended sediments (Lenat and Crawford 1994, Wang *et al.* 1997). In aquatic systems bordering agricultural areas, the application of fertilizers increases nutrient levels and the application of animal waste to land and the release of waste by livestock in the river increases nutrients and bacteria levels (Omernik *et al.* 1981, Osborne 1988). Other types of disturbances include dredging to maintain channel depth, removal of excess macrophyte growth, and ice blasting to prevent ice damage to the locks. These perturbations change the chemical and hydrological dynamics of the ecosystem as well as the diversity of the aquatic and shoreline vegetation. This ultimately results in the modification of invertebrate and fish communities (Benke 1979, Scott *et al.* 1986, Kingsbury 1987, Steedman 1988, Sly 1991, Garman 1991, Garman and Morring 1993, Weaver and Garman 1994, Wang *et al.* 1997)

Odum (1985) found that habitat degradation decreases species diversity, allowing communities to become dominated by a few species. This holds true for warm-water rivers: the number of species decreases as degradation increases. Warm-water systems have an average daily summer temperature above 24-26°C and are dominated by cyprinids, catostomids, ictalurids, centrarchids, and percids (Lyons *et al.* 1996). Cold-water rivers have an average daily summer temperature below 22°C and are dominated by salmonids and cottids. In cold-water rivers, moderate levels of degradation often result in increased species richness since increased water temperature allows warm-water families to colonize these areas (Lyons *et al.* 1996). The average daily summer temperature of the Rideau River is between 22-24°C (P. Hamilton, CMN, personal communication) and exhibits a range of warm and cold water fish species.

This investigation forms the fish component of a three-year Rideau River Biodiversity Project (RRBP) involving the Canadian Museum of Nature, the Rideau Valley Conservation Authority, and the University of Ottawa. The goal of the RRBP was to document the diversity and distribution of phytoplankton, aquatic plants, molluscs, fishes, amphibians, reptiles, and birds within the Rideau River. This documentation will allow for an evaluation of the river's ecological health, the river's ability to support and maintain a balanced, integrated, and adaptive ecosystem. It is only through extensive analyses such as the RRBP that the magnitude of such disturbances may be assessed, and recommendations for remediation can be made before permanent damage or loss of species and habitat result.

The Rideau River fish community has been extensively studied along several reaches of the Rideau River between 1995 and 2000. The Regional Municipality of Ottawa-Carleton (RMOC), Surface Water Quality Branch has played an important role in contributing to the existing Rideau River database. They have undertaken surveys of the Rideau River fish community since 1995 between downtown Ottawa and Long Island, Manotick. Their objectives were to determine potential nursery habitat along the Rideau River, document young-of-the-year (YOY) abundance and distribution, and yearly index-netting providing information on the adult sportfish population (RMOC 1999*). The RMOC dataset was used to reconstruct the recent history of the Rideau River fish community (Chapter 1).

The objective of this study was to examine the relationship between the relative abundance and diversity of the Rideau River fish community and the aquatic habitat characteristics that result from agricultural, forested, and urban land-use. This study differs from previous studies in that it was not restricted to a single reach of the river; the entire length of the river was sampled. Also, the fish community was sampled with a variety of gear types and the study was not restricted to sportfishes. This study aimed to answer the broader questions of: why fishes are where they are and what controls the structure of their community? The hypothesis of this study was as follows: Do land-use types influence adjoining aquatic habitat characteristics, thereby influencing the relative abundance and diversity of the fish community? Three predictions stemmed from this hypothesis: aquatic habitat characteristics differ between land-use types, aquatic habitat characteristics are correlated to the abundance and diversity of the fish community, and the diversity and abundance of the fish community differ between land-use types.

The relationship between the relative abundance and diversity of the Rideau River fish community and the aquatic habitat characteristics that result from land-use was addressed by first examining the relationship between land-use and the aquatic habitat characteristics. Next, the relationship between the aquatic habitat characteristics and the fish community was examined. Lastly, the relationship between land-use type and the fish community was examined (Fig. 5). If it was found that land-use type was correlated with habitat characteristics and the habitat characteristics were correlated with the fish community, the results support the hypothesis that adjoining land-use type influences the fish community. If land-use type was also correlated with the fish community, this lends additional support to the hypothesis that land-use type influences the fish community.

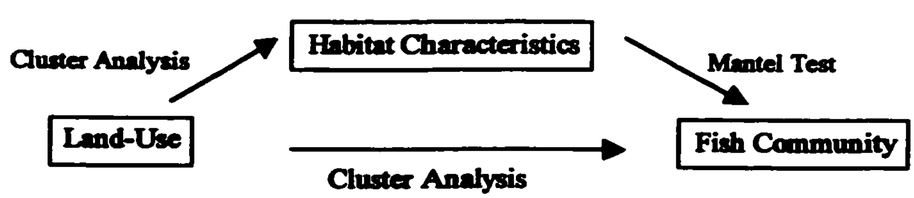


Fig. 5. A diagram describing the relationships between the factors considered in this analysis.

There are numerous reasons why fish are commonly used in studies of environmental degradation: Fish depend upon many components of the ecosystem for their survival and show deleterious effects when any of the factors upon which they depend are perturbed. For example, missing species are indicative of acute toxicity. Stunted growth and reduced reproductive success are indicative of stress (Karr 1981, Weaver *et al.* 1996). Fishes are also more sensitive to suspended sediment than invertebrate species (Stern and Stickle 1978). In addition, fish exhibit avoidance behavior, as they are highly motile and are able to select preferred habitat or flee when conditions are intolerable (Weaver *et al.* 1996). Many fish are relatively long-lived, providing long-term records and life history information is extensive for many species. Lastly, fish have economic and aesthetic importance and are easily identified (Karr 1981).

2.2. Review of Literature

Studies have proposed that the removal of riparian vegetation stimulates primary productivity (Scott *et al.* 1986, Hinch and Collins 1993). The removal of shady trees increases stormwater runoff, while the loss of shade increases water temperature. Higher temperatures increase productivity, which results in an increase in the fish biomass of tolerant species. Tolerant species are habitat generalists that are able to thrive within a wide range of environmental conditions; these fish are common to degraded systems (Fausch *et al.* 1990).

Contrary to this, other studies have shown that increases in macrophyte diversity and abundance resulting from development reduces fish abundance and species richness (Benson and Magnuson 1992, Brazner and Magnuson 1994, Lenat and Crawford 1994, Weaver and Garman 1994). In these studies, sensitive species were eliminated and tolerant species did not increase in abundance. Deppe and Lathrop (1993) concluded that fish species richness responded negatively to macrophyte abundance, richness, and structural complexity in their study of the exotic eurasian watermilfoil, *Myriophyllum spicatum*. Watermilfoil reduced both the diversity of the indigenous aquatic vegetation and the fish species richness.

A common preventative measure against shoreline habitat degradation resulting from development is the use of bank stabilizing structures such as riprapping or retaining walls to minimize erosion. These structures reduce the heterogeneity of the shoreline, which results in a less diverse fish community (Weaver *et al.* 1996). Tonn and Magnuson (1982) found that greater habitat diversity was associated with higher species richness. Similarly, Benson and Magnuson (1992) found that species richness was correlated with depth gradient diversity and macrophyte diversity. An alternative defence against habitat degradation is to leave strips of riparian vegetation along the shoreline in order to reduce the erosion associated with stormwater runoff. Unfortunately, these buffer strips do not adequately reduce the nutrients within the runoff due to the absence of a sufficient plant root network (Karr and Schlosser 1978, Omernik *et al.* 1981).

Localized changes in water quality or increases in the amount of suspended sediment may render areas sub-optimal for fish survival. Such changes result in the re-structuring of the fish community by eliminating the sensitive species (minnows, sportfish fry) and increasing the abundance of more adaptable and hardy habitat generalists (sunfishes) characteristic of degraded systems. The overall number of fishes in the river may not be affected by habitat change, while species composition may. The effects of suspended sediment on fish and their habitat depend on the characteristics of the suspended sediment such as particle size, composition, concentration, and duration of exposure (Anderson *et al.* 1996). The severity of effects also depends upon the characteristics of the fish that are exposed; generally younger and smaller fish are more sensitive to suspended sediment (Newcombe and Jensen 1996). Similar responses to suspended sediment have been seen among fish with similar ecological requirements (Table 6) (Berkman and Rabeni 1987). For example, bottom dwelling species such as catfish are tolerant of higher levels of suspended sediment than fish species that reside higher in the water column such as brook silversides. Concentrations of suspended sediment may lead to changes in territorial or spawning behaviour, feeding strategies, avoidance of predation, and physiological changes such as increased cough reflexes and blood sugar levels, (Berg and Northcote 1985, McLeay *et al.* 1987, Servizi and Martens 1992). The settling of suspended sediment leads to bottom smothering, which has deleterious effects on spawning ground, gas exchange in fish eggs, and bottom productivity of benthic organisms (Anderson *et al.* 1996).

In addition to changes that result from anthropogenic disturbance, fish communities are also structured by natural factors such as geography (temperate or tropical) and geology of the drainage basin. One such example is the longitudinal gradient along rivers, the river-continuum concept, which states that rivers have a longitudinal structure that changes predictably along the length of the river. This structure results from increasing stream order leading to an increase in species richness from the headwaters to the mouth of the river (Vannote *et al.* 1980). This concept assumes that rivers begin as lower-order streams with few species and uniform environments, which then form higher-order streams or rivers with reduced forest canopy, increased primary productivity, and non-uniform habitats. The result is increased macrophyte growth creating nursery areas for fish and invertebrates. These conditions lead to higher biological diversity in downstream areas (Wootton 1995). However, in rivers flowing through agricultural or urban lands there is often a decrease in diversity, since downstream areas are wide and homogeneous with silt and pollution build-up from areas further upstream (Matthews 1998). It is difficult to apply the river-continuum concept to the Rideau River because the river does not begin as a first-order stream. It flows from the Big Rideau Lakes through 28 locks between downtown Ottawa and Smiths Falls, with a total lift of 70 m. The locks interrupt the longitudinal continuum of the river and limit fish movement; they may be another factor structuring the fish community.

Problems specific to the Rideau River possibly affecting the fish community include water level fluctuations and the introduction of exotics. Water levels are raised 3.0 - 3.5 m in the spring and lowered an equivalent amount in the fall to maintain navigable channels during the summer and prevent ice damage to the locks during the winter (Parks Canada 1994). Water level fluctuations have been made within a 24-hour period, resulting in severe consequences for the fish community (RMOC 1996 a, b). In the spring, if the water level is raised too late, low water may prevent fish from reaching suitable shoreline habitat for spawning. If the water level is raised too early, just after spawning, eggs may be washed away. In the fall, if the water level is lowered too quickly, fish will not be allowed sufficient time to move out of the shallow weed beds into the main channel (RMOC 1996 a, b). Thousands of fish have been trapped in exposed aquatic vegetation or isolated in small pools, which are not deep enough to support fish during the winter (City of Gloucester 1992). It has been suggested to Parks Canada, the agency operating the locks, that the raising and lowering of water levels be regulated by temperature and not calendar date. As well, the fluctuations should be much more gradual, spanning days rather than hours (City of Gloucester 1992). Improvements have been made to the Parks Canada water level draw-down schedule and fewer dead fish have been found (RMOC 1998). There are positive aspects to a gradual draw-down: Zebra mussels, algal mats and macrophyte beds become exposed to desiccation and freezing, which helps control their populations. Additionally, the fish are concentrated in a smaller volume of water with less cover, enhancing the foraging efficiency of piscivorous fish (Rogers and Bergerson 1995).

The introduction of invasive or exotic species is another form of disturbance that incites change to both habitat and fish communities. Exotic species are those organisms introduced into areas where they are not native. Species with high reproductive and dispersal rates, high genetic variability, broad diets, and able to live in close proximity to humans are known to be successful invaders. The characteristics of habitats that make them conducive to invasion by exotic species include a climate similar to that of the original habitat of the invader, a low diversity of native species, absence of predators, absence of native species that are morphologically or ecologically similar, and a habitat that has been anthropogenically disturbed. The invasion of successful exotics results in dramatic population increases that competitively exclude native species. Native species with very low numbers of individuals or fluctuating population size are most at risk of being extirpated from invaded areas (Lodge 1993). There are several exotic species of fishes, crayfishes, molluscs, and plants in the Rideau River, which have become established and disturbed the ecosystem.

The common carp, *Cyprinus carpio*, native to Eurasia, was introduced into Ontario from the United States in 1880 as a potentially inexpensive food source. This fish quickly spread throughout southern Ontario and northward as far as Sturgeon Bay, northern Ontario, because it tolerates warm, weedy, polluted waters and sedimentation (Dymond 1955). This nuisance species has been blamed for the loss of native species and habitat degradation, as it roots along shorelines disturbing aquatic plants and increasing the turbidity of the water, destroying spawning grounds and making areas unsuitable for other organisms to inhabit (Nico 1999). The common carp has been found throughout the Rideau River since the 1930's (McAllister and Coad 1974).

The rusty crayfish, *Orconectes rusticus*, native to the states of Ohio, Kentucky and Tennessee in the United States, has been spread by anglers into northern, non-native waters as a result of bait bucket and livewell dumping. In the 1960's, rusty crayfish had dispersed as far north as Lake of the Woods in northwestern Ontario. The native range of this crayfish has even been reflected in the license plates of cars parked by cottages around northern lakes (F. Schueler, Eastern Ontario Biodiversity Museum, personal communication)! Rusty crayfish were first captured in the Jock River, a tributary to the Rideau River in 1986. Two years later, the crayfish had been found in the Rideau River itself (F. Schueler, personal communication). They are aggressive predators that dramatically reduce aquatic plant diversity and invertebrate populations, out-competing the native crayfish for food and cover. Rusty crayfish have exterminated native populations of crayfish throughout much of Ontario.

Zebra mussels, *Dreissena polymorpha*, were transported from Europe into the Great Lakes in the bilge water of barges in 1985. These mussels have since dispersed throughout much of North America as a result of bilge water and livewell dumping and by moving unwashed boats or other equipment from one water body to another. Once in their new river habitat, the zebra mussels' free-swimming larva leads to rapid downstream colonization. Jennings (1996) and Richardson and Bartsch (1997) found that zebra mussels compete with juvenile and larval fish for plankton food resources. Fish species that are most at risk are strict planktivores or those that live in areas where there is no continuous resupply of plankton, such as in small, sheltered, isolated lakes. Klerks *et al.* (1996) found that increases in zebra mussel density increased the deposition of organic waste products, increasing food supply for aquatic invertebrates. The increase in invertebrate biomass caused the biomass of benthic fish to increase due to the increase in food supply. Zebra mussels grow vigorously in shallow backwaters with little current, and ample hard substrate for the mussels to attach themselves. Unfortunately, these are the same areas that are favoured by many fish species as nursery habitats (Jennings 1996). Zebra mussels were first reported in the Rideau River in October 1990 (Martel 1995).

Eurasian watermilfoil, *Myriophyllum spicatum*, was introduced into North America from Europe. This is a nuisance species that grows in dense mats, disrupting boat traffic and swimming. Some fish species avoid these vegetated mats while others thrive in them, thus changing the fish community (Gorman and Karr 1978). Watermilfoil is spread by water birds and boat traffic since propellers get tangled in the mats and transport the stems into new areas (Minnesota Department of Natural Resources 1993*). Watermilfoil has been found along the length of the Rideau River.

2.3. Methods

2.3.1. Field Methods

During the summers of 1998 and 1999, surveys of the fish community within the Rideau River and its tributaries were conducted as part of a three-year multidisciplinary study, the Rideau River Biodiversity Project (RRBP), involving the Canadian Museum of Nature, the Rideau Valley Conservation Authority, and the University of Ottawa. The field methodology was the same as described in Chapter 1.

At each site, the percentage of plant material (total cover) and the percentage of each plant species and substrate type was visually estimated within a 1 m radius of the sampling point at three plots along the shoreline and at three plots at a distance of 7 m from the shoreline towards the river. The shoreline habitat characteristics were identified as shallow variables; the habitat characteristics 7 m from the shoreline were identified as deep variables. The trap net lead was used to measure the distance from the shoreline. The values for total cover, aquatic plant, and substrate type were calculated for the shallow and deep areas by averaging the three plots.

2.3.2. Statistical Methods

Several factors were considered when deciding upon a method for analysis. The development of an index of biotic integrity (IBI) was initially considered for use in evaluating the ecological health of the Rideau River. The IBI, developed by James Karr (1981) measures aquatic ecosystem health by comparing degraded systems to similar un-degraded waterbodies by taking into account characteristics that change in response to human disturbance and not natural environmental variability (Fausch *et al.* 1990). The IBI is not universally applicable because the characteristics of healthy watercourses differ depending on the size, temperature, and geography of the waterbody. For example, an IBI developed for warm-water assumes that biotic integrity decreases (the number of species decreases) as degradation increases. In cool or cold water, moderate levels of degradation result in increased numbers of species. The development of an IBI for the Rideau River was not appropriate for this study for the following reasons: Information is lost when the ecosystem is reduced to a few indices, there is error involved in choosing metrics that represent the Rideau River adequately, there are few un-degraded areas along the Rideau River for comparison, and an extensive validation process would have to be undertaken involving comparisons with evaluations of river health based on water quality data and sampling subsequent years in order to properly validate the index.

The fish community dataset comprised a binary, presence/absence matrix and a standardized, continuous, relative abundance matrix. Both matrices described the fish community at each sampling site and were further broken down into four smaller matrices, which were functional subgroups representing the general behavioural and habitat use strategies of fish species. These subgroups were large-bodied piscivores, large-bodied insectivores, small-bodied fishes, and young-of-the-year (YOY) (Table 7). Fish were classified as large-bodied if their adult size was greater than 20 cm in total length and small-bodied if their adult size was smaller than 20 cm in total length as per Scott and Crossman (1973). Yellow perch were classified as insectivores even though, according to Scott and Crossman (1973), individuals larger than 15 cm in total length consume fish. This is because only 9% of the yellow perch captured in the Rideau River were larger than 15 cm, (54 fish out of 625 were larger than 15 cm) the majority of individuals were insectivores. Subgroups were used in the analyses because trends may have been obscured when the entire fish community matrix was incorporated in the analysis.

Habitat characteristics were described at each sampling site, contributing to a binary presence/absence matrix and a standardized continuous relative abundance matrix. Data were standardized by subtracting the sample mean from each value and dividing the difference by the sample standard deviation. Habitat characteristics were also broken down into smaller submatrices representing deep and shallow aquatic plants and substrate type. Water depth of the sampling site 7 m from shore and amount of overhanging shoreline vegetation were also included.

Both the fish community and habitat characteristic datasets had a low ratio of sites to variables; there were 14 sites with 30 fish species and 24 habitat variables. This low ratio decreased the power of analyses. Normal probability plots of the residuals, generated from an analysis of variance (ANOVA) model, (independent variable: land -use, dependent variable: species relative abundance) showed that the data were not univariately normally distributed due to the high number of zeros and small numbers within the dataset. The high number of 'zero' values was due to the likelihood that fish species would be absent from a site. The assumption of homogeneity of variances was not met. Data transformations were not able to improve the normality or heteroscedasticity. In light of these restrictions, non-parametric analyses were chosen.

2.3.2.1. Statistical Assumptions

Prior to analyzing the data, the young-of-the- year (YOY, age 0+ fishes), were removed from the dataset (Table 8). The YOY tend to school together and increase sampling bias. Fishes that were classified as YOY were distinguished by length, as determined from species specific, length-frequency histograms where each year class was represented by a separate mode (Wootton 1995). Urban sites were sampled earlier during the summer of 1998 when the YOY were much smaller and easier to distinguish from the adult fish. In order to determine if the number of YOY sampled at agricultural and forested sites, sampled later in the season, were underestimated, a Spearman correlation between the average number of

YOY removed from each site and sampling date was performed. This type of analysis was chosen due to deviations from normality.

Six species were removed from the dataset prior to analysis because they were captured in low abundance at two or fewer sites. These species may have had a disruptive effect on the statistical analysis (Hinch *et al.* 1991). The removed species included freshwater drum, mottled sculpin, tadpole madtom, and emerald shiner all captured at one site, and blackchin shiner and muskellunge captured at two sites.

Catch per unit effort (CUE) was used as a measure of relative abundance. CUE was calculated for each fish species for each site by summing the number of each species captured per site then dividing by the number of gear types used at each site. The gear types, the number of sets, and the duration of each net set were the same for each site except for the number of seines per site. At the beginning of the sampling season, the number of seine hauls that could be processed per site was overestimated.

Non-aquatic shoreline plants such as purple loosestrife, cattails, and rushes were removed from the shallow aquatic plant dataset prior to analysis. To determine if changes in aquatic plant cover could be attributed to plant growth over the sampling season, rather than being attributed to land-use type, a Spearman correlation between total aquatic plant cover (shallow and deep areas) and sampling date was performed.

Sampling sites were located such that all of the urban sites were clustered together at the downstream end of the Rideau River near its confluence with the Ottawa River. The agricultural and forested sites were randomly distributed further upstream. This patchy, non-random distribution of sampling sites may have contributed to spatial autocorrelation among sites where the observations at neighbouring sites were not independent of one another (Legendre and Fortin 1989). A randomized distribution of sampling sites usually corrects for this, which was impossible in this study due to the location of the urban areas along the Rideau River. A Mantel test was used to quantify this potential source of spatial autocorrelation. Mantel tests determine the significance of a correlation between two independent distance matrices, in this case a habitat or fish community matrix and a matrix of geographic distances among sites. It tests the null hypothesis that there is no association between the elements of one matrix and the elements of another (Legendre and Fortin 1989, Sokal and Rohlf 1995, Miller 1999). A positive correlation indicates that sites that are geographically close together have fish communities or habitat characteristics that are similar thus spatially autocorrelated.

First, distance matrices were calculated: A Jaccard similarity matrix was calculated from each binary matrix of presence/absence habitat and fish community data, after which each similarity was subtracted from one, creating a distance matrix. A Euclidean distance matrix was calculated from each of the continuous matrices of relative abundance for habitat and fish community data. The correlation between one habitat or one fish community's distance matrix and a matrix of geographic distances among sites was tested pairwise. The two distance matrices of interest were used to calculate an observed Z-statistic by taking the products of half of the corresponding off-diagonal elements in the two matrices and summing them (Manly 1995). Next, one of the distance matrices was randomized and then the Z-statistic was re-calculated. The randomization was run 1000 times producing a z-distribution. The observed Z-statistic was compared to the z-distribution, after which a p-value could be calculated based on where the observed value fell along the distribution. A positive correlation was obtained when the Z-statistic was larger than the values given by the z distribution and a negative correlation was obtained when the Z-statistic was smaller than the values given by the distribution. A Visual Basic macro was written for use in MS Excel 97 to perform the Mantel tests (Francis 2000) (Appendix 5). Sequential Bonferroni tests using the Dun Sidak method, a slightly less conservative approach (Sokal and Rolf 1995) were used to adjust the alpha values to control for type 1 error. The procedure involved rank ordering the significance values from smallest to largest. The significance of the first test was evaluated at alpha/number of tests. The next test statistic is evaluated at alpha/(number of tests –1), the third significance value is evaluated at alpha/(number of tests – 2). The significance values are evaluated in this fashion until a non-significant test statistic is obtained.

In order to determine if a longitudinal continuum exists along the length of the Rideau River and whether this continuum is interrupted by locks two types of analyses were undertaken. Graphs of the relative abundance of fish species and habitat characteristics for each site were plotted against each site's distance from the confluence of the Rideau and Ottawa Rivers. If there appeared to be an increasing or decreasing trend from upstream to downstream, it might have indicated that distance from the confluence of the Rideau and Ottawa rivers played a role in structuring the fish community, an argument for the existence of a longitudinal continuum along the length of the river.

Hierarchical cluster analyses were also examined to determine if sampling sites grouped together according to their lock reach. Separate groupings of each lock reach were expected within the cluster tree if the fish community or habitat characteristics differed between lock reaches because variables with high pair wise correlations would be assigned to the same group. Prior to running the analysis, distance metrics were calculated for continuous data using the Pearson distance measure (Wilkinson 1996). Complete and Ward joining algorithms were used depending on which gave the best separation of lock reaches (Wilkinson 1996).

2.3.2.2. Habitat characteristics and land-use

Hierarchical cluster analyses were used to determine whether habitat characteristics differed among land-use types. One analysis was performed using all relative abundance variables for deep and shallow aquatic plants and substrate type; three other cluster analyses were completed using the relative abundance variables for deep and shallow aquatic plants and substrate type separately. Separate groupings of land-use type were expected within the cluster tree if the habitat characteristics differed between land-use types. This is because variables with high pair wise correlations would be assigned to the same group. Prior to running the analysis, distance metrics were calculated for binary data using the Jaccard distance measure and the Pearson distance measure for continuous data. Complete and Ward joining algorithms were used depending on which gave the best separation of land-use types (Wilkinson 1996).

To ascertain whether a particular habitat characteristic was more variable along one land-use type than another, Levene's tests were used to compare the equality of variance among land-use types with respect to habitat characteristics. An ANOVA was used to create residuals with relative abundance being the dependent variable and land-use type being the independent variable. An ANOVA was then re-run using the absolute value of the residuals. A significant p-value would indicate that the habitat variable was more variable within one land-use type than another.

2.3.2.3. *Habitat characteristics and the fish community*

In order to determine if the habitat characteristics were correlated with fish community characteristics, a series of Mantel tests were performed according to the methods previously described. If large values in one matrix match large values in the second matrix, Z will be larger than average resulting in a positive correlation. If small values in one matrix match small values in the second matrix, Z will be smaller than average resulting in a negative correlation. A statistically significant positive or negative correlation between distance matrices would indicate that sites with similar fish populations also have similar habitat characteristics, indicating a relationship between the fish community and the habitat characteristics.

2.3.2.4. *Fish community and land-use*

Hierarchical cluster analyses were used to determine whether the relative abundance and diversity of the fish community differed between land-use types. A cluster analysis was performed using the relative abundance variables for all fish species present at 3 or more sites (with YOY removed). Cluster analyses were also performed using the relative abundance variables for the large-bodied piscivores, large-bodied insectivores, small-bodied fish, and YOY separately. Separate groupings of land-use type would be expected within the cluster tree if the fish community characteristics differed between land-use types. Prior to running the analyses, distance metrics were calculated for binary data using the Jaccard distance measure and the Pearson distance measure for continuous data. Complete and Ward joining algorithms were used, depending on which gave the best separation of land-use types (Wilkinson 1996).

To ascertain whether the relative abundance of a particular fish family was more variable along one land-use type than another, Levene's tests were used to compare the equality of variance among land-use types with respect to fish community characteristics. An ANOVA was used to create residuals, relative abundance was the dependent variable and land-use type was the independent variable. Then an ANOVA was re-run on the absolute value of the residuals. A significant p-value would indicate that the relative abundance variable was more variable along one land-use type than another.

2.4. Results

2.4.1. General Results – Fish Community

During the 1998 sampling season, 6904 fishes were captured, representing 30 species from 10 families (Appendix 7). None of these have been designated by the Ontario Ministry of Natural Resources (OMNR) or the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as "at risk" (Ontario Ministry of Natural Resources 1998*). Of the total number of fishes captured, 1888 were YOY, age 0+ fishes (Table 8). The number of fishes captured in agricultural areas represented 50% of the total catch belonging to 27 species. The number of fishes captured in forested and urban areas represented the remainder belonging to 22 and 25 species respectively. Centrarchidae (sunfishes), Cyprinidae (minnows), and Percidae (perch) families dominated the Rideau River fish community in terms of highest catch-per-unit-effort (CUE) (Fig. 6). Urban sites had the lowest CUE for each family of fishes except for Fundulidae: more banded killifishes were captured at urban sites than forested or agricultural sites. Representatives from all families were captured at forested sites except for catostomids. All families were captured at agricultural sites with Cyprinidae and Centrarchidae being the most abundant.

Six fish species were removed from the dataset prior to analysis because they were captured at too few sites: A freshwater drum was captured downstream at urban site three near the Bronson St. bridge. This first record of capture for the Rideau River (Phelps *et al.* 2000b) was likely a stray from the Ottawa or St. Lawrence Rivers. A mottled sculpin was also captured at this site. A tadpole madtom was captured for the first time in the Rideau River at agricultural site twelve, halfway between Burritts Rapids and Becketts Landing (Phelps *et al.*

2000a). One emerald shiner and one blackchin shiner were captured at agricultural site six. Nine additional blackchin shiners were captured at urban site two. One muskellunge was captured at urban site four and one was captured at forested site eight.

The majority of fishes were captured with seine nets, 86.2% of fish representing 24 of 30 species. Trap nets captured approximately 4.8% of fish representing 14 species and 4.4% of fish from 11 species were captured in large hoop nets. Small hoop nets captured 3.5% of fish representing 15 species, and 4.6% of fish from 21 species were captured with a backpack electrofisher. Seine nets were found to be best suited for the Rideau River because they caught a variety of fish species and size classes. There was also no fear of equipment vandalism, as the nets did not need to be left out overnight. Backpack electrofishing was limited in that it could only be used along shallow shorelines and CUE was minimal. This method was best for catching bottom dwellers ineffectively captured by other methods. Ideally, a variety of gear types are incorporated into a sampling protocol in order to eliminate the sampling bias inherent in each gear type.

CUE was graphed for each fish species in order to examine the relative abundance and diversity of fish species dominating each land-use type. The graph describing the CUE for the large-bodied insectivore species showed that agricultural sites had the most abundant and diverse insectivore communities; all seven species were present at these sites (Fig. 7). Urban sites had the lowest abundance of insectivorous species. Pumpkinseed, bluegill, and yellow perch dominated all three land-use types. Pumpkinseed and bluegill were captured at 90% of all sites. Catostomids and ictalurids were far less abundant. No catostomids were captured at forested sites, although the majority of brown bullhead were captured at these sites.

All six piscivore species were captured within each land-use type (Fig. 8). Agricultural areas were dominated by black crappie. Rock bass were a ubiquitous species, captured at every sampling site; they were the most dominant piscivore in urban areas. Very few largemouth bass were captured at downstream urban sites while smallmouth bass were rarely captured at the upstream forested sites. Smallmouth bass are known to prefer rockier substrates and cooler, deeper water than largemouth bass. In addition, smallmouth bass are less associated with dense vegetation than largemouth bass (Scott and Crossman 1973). The urban sites along the Rideau River where smallmouth bass were captured were deeper than forested or agricultural sites (Fig. 13) and had substrates composed of boulder bedrock and rubble (Fig. 14). Very few walleye were captured in the Rideau River, although specimens were caught within each land-use type.

Ten species were classified as small-bodied fish, all of which were captured at forested and agricultural sites (Fig. 9). Common shiners were the most abundant minnow in the Rideau River and the dominant minnow at forested and agricultural sites. Blacknose shiner and bluntnose minnows were absent from urban sites. Spottail and golden shiners were the most abundant minnows at urban sites, although these sites had the lowest abundance and diversity of minnow species. Tesselated darters were uniformly captured at all land-use types. Fewer brook silversides were captured at urban sites, as compared to forested and agricultural sites. Banded killifish were present at all land-use types, although more abundant at urban sites. Logperch were most abundant at urban and agricultural sites.

Young-of-the-year, YOY, were captured at every sampling site although the variability in abundance among sites was high as indicated by the large standard deviation bars in figure 10. The variability may be explained by the localized home ranges and specific habitat requirements of these young fish or schooling behaviour. The abundance of YOY present at each land-use type also reflects the proportions of adults that were captured. Agricultural and forested sites had the highest abundance of YOY. Rock bass were the predominant YOY present at urban sites.

In summary, Centrarchidae and Cyprinidae dominate the Rideau River fish community. Using a criteria of greater than five fish to denote a significant abundance, urban sites were characterized by the presence of spottail shiner, banded killifish, yellow perch, logperch, pumpkinseed, rock bass and smallmouth bass. All centrarchid species were captured at urban sites except YOY largemouth bass. Very few ictalurid or catostomid species were captured in urban areas. An abundant and diverse minnow (common, golden, and blacknose shiners, bluntnose minnow) and bass (pumpkinseed, bluegill, black crappie, rock bass, and largemouth bass) community and the presence of all centrarchidae species, catfish and sucker species, yellow perch, and logperch defined agricultural sites. Forested sites were characterized by the presence of brown bullhead, pumpkinseed, bluegill, rock bass, yellow perch, common shiner, bluntnose minnow, banded killifish, and brook silverside.

Mantel tests were conducted to determine if a matrix of piscivorous fish relative abundance was correlated with matrices of small-bodied fish and YOY relative abundance (Table 9). Piscivores were positively correlated with small-bodied fish as well as with YOY, indicating that there was a relationship between piscivores and these prey species. Sites with similar abundances of piscivores also have similar abundances of YOY and small-bodied fish. Graphs of the CUE for piscivores, YOY, and small-bodied fish were further examined to explain the relationship between them. The majority of YOY and small-bodied fish were captured at agricultural and forested sites as were the majority of piscivores. Young soft-rayed insectivores such as the white sucker are also known prey items of piscivorous fish (Hinch *et al.* 1991), however an insufficient number of young white sucker were captured for a Mantel test to be conducted.

2.4.2. General Results – Aquatic Habitat

Aquatic habitat characteristics consisted of nine types of aquatic plants and eight classes of substrate based on particle size (Tables 2 and 3). Tape grass was the most abundant aquatic plant in the river. In shallow areas, seven types of aquatic plants were identified. Urban shallow areas were characterized by five types of aquatic plants with tape grass and algae dominating (Fig. 11). Milfoil and duckweed were not identified at urban sites. The shallow aquatic plants at forested sites consisted of tape grass with some milfoil, *Potamogeton*, duckweed and *Elodea* but no lily or algae. An abundant and diverse aquatic plant community characterized the shallows of agricultural sites. All aquatic plant types were found at agricultural sites except for algae.

In deep areas, seven types of aquatic plants were identified (Fig. 12). The deep areas of urban sites were characterized by an abundance of tape grass with a small amount of milfoil, coontail, and *Potamogeton* but no lily, duckweed or *Elodea*. All aquatic plant species were found in deep areas of forested sites with tape grass the most abundant. Deep areas of agricultural sites were characterized by the presence of all species of aquatic plants except for coontail.

Large woody debris were more abundant at agricultural sites than urban sites (Fig. 13). This may be because urban areas were deeper with faster flowing current, inhibiting wood settlement. The amount of overhanging vegetation, a source of large woody debris, did not differ among land-use types, a few overhanging trees were found at sites within each land-use type.

Sand was the ubiquitous substrate type (Fig. 14). Urban sites were characterized by mostly sand with some of the larger particle size substrates: boulder, bedrock, rubble, and gravel. The substrate at forested sites consisted of sand with clay and detritus, while agricultural sites were dominated by clay, with sand, boulder, bedrock and detritus.

The phytoplankton team from the RRBP as well as the Regional Municipality of Ottawa-Carleton measured the amount of total suspended sediment within the water column along the length of the Rideau River during the 1998 sampling season (Table 10). Their results showed a slight increasing trend upstream, although there was no statistical difference in the amount of total suspended solids (TSS) measured along the length of the Rideau River.

2.4.3. Statistical Assumptions

Spearman correlation was used to determine whether the number of YOY removed from the dataset correlated with sampling date. Sites sampled later in the season did not differ from sites sampled earlier, as there was no correlation between the number of YOY and sampling date (Spearman correlation coefficient 0.210). This indicated that YOY captured at sites sampled later during the sampling season were not erroneously classified as adult fish.

Spearman correlation was also used to determine whether total aquatic plant cover in deep or shallow areas was correlated with the time of year during which the estimation of cover was made. Sites sampled later in the season did not differ from sites sampled earlier in terms of the total amount of plant material covering the substrate. There was little correlation between total aquatic plant cover in shallow or deep areas and sampling date. (Spearman correlation coefficients: 0.476 and 0.222 respectively).

Mantel tests were used to explore potential spatial autocorrelation resulting from the patchy, non-random distribution of sites as urban sites were grouped together downstream while agricultural and forested sites were randomly distributed further upstream. Table 11 shows correlations between the geographic distance matrix and the distance matrices describing the relative abundance of fish and habitat characteristics. There were positive correlations between the geographic distance among sites and the distance matrices of piscivores and insectivores. This indicated that as geographic distance among sites decreased, the differences among sites with respect to the relative abundance of piscivores, insectivores and substrate type also decreased. The presence of spatial autocorrelation within the dataset is indicative of a lack of independence among sampling sites. Independence among sites is an assumption of parametric statistics. The use of non-parametric cluster analyses or randomization tests such as Mantel tests minimize the effects of violating this assumption (Legendre and Fortin 1989).

Diversity (presence/absence) and relative abundance (CUE) of the fish community and the habitat characteristics for each site were plotted against the distance of each site away from the confluence of the Rideau and Ottawa Rivers, in order to determine if a longitudinal continuum existed along the length of the Rideau River (Appendix 6). If there appeared to be an increasing or decreasing trend from upstream to downstream, distance from the river's confluence may have played a role in structuring the fish community.

There were no trends in the total number of fish species captured overall or in the CUE of the piscivores, small-bodied fish, or YOY (Appendix 6a). However, the CUE of insectivores increased as the distance to upstream sites increased. The preferred substrate of insectivores, clay and detritus, also increased and the percentage of boulder cover decreased with increasing distance upstream (Appendix 6b). Other substrate types did not show any trend.

Aquatic plant cover in deep areas was dominated by tape grass (Appendix 6c). Milfoil, lilies, and duckweed were present at few downstream locations but increased in abundance upstream. Tape grass, coontail, and *Potamogeton* did not show any trend. In shallow areas, milfoil, and large woody-debris increased in abundance upstream (Appendix 6d). Algae decreased in abundance upstream and was found only in urban areas (Fig. 11). These habitat trends may reflect urban versus agricultural and forested land-use types or a longitudinal continuum may exist.

The distance graphs (Appendix 6) show that insectivorous fish may increase from downstream to upstream sites within the Rideau River. It seems unlikely that a longitudinal continuum exists along the length of the river because only insectivorous fish show a trend and locks may interrupt the river to such an extent that a continuum is not seen.

To determine if locks structured the fish community and acted as a barrier to fish movement, hierarchical cluster analyses were examined to determine if sites grouped together according to their lock reach (Table 12). Exclusive groupings of each lock reach were expected within the cluster tree if the fish community differed between lock reaches. Cluster analyses based on the relative abundance of all fish species and subsets of fish species, the piscivores, insectivores, small-bodied fish, and YOY, did not exhibit exclusive lock reach groupings (Figs. 15 to 19). However, four of the five urban sites were located within the same lock reach and all five urban sites clustered together when piscivores and all species were examined. The sites clustered exclusively when the relative abundance of insectivores were examined. It is difficult to determine whether lock reach influences urban sites. The idea that lock reaches influence the fish community is attractive, yet inconclusive.

2.4.4. Aquatic Habitat Characteristics and Land-use

To determine if habitat characteristics differed between land-use types, four hierarchical cluster analyses were completed based on the relative abundance of shallow and deep aquatic plant variables and substrate type. The first cluster analysis, based on the relative abundance of deep and shallow aquatic plants and substrate type revealed two clusters where urban sites could be distinguished from agricultural sites (Fig. 20). In cluster A, all five urban sites were represented along with two forested sites. These sites were characterized by an abundance of wild celery (tape grass) in deep areas and the presence of algae in shallow areas. Substrate was composed primarily of sand. In cluster B four agricultural sites and one forested site grouped together. Cluster B was characterized by the presence of tape grass and lilies in deep areas, large woody debris with a substrate composed primarily of clay, sand and detritus. The separate groupings of land-use type demonstrated that the urban and agricultural habitat characteristics differed between land-use types.

The cluster analyses based on the relative abundance of the habitat variables separately did not show strong separation among land-use types. The relative abundance of shallow aquatic plants separated sites into three clusters with a mixture of land-use types in each (Fig. 21). Cluster A included three urban sites, one agricultural site, and one forested site and was characterized by sparse shallow aquatic vegetation. Cluster B included two agricultural sites and a forested site and was characterized by large woody debris, milfoil and tape grass. Cluster C included two urban sites, one agricultural, and one forested site. This cluster was characterized by *Elodea*, tape grass, and *Potomageton*.

The relative abundance of deep aquatic plants loosely separated land-use types into separate groupings (Fig. 22). Cluster A included four urban sites, two forested and two agricultural sites. These sites were characterized by a moderate abundance of tape grass. Cluster B included two agricultural sites, one urban site and a forested site, these sites being characterized by a high abundance of tape grass.

Substrate type clustered the sampling sites into two groups, separating urban and agricultural land-use types (Fig. 23). Cluster A included four of five agricultural sites and two forested sites and was characterized by an abundance of clay. Cluster B contained all five urban sites, two forested sites and one agricultural site, all sites having sand in common. Cluster analyses enabled the urban sites to be distinguished from the agricultural sites, providing support for the existence of a relationship between the habitat characteristics and land-use type.

Levene's tests compared the equality of variance among land-use types with respect to depth and the total relative abundance of aquatic vegetation in deep and shallow areas (Table 13). No land-use-type was more variable than another with respect to these habitat characteristics.

2.4.5. Fish Community and Aquatic Habitat Characteristics

Mantel tests were conducted to determine if matrices of aquatic habitat characteristics were correlated with matrices of fish abundance and diversity. Table 14 describes these relationships between habitat characteristics and all fish species present at three or more sampling sites. The presence/absence matrix (diversity) of deep aquatic plants and the presence/absence matrix (diversity) of substrate type were both positively correlated with the relative abundance of the fish community. The relative abundance of deep aquatic plants was also positively correlated with the relative abundance of fish. These results show that there was a relationship between the abundance of the fish community and the diversity and abundance of deep aquatic plants and the diversity of substrate type, since sites with similar abundances of fish species also had similar abundances of deep plant species and substrate types.

Mantel tests were also conducted to determine if matrices of habitat characteristics were correlated with sub-matrices of fish abundance and diversity where fish species were divided into the functional groups insectivores, piscivores, small-bodied fish, and YOY (Table 15). Positive correlations indicate that there is a relationship between the matrices, (i.e. the sites with similar habitat characteristics also have similar fish community characteristics).

The relative abundance of insectivores was positively correlated with the diversity and abundance of deep aquatic plants and substrate type indicating that there was a relationship between the fish community and the habitat characteristics. Returning to the graphs describing the CUE of insectivores (Fig. 7), percent deep aquatic plant cover (Fig. 12), and percent substrate cover (Fig. 14), pumpkinseed, bluegill, and yellow perch were most abundant at agricultural and forested sites. These sites were associated with a higher abundance of deep aquatic plants and substrate composed of mostly sand, clay, and detritus.

The abundance and diversity of piscivores were not correlated with aquatic plants or substrate but with the relative abundance of YOY and small-bodied fish (Table 9 and 11). Perhaps piscivores are more closely associated with prey species than aquatic habitat characteristics.

The abundance of YOY was not correlated with the abundance or diversity of aquatic plants or substrate type. This may be due to their localized home ranges, specific habitat requirements or their schooling behaviour. A correlation analysis could not be conducted between the diversity (presence /absence) of YOY and the habitat characteristics because all YOY were captured at all of the sites. There was no difference between sites, except largemouth bass YOY were absent from all five urban sites.

The abundance of small-bodied fish was positively correlated with the abundance and diversity of deep aquatic plants and substrate type. Sites with similar small-bodied fish communities also had similar deep aquatic plants and substrate type, indicative of a relationship between small-bodied fish, deep plants, and substrate. Urban sites had sparse minnow communities, but abundant populations of banded killifish (Fig. 9) with tape grass dominating at these sites (Fig. 12). All small-bodied fish species were captured at both agricultural and forested sites, although the CUE of fishes captured at agricultural sites was much higher (Fig. 9). Agricultural and forested sites had the highest abundance of deep aquatic plants and these sites had substrate composed of mostly sand, clay, and detritus (Figs. 12, 14).

2.4.6. *Fish Community and Land-use*

In order to determine if the fish community differed between land-use types, five cluster analyses were completed based on the relative abundance of all fish species and functional subgroups of the fish community: piscivores, large-bodied insectivores, small-bodied fish and YOY. The cluster analysis based on the relative abundance of all fish species revealed two clusters where urban sites could be distinguished from the agricultural and forested sites (Fig. 15). Within cluster A, urban sites grouped together along with site 6, a misclassified agricultural site, located the furthest downstream and closest to the urban sites. In cluster B it was not possible to distinguish between the agricultural and forested sites.

A cluster analysis was run using the relative abundance of piscivores to group land-use types (Fig. 16). Cluster A consisted of all urban sites with two misclassified forested sites and cluster B consisted of all agricultural sites with one misclassified forested site. Cluster A was characterized by an abundance of rock bass. Very few black crappies or largemouth bass were captured at sites within this cluster. Cluster B was characterized by an abundance of black crappie and largemouth bass. Fewer rock bass were captured at these sites. This analysis allowed urban and agricultural sites to be distinguished based on the relative abundance of piscivore species.

The cluster analysis based on the relative abundance of insectivores enabled the urban sites to be separated from the agricultural and forested sites (Fig. 17). Three clusters were produced: Cluster A included urban sites exclusively, while cluster B and C contained both a mixture of agricultural and forested sites. Cluster A was characterized by a low abundance of bluegill, pumpkinseed, yellow perch, brown bullhead, and white sucker. An abundance of bluegill, pumpkinseed, and yellow perch and very few redhorse species characterized the two agricultural and two forested sites in cluster B. The two agricultural and two forested sites in cluster C were characterized by an abundance of bluegill, pumpkinseed, and brown bullhead.

The cluster analysis involving YOY fish consisted of two clusters, which separated urban sites from agricultural and forested sites (Fig. 18). One agricultural and one forested site were misclassified and included within the predominantly urban cluster A. An abundance of rock bass and black crappie, and a lack of pumpkinseed, bluegill, and largemouth bass characterized this cluster. Cluster B included a mixture of land-use types, four agricultural sites, three forested sites, and an urban site. This cluster was characterized by an abundance of pumpkinseed, bluegill, smallmouth and largemouth bass and very few black crappie or rock bass.

The cluster analysis that incorporated the relative abundance of small-bodied fish did not allow for separate groupings of land-use types (Fig. 19). Three clusters were produced with a mixture of land-use types within each. Cluster A included three agricultural sites, two urban sites, and a forested site. This cluster was characterized by an abundance of logperch, spottail shiner, brook silverside, and common shiner. Cluster B included two agricultural sites and a forested site and was characterized by blacknose shiner, bluntnose minnow, and very few logperch and common shiner. Cluster C included three urban sites and two forested sites. It was characterized by lots of killifish, but very few fallfish, bluntnose minnow, blacknose shiner, brook silverside, and common shiner.

Levene's tests compared the equality of variance among land-use types with respect to the relative abundance of piscivores, insectivores, small-bodied fish, and YOY (Table 13). Insectivores were the only fish grouping that were more variable among land-use types.

2.5. Discussion

The objective of this study was to examine the relationship between the relative abundance and diversity of the Rideau River fish community and the aquatic habitat characteristics that result from agricultural, forested, and urban land-use. Habitat characteristics differed among land-use types as shown from the four hierarchical cluster analyses (Figs. 20-23). Urban sites were distinguished from agricultural sites based on substrate type. Relative abundance of deep and shallow plants allowed urban sites to be loosely separated from agricultural and forested sites. When all of the habitat variables were included in the cluster analysis, the agricultural sites could be distinguished from the urban sites. These cluster results are evidence that land-use type was correlated with habitat characteristics.

The relationships between the fish community and the habitat characteristics were explored through Mantel tests (Tables 14 and 15). The diversity of deep aquatic plants and substrate type were both positively correlated with the relative abundance of the fish community. The relative abundance of deep aquatic plants was also positively correlated with the relative abundance of fish. These results show that there was a relationship between the abundance of the fish community and the diversity and abundance of deep aquatic plants and the diversity of substrate type. The relative abundance of insectivores and small-bodied fish were positively correlated with the diversity of deep aquatic plants and substrate type. Insectivores and small-bodied fish rely heavily on macrophytes for cover and food. Randall *et al.* (1996) found that smaller fish were captured at more heavily vegetated sampling sites. Sandy substrates allow macrophytes to proliferate and support the invertebrate communities that are the primary food source of these fish. Piscivores were not correlated with the aquatic plants or substrate type according to the Mantel test. These fish may be more closely associated with their prey species than aquatic habitat characteristics or it is possible that piscivores with opposing habitat preferences were included in the same matrix diluting any possible correlations between matrices. For example, if largemouth bass are examined individually (Fig. 8), they are more abundant at agricultural sites than urban sites. Kerr and Grant (2000) found that largemouth bass were associated with lilies and *Potamogeton*, both of which were abundant at agricultural sites within the Rideau River. These correlations illustrate the relationship between the fish community and the habitat characteristics.

The correlations between the fish community and land-use were determined through five hierarchical cluster analyses (Figs. 15-19). The cluster analysis based on the relative abundance of all fish species revealed two clusters where urban sites could be distinguished from the agricultural and forested sites. When the relative abundance of piscivores was included in the cluster analysis, urban and agricultural sites could be distinguished. The relative abundance of insectivores enabled the urban sites to be separated from the agricultural and forested sites. Agricultural and forested sites could be distinguished when the relative abundance of YOY was used in the analysis. A cluster analysis including the relative abundance of small-bodied fish did not allow land-use types to be distinguished. The correlations between the fish community and land-use type lend additional support to the hypothesis that land-use type influences the fish community.

This study has also allowed the aquatic habitat characteristics and the diversity and abundance of the fish community to be characterized for urban, agricultural, and forested land-use along the Rideau River. These results are a first step along the way to being able to predict the abundance and diversity of the fish community given land-use type, which would ultimately make it possible to foretell how the fish community would change given land-use change.

Areas along the Rideau River designated as urban included shopping malls, parking lots, residential areas, and urban parkland. These paved and manicured areas create increased run-off, which generally results in swifter, deeper regions of river. The shorelines consisted of uniform concrete, wood, or aluminium retaining walls, rip-rapping, or loose rubble in order to stabilize banks. Substrate consisted of sand with bedrock, boulder, and gravel. Tape grass and algae dominated urban areas. Tape grass is known to thrive in built-up or urban areas with stronger water current and turbidity (Newmaster *et al.* 1997). The higher phosphorus and nitrogen levels in downstream areas contributed to the increased algal growth. The physical environment within urban areas contributed to the dominance of only a few species of aquatic plants, which reduced the heterogeneity of the aquatic habitat and allowed fewer fish to inhabit the area.

A sparse fish community characterized urban sites. Spottail shiner, golden shiner, and blackchin shiner inhabited these areas. Spottail shiner are known to be intolerant of suspended sediment and prefer areas with minimal current, a sandy bottom, and vegetation (McAllister and Coad 1974, Lyons 1992, Lyons *et al.*1996). This species was captured in highest abundance at urban sites. Golden shiner are tolerant of suspended sediment and prefer areas with slow current and dense vegetation (McAllister and Coad 1974, Lyons 1992, Lyons *et al.* 1996). Characteristics that describe agricultural and forested upstream sites (Figure 11 and 12, Table 10). These characteristics may explain why this species was found in higher abundance further upstream at agricultural and forested sites. Blackchin shiner were captured at only one urban site. This delicate species is known to inhabit weedy sections of clear, clean streams and rivers but is intolerant of suspended sediment and is easily displaced once its habitat changes (McAllister and Coad 1974). Banded killifish were most abundant at urban sites as their habitat requirements are broad, ranging from boulder to mud and vegetated to non-vegetated, thereby allowing them to live in a variety of habitats. Rock bass and smallmouth bass were the most abundant piscivores captured at urban sites. Rock bass are intolerant of suspended sediment and prefer the rocky substrate present at urban sites (McAllister and Coad 1974, Lyons 1992, Lyons *et al.* 1996). Soft-rayed insectivores prefer areas with lots of detritus, vegetation, and soft substrate suitable for supporting insectivore populations amongst the macrophytes. The urban sites along the Rideau River had substrates composed of more boulder, bedrock and rubble than agricultural or forested sites (Fig 14). The hardy, spiny-rayed insectivores such as pumpkinseed, bluegill, and yellow perch are habitat generalists and dominated the majority of sites along the length of the Rideau River. These were the most abundant insectivores captured at urban sites because they easily adapt to a variety of habitats and prey characteristics (McAllister and Coad 1974).

Habitat generalists were much more abundant and were captured at the majority of sampling sites, whereas the more sensitive species were captured in very low abundance at only a few select sites. A low species diversity is indicative of an unstable community especially when the small number of species present are mostly habitat generalists or exotics (Randall *et al.* 1998). This demonstrates the extent of heterogeneity within the Rideau River and the importance of preserving habitat for these delicate fish species that live in areas of locally suitable conditions.

Agricultural areas included farms growing cash crops, pigs, cow grazing, and horse pastures and these showed the most evidence of shoreline erosion. The most severely degraded shorelines consisted of mudslides that were created by cows walking in and out of the river, leaving the river water thick with mud and cow feces. Yet other agricultural shorelines were sandy banks that were exposed and devoid of vegetation, obviously being actively eroded with every motorboat wake as the water along the shoreline was opaque with sand and silt (personal observation). Several shoreline plant species, such as purple loosestrife and cattails, provide shoreline protection against erosion by dispersing the energy from wave action. The high levels of suspended sediment that resulted from agricultural land-use seemed to be localized effects because the sandy sediment settled out before travelling any significant distance downstream.

The substrate at agricultural sites consisted of finer grained substrate types such as sand, clay and organic detritus. These substrate types enable the growth of significantly more aquatic plants than the boulder or bedrock present at urban sites. Agricultural areas had the most abundant and diverse aquatic plant community; all species of aquatic plants were identified at agricultural sites except algae. The heterogeneity of the aquatic plant community created a variety of habitat types allowing an abundance and diversity of fish species to colonize these areas. Diverse plant communities also support diverse invertebrate communities, which are utilized by fish as prey (Randall *et al.* 1996).

The majority of YOY were captured at agricultural sites. Sunfish and perch YOY were most abundant. These rapidly growing fish rely heavily on their habitat for their growth and survival and agricultural sites were the most densely and diversely vegetated. Minnow YOY were far scarcer; golden shiner YOY were identified from four sites, the only species of minnow for which YOY were identified. The rarity of YOY minnows may indicate that these species were more sensitive to habitat disturbance and alterations to their invertebrate diets than the sunfish or perch YOY. The presence of YOY is an indication that sufficient habitat diversity was present at agricultural sites to satisfy the changing habitat needs of developing larvae. The presence of YOY is also indicative of healthy adult spawning populations, the presence of suitable water quality parameters for egg and larval development, and adequate spawning and nursery habitat. Detrimental changes to nursery habitats directly affect the number of young fish surviving to maturity.

The abundance and diversity of aquatic plants, the sand and clay substrate, in addition to shallower depths made agricultural sites suitable habitat for the majority of the Rideau River's minnow species. The sensitive blacknose shiner was captured at agricultural sites preferring areas with little current, a sandy bottom, and vegetation. One specimen of both emerald shiner and blackchin shiner were also captured at an agricultural site. However, the most abundant minnow species was the common shiner. Schools of common shiner were captured at several agricultural sites causing the CUE of cyprinids to surpass the CUE of centrarchids at these sites. Common shiner are generalist feeders that tolerate cloudy water with higher levels of suspended solids, characteristic of agricultural areas (McAllister and

Coad 1974) (Table 10). Common shiner and smallmouth bass co-occur because common shiner spawn in smallmouth bass nests. Extremely heavy use of bass nests by common shiner may limit bass spawning success but the extent is not known (Kerr and Grant 2000). Both the common shiner and smallmouth bass were present at agricultural sites. Golden shiner and largemouth bass are thought to co-occur as well. Golden shiner spawn in largemouth bass nests (Kramer and Smith 1960). Both of these species were present at agricultural sites. Bluntnose minnow were abundant at agricultural sites. These fish are tolerant of suspended sediment and are habitat generalists. The dominance of habitat generalists within a fish community is usually indicative of habitat degradation (Odum 1995).

The hardy, tolerant, spiny-rayed insectivores such as pumpkinseed, bluegill, and yellow perch dominated agricultural sites because these habitat generalists thrive in these developed areas, out competing the more sensitive species. Soft-rayed insectivores such as white sucker and the redhorse species were most abundant at agricultural sites, as these fish prefer a soft substrate and dense vegetation. Delicate brook silverside were captured in highest abundance at forested and agricultural sites in the shallows amongst weeds. Logperch were most abundant at the most degraded agricultural sites and least abundant at the most pristine forested sites. This species thrives in degraded conditions as it has broad habitat requirements and it tolerates suspended sediment within the water column. Agricultural sites had the highest abundance of piscivores. These fish were associated with the densely vegetated sites because their prey, small-bodied fish, YOY, and young soft-bodied insectivores also inhabited these areas. Black crappie were most abundant at agricultural sites. These fish are sensitive to water level fluctuations and draw-down during spawning. Water fluctuations in combination with high winds and turbidity cause stunted populations of black crappie (McNeil 1992). The average total length of black crappies in Ontario waters is between 17 and 25 cm (Scott and Crossman 1973). In the Rideau River during the 1998 sampling season, the average total length of black crappies was 16 cm (n=117, std. deviation=4.6, YOY removed from dataset). Regardless of the frequent water level fluctuations along the Rideau River, the black crappie population does not appear to be stunted. Black crappie are abundant in areas where winterkill occurs because they tolerate lower oxygen levels. However, these fish are sensitive to high levels of suspended sediment (McNeil 1992).

The shorelines along forested sites were composed of trees and shrubs with some rocks and fallen trees. Very little erosion was evident at these sites. The substrate at forested sites consisted of sand, clay, and detritus. The aquatic vegetation at forested sites was as diverse and abundant as at agricultural sites. The abundance of aquatic plants may be due to shallower depths and softer substrate. Duckweed was more abundant at forested sites. The abundance of piscivores and small-bodied fish captured at forested sites were more evenly distributed as compared to agricultural sites. Agricultural sites were dominated by an abundance of a few species of habitat generalists. At forested sites, piscivores and small-bodied fish were captured in equal abundance. Communities with even distributions of species are more diverse than communities dominated by one or two species. The large-bodied insectivore community on the other hand, was dominated by pumpkinseed, bluegill, and yellow perch. White sucker and redhorse species were not present at forested sites possibly because these fish prefer substrates composed of boulder or gravel (McAllister and Coad 1974).

Several fish species did not differ in their abundance among land-use types such as the northern pike, walleye and the tessellated darter. Very few northern pike or walleye were captured along the Rideau River, one or two specimens were captured within each land-use type. Too few specimens were captured to observe their habitat preferences. The tessellated darter was captured evenly at all land-use types; this species may not have been influenced by the habitat variables measured in this study.

Other factors, both biotic and abiotic, influence the distribution of fish within the Rideau River in addition to the aquatic habitat characteristics measured in this study. Abiotic factors include flow, fluctuating water levels, water quality, and the presence of locks. Biotic factors include competition, parasitism, and the predation of small-bodied fish and YOY by piscivorous fish (Olson 1996). The distribution of prey may also influence the distribution of fish species. For example, distributions of smallmouth bass were found to be correlated with crayfish distributions (Kerr and Grant 2000). Factors influencing the fish community may also act in concert with each other and with land-use type. For example, urbanization may have reduced the abundance of aquatic plants in a region, eliminating necessary refugia for small-bodied fish. These fish may succumb to predation pressure, as they have nowhere to escape (Diehl 1992). The incorporation of these synergies and other abiotic and biotic factors into the analysis would provide a more balanced view of the Rideau River. It is difficult to quantify these factors, however, with a broad study such as this.

Since fish community characteristics differed among land-use types, it was predicted that as development changes forested land into agricultural or urban land, the habitat characteristics and the fish community would also change. These results showed that diverse and evenly abundant forested fish communities may become dominated by one or two habitat generalists, which may contribute to the elimination of sensitive species upon agricultural or urban land-use development.

2.5.1. Management Issues

The Rideau River is a fairly pristine river for this region. There are no large industries along the river dumping their effluent and agricultural practices are generally small family owned farms that do not directly dump waste into the river. In order to effectively manage aquatic habitat for the purpose of maintaining a diverse and abundant fish community, an understanding of fish behaviour and their relationship with aquatic habitat is necessary. Rideau River management should revolve around maintaining the heterogeneity of substrate, flow and depth, providing a diversely vegetated littoral zone, and elimination of pollution sources. The maintenance of such heterogeneity would ensure that a diversity of habitat were available for all life stages of young fish and the needs of different species. The Rideau River is over fertilized; downstream areas have high levels of nitrogen and phosphorus due to point source and non-point source pollution (P. Hamilton, Canadian Museum of Nature, personal communication). The further reduction of these nutrients, however, would be a slow process requiring both urban and agricultural sources to limit the amount of fertilizer that leaches into the river.

Sites deemed 'the best' along the Rideau River were those with the highest abundance and diversity of aquatic plants and fishes. These sites were the most heterogeneous. Site five, the area below Hogs Back Falls called Brewer Park was the best urban site. This area was the target of a community service initiative that cleaned-up and replanted the shoreline vegetation. This site had a variety of flow regimes, due to Hogs Back Falls, creating a variety of habitats suitable for a variety of aquatic plant and fish species. Several minnow species were captured in this area as well as a mottled sculpin, a freshwater drum, and an abundance of YOY.

The best agricultural area was site twelve, located near buoy N211 close to Muldoon Road. This site was characterized by a variety of aquatic plant species, lots of large-woody debris, and a variety of depths. This site had a high number of species and a high abundance of YOY. Walleye, several minnow species, and a tadpole madtom were captured here.

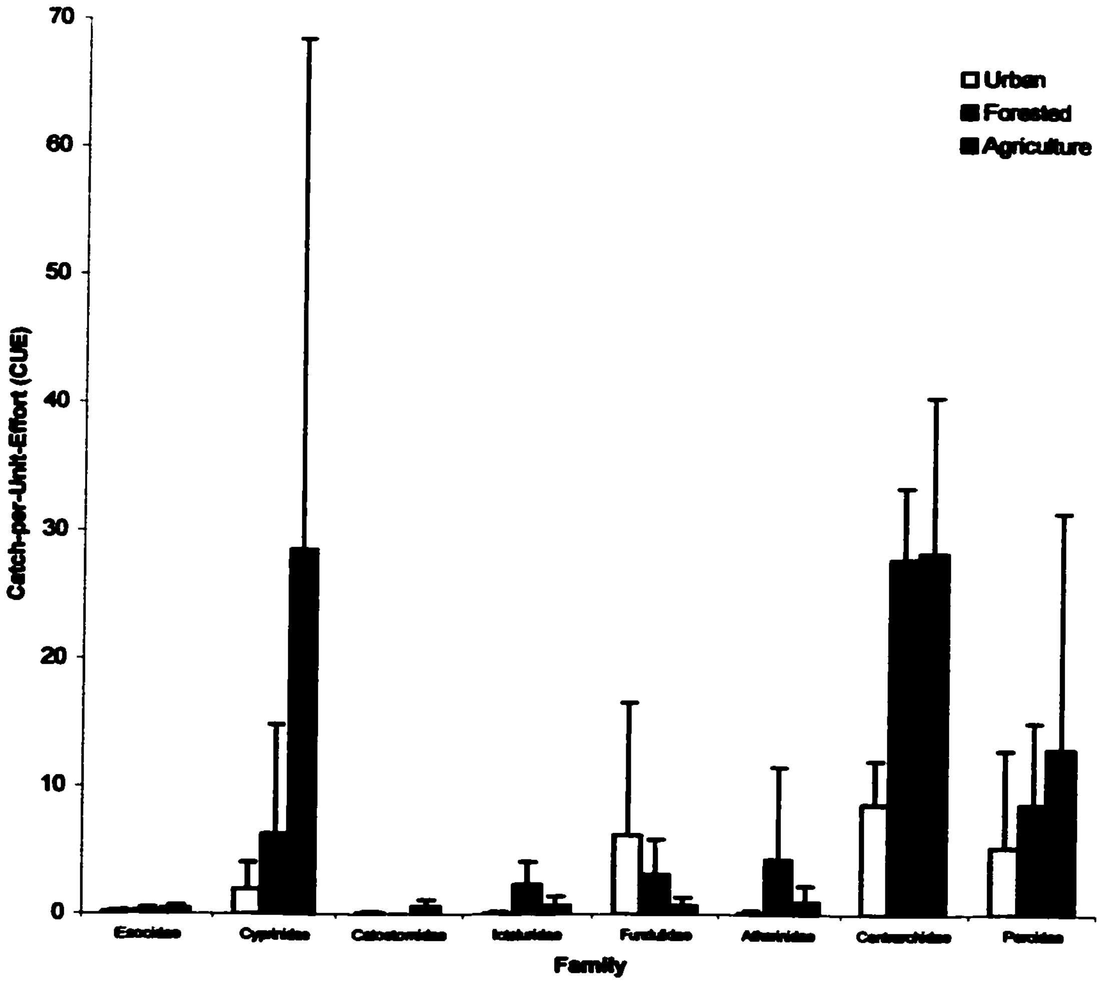
Forested site seven was located slightly west of Rideau River Provincial Park and the mouth of Kemptville Creek. This was the best forested site because it was home to an abundance of many species including brook silverside, several minnow species, large and smallmouth bass, and walleye. This site also had the highest catch per unit effort for forested sites. Site seven had an enormous amount of aquatic vegetation creating a diversity of habitats for fish species.

The worst sites along the Rideau River were located within the Eccolands reach of the river in-between Blacks Rapids and Long Island. Along this reach there were stretches of cash-crops growing to the very edge of the steep, sandy riverbanks devoid of vegetation that were actively being eroded away. Several dairy farms were also located within this reach. Cows had unhindered access to the river creating muddy polluted areas. Ideally, the worst areas in addition to the three best areas should be prioritized for a conservation initiative. The worst should be restored while the best sites should be preserved because they are representative of the Rideau River fish community and are home to a variety of sensitive species.

2.6. Conclusion

The objective of this study was to examine the relationship between the relative abundance and diversity of the Rideau River fish community and the aquatic habitat characteristics that result from agricultural, forested, and urban land-use. The objective was addressed by first examining the relationship between land-use and the aquatic habitat characteristics. Next, the relationship between the aquatic habitat characteristics and the fish community was examined and lastly, the relationship between land-use type and the fish community was examined. The results indicate that land-use type was correlated with deep and shallow aquatic plant abundance and substrate type. These habitat characteristics were correlated with several sub-groups of fish species. As such, the sub-groups of fish species were correlated with land-use type. These results support the hypothesis that adjoining land-use type influences the fish community. These finding have allowed the habitat characteristics and the diversity and abundance of the fish community to be characterized for each land-use type along the Rideau River.

Fig. 6:
Catch-per-unit-effort (CUE) for fish families captured in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.



70
60
50
40
30
20
10
0
Catch-per-Unit-Effort (CUE)
Urban
Forested
Agriculture
Family

Fig. 7:
Catch-per-unit-effort (CUE) for large-bodied insectivores captured in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.

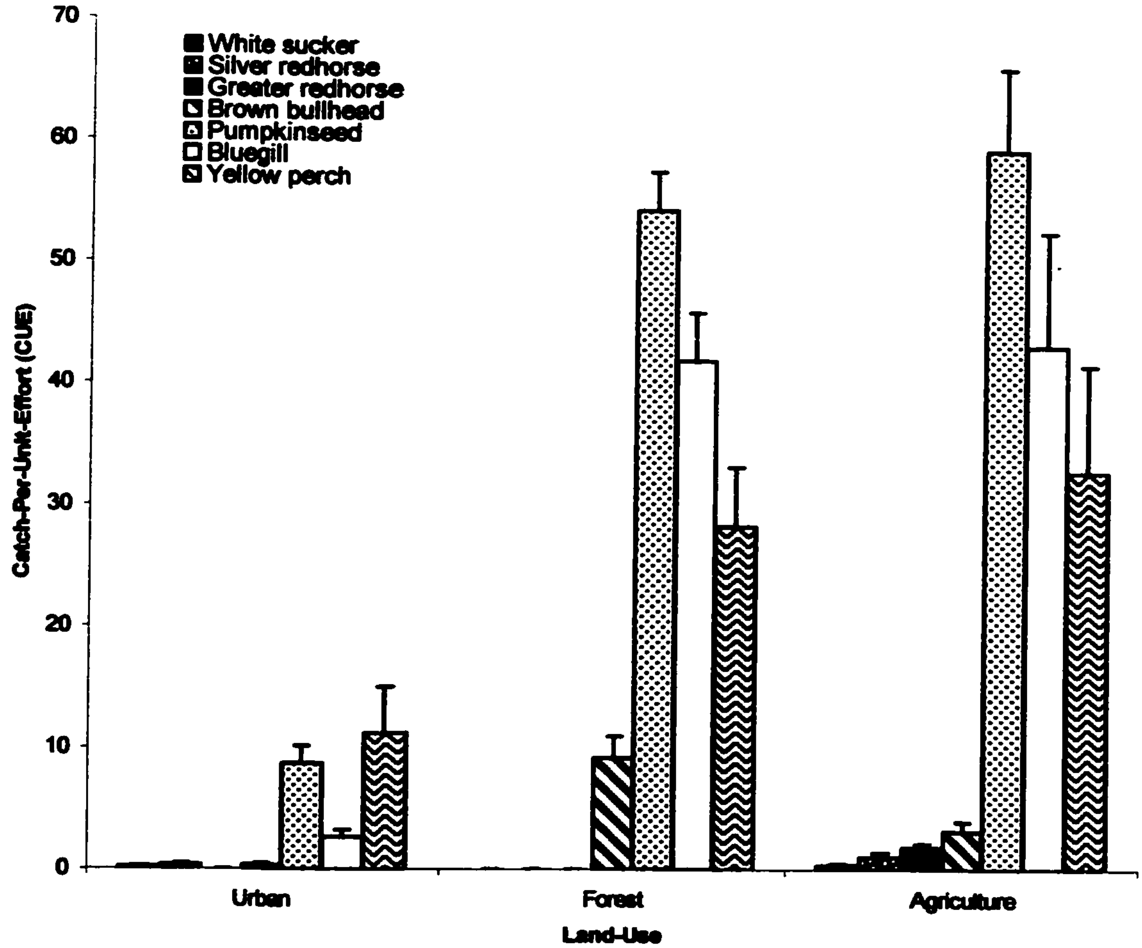
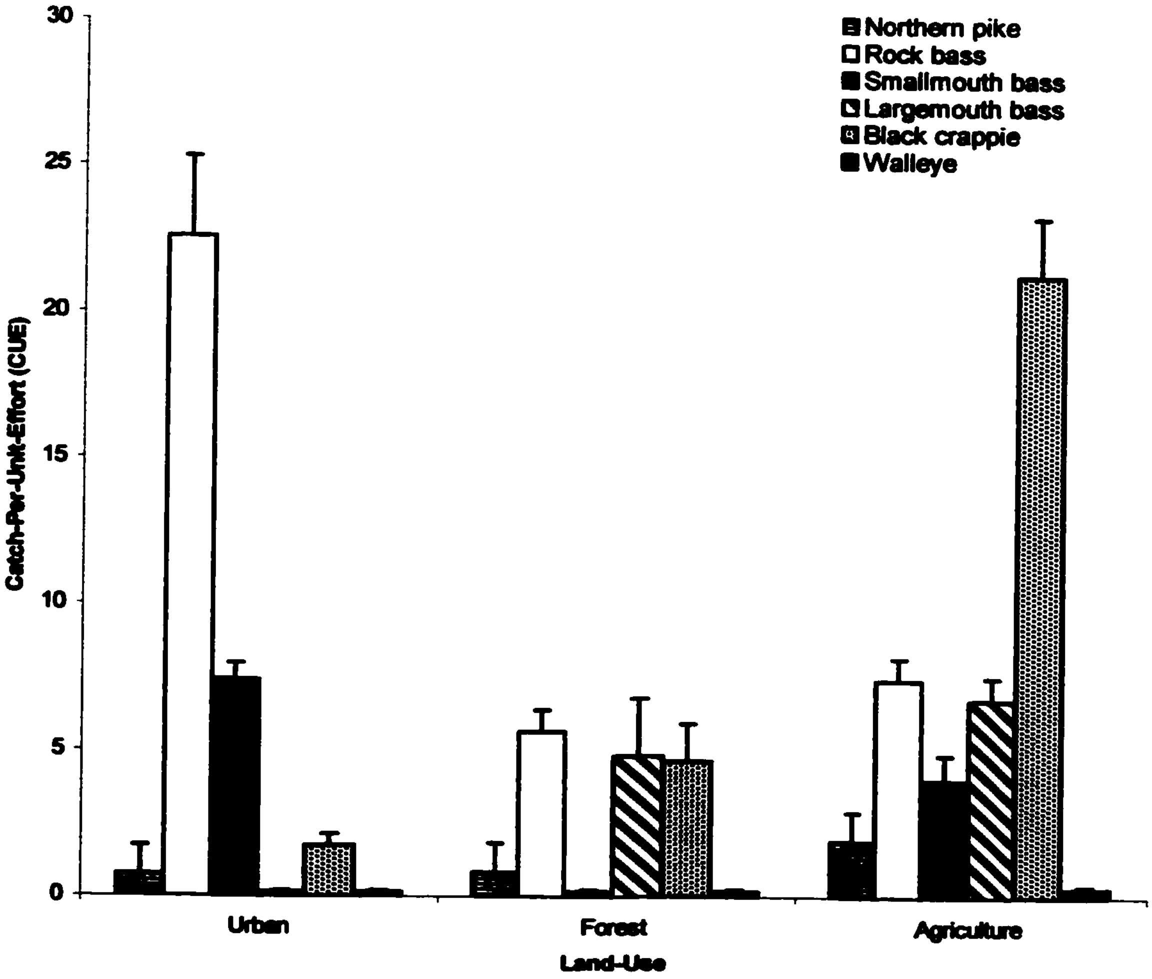
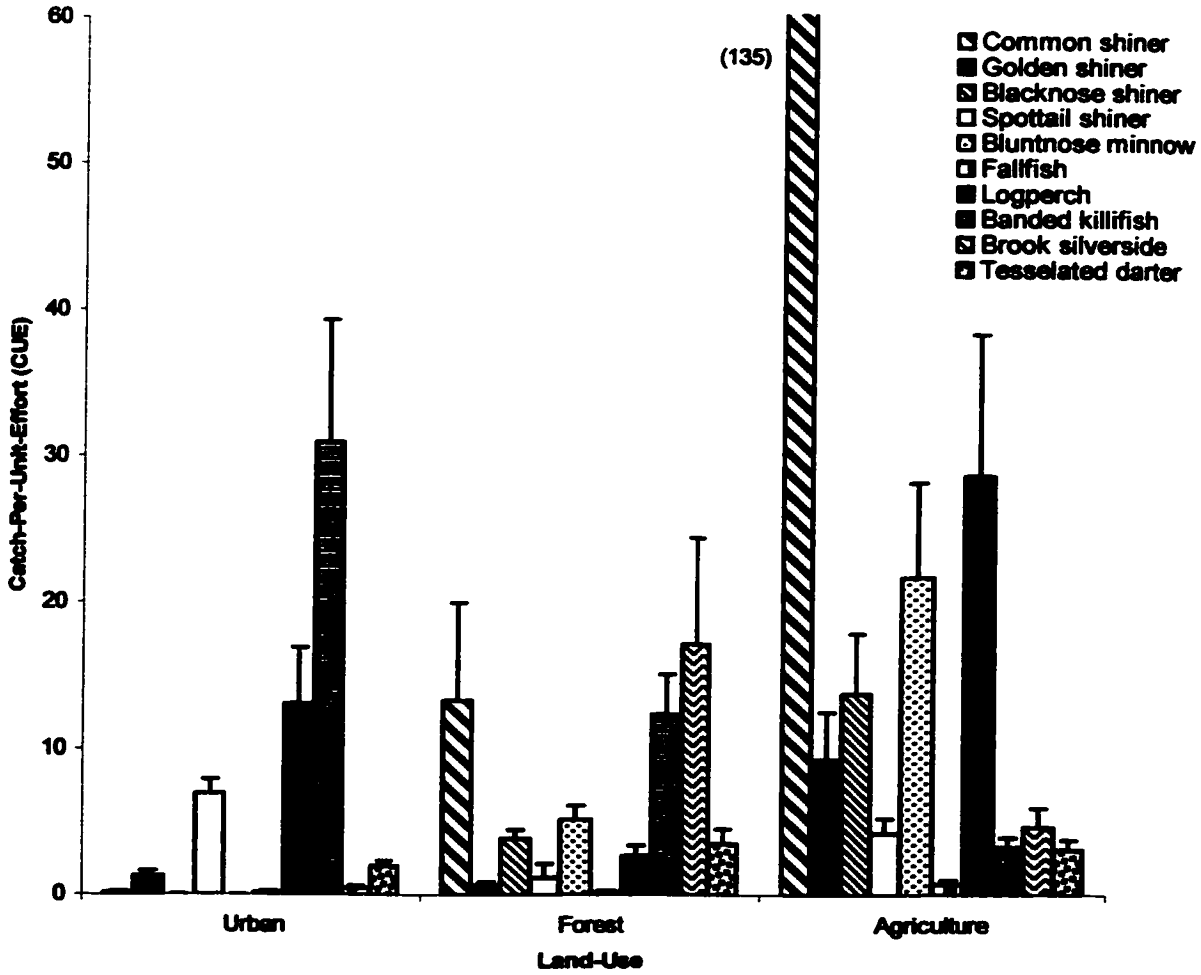

70
60
50
40
30
20
10
0
Catch-Per-Unit-Effort (CUE)
White sucker
Silver redhorse
Greater redhorse
Brown bullhead
Pumpkinseed
Bluegill
Yellow perch
Urban
Forest
Agriculture
Land-Use

Fig. 8:
Catch-per-unit-effort (CUE) for piscivores captured in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.



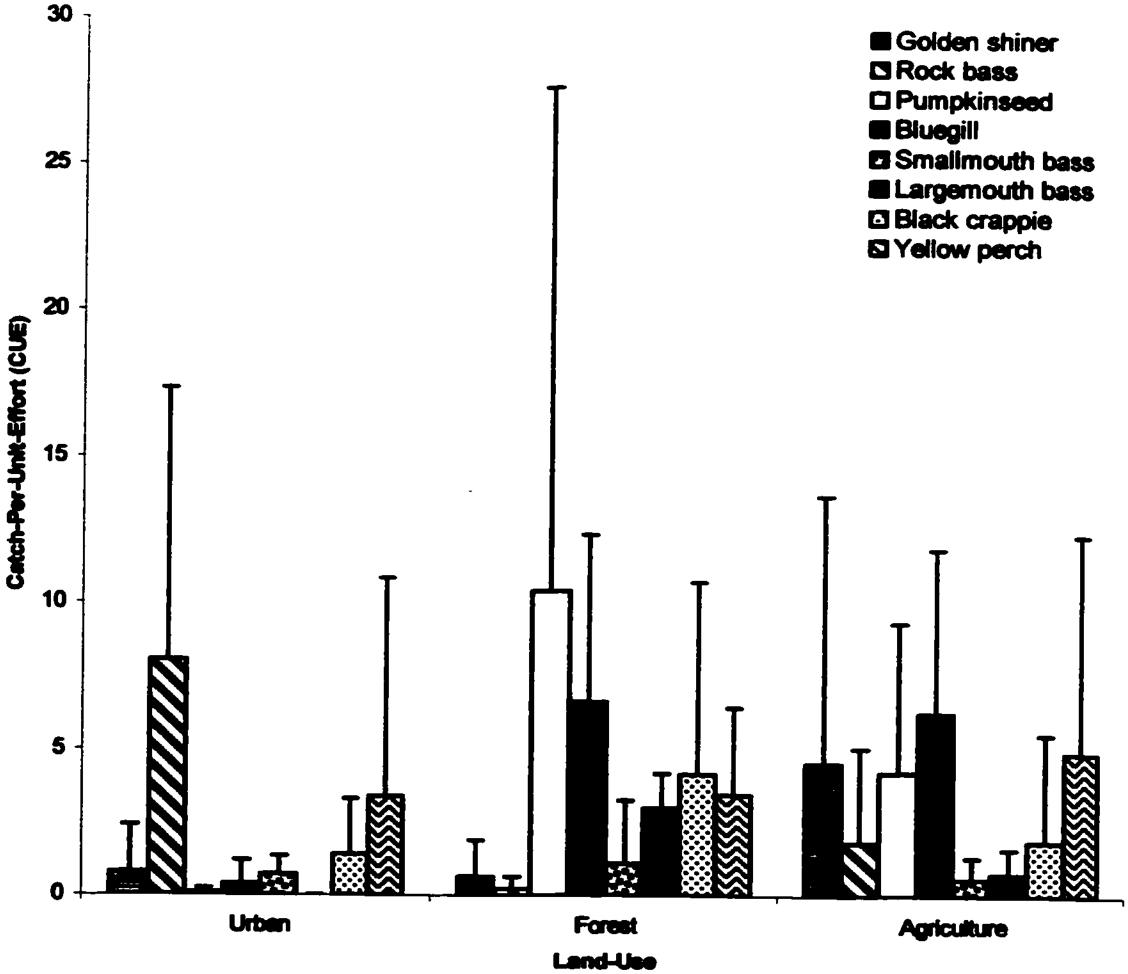
30
25
20
15
10
5
0
Catch-Per-Unit-Effort (CUE)
Northern pike
Rock bass
Smallmouth bass
Largemouth bass
Black crappie
Walleye
Urban
Forest
Agriculture
Land-Use

Fig. 9:
Catch-per-unit-effort (CUE) for small-bodied fish captured in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.



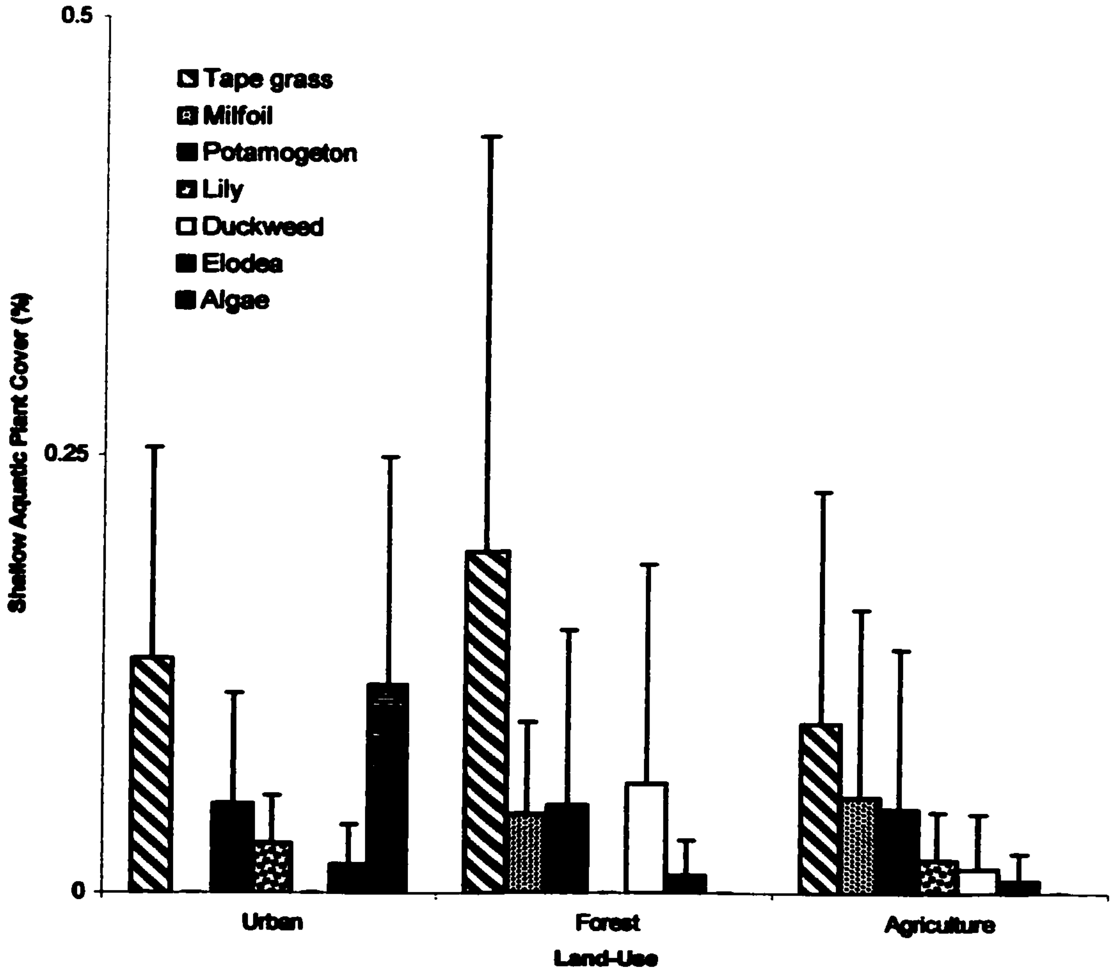
60
50
40
30
20
10
0
Catch-Per-Unit-Effort (CUE)
(135)
Common shiner
Golden shiner
Blacknose shiner
Spottail shiner
Bluntnose minnow
Fallfish
Logperch
Banded killifish
Brook silverside
Tesselated darter
Urban
Forest
Agriculture
Land-Use

Fig. 10:
Catch-per-unit-effort (CUE) of young-of-the-year (YOY) fish captured in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.



30
25
20
15
10
5
0
Catch-Per-Unit-Effort (CUE)
Golden shiner
Rock bass
Pumpkinseed
Bluegill
Smallmouth bass
Largemouth bass
Black crappie
Yellow perch
Urban
Forest
Agriculture
Land-Use

Fig. 11:
The percentage of shallow aquatic cover at urban, forested, and agricultural sites in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.



0.5
0.25
0
Tape grass
Milfoil
Potamogeton
Lily
Duckweed
Elodea
Algae
Shallow Aquatic Plant Cover (%)
Urban
Forest
Agriculture
Land-Use

Fig. 12:

The percentage of deep aquatic cover at urban, forested, and agricultural sites in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.

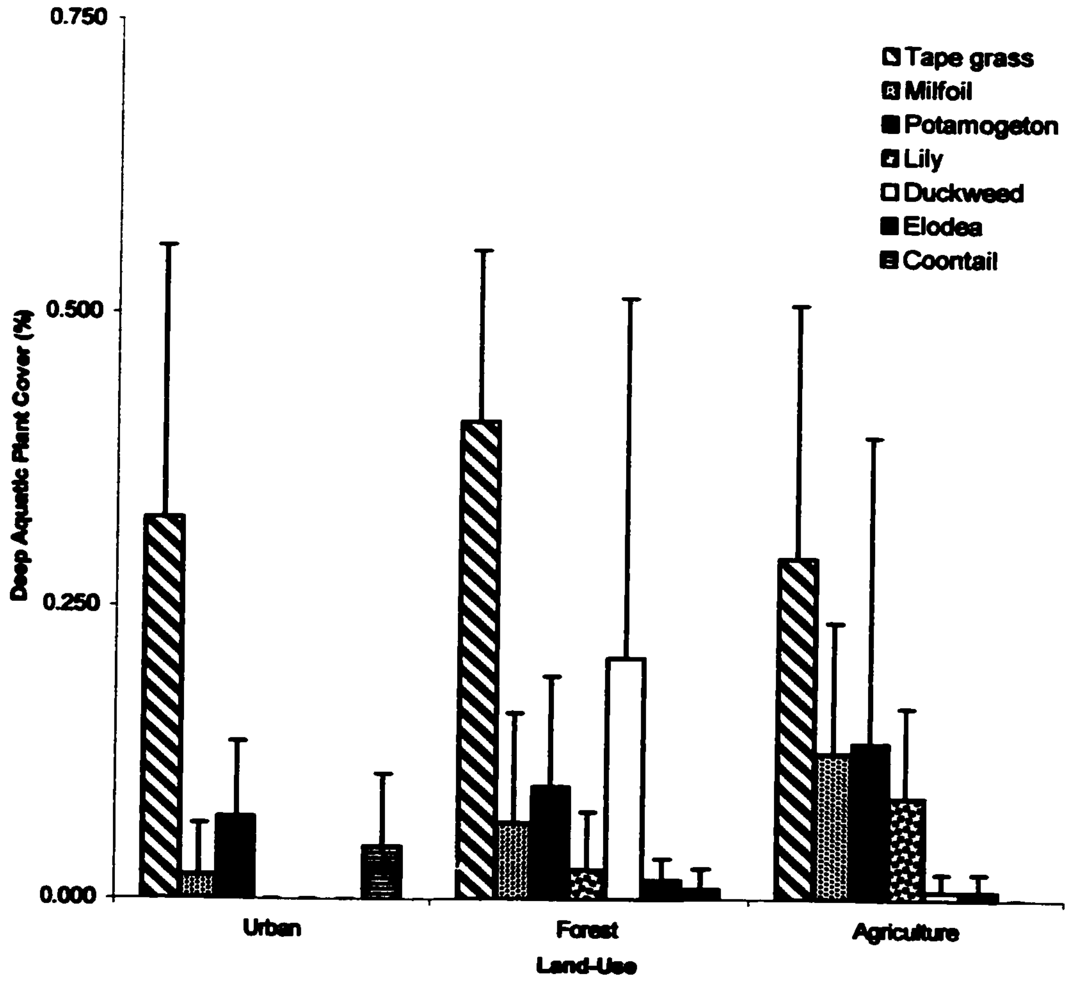
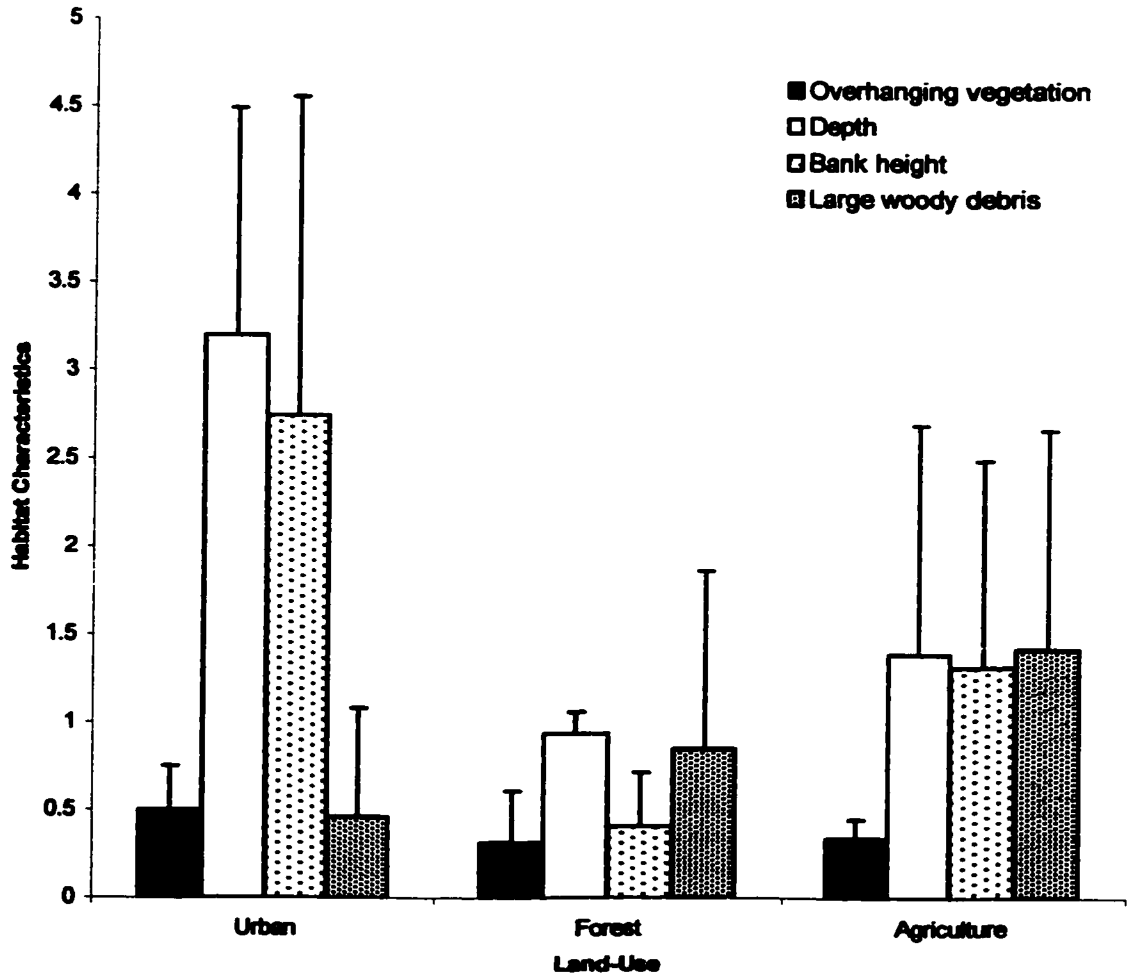
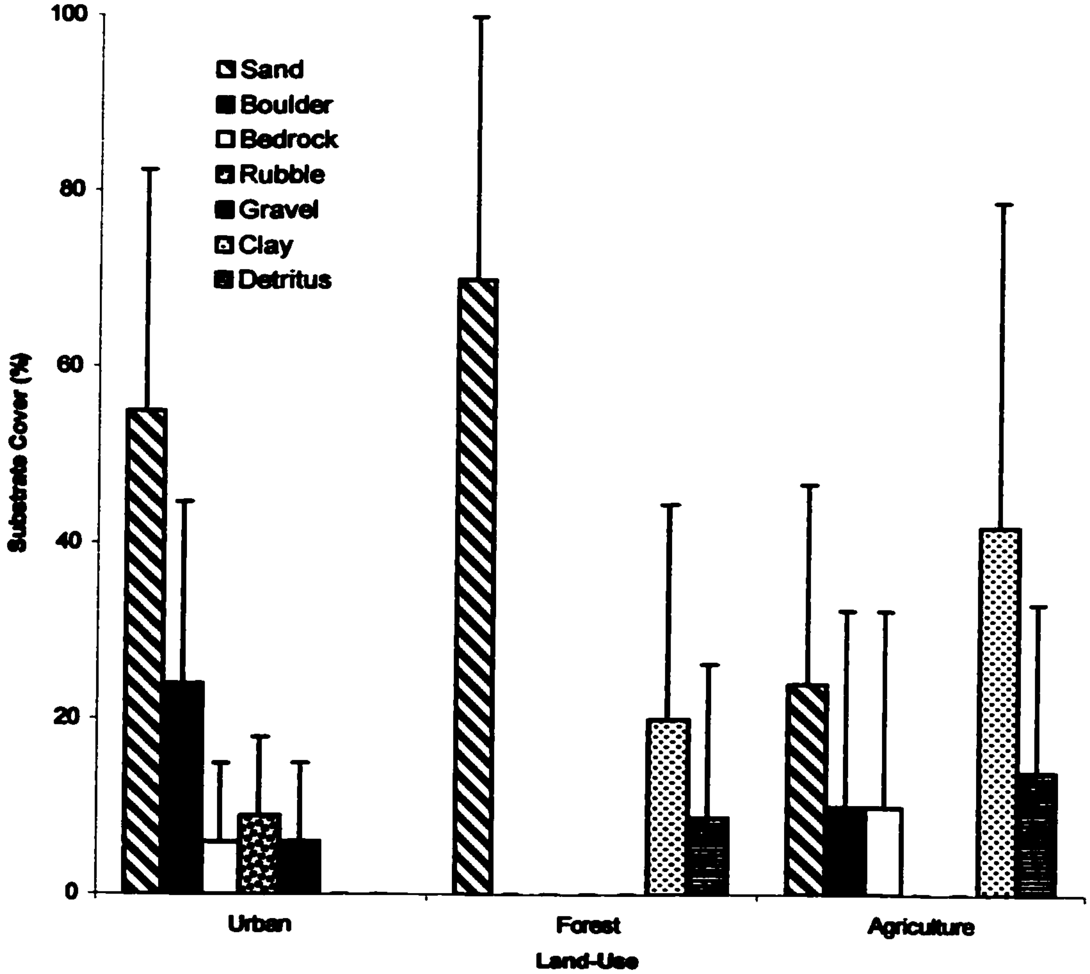

0.750
0.500
0.250
0.000
Deep Aquatic Plant Cover (%)
Tape grass
Milfoil
Potamogeton
Lily
Duckweed
Elodea
Coontail
Urban
Forest
Agriculture
Land-Use

Fig. 13:
The values obtained for percentage of overhanging vegetation (%) x 10, depth (m), bank height (m), and percentage of large woody debris (%) x 10 along the Rideau River. Measurements were made during the 1998 sampling season. Error bars represent one standard deviation around the mean.



5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Habitat Characteristics
Overhanging vegetation
Depth
Bank height
Large woody debris
Urban
Forest
Agriculture
Land-Use

Fig. 14:
The percentage of substrate cover at urban, forested, and agricultural sites in the Rideau River during the 1998 sampling season. Error bars represent one standard deviation around the mean.



100
80
60
40
20
0
Sand
Boulder
Bedrock
Rubble
Gravel
Clay
Detritus
Substrate Cover (%)
Urban
Forest
Agriculture
Land-Use

Fig. 15:

Sampling sites along the Rideau River clustered by the relative abundance of fish species present at 3 or more sites. The YOY were removed from the data. Group A consists of mostly urban sites and clusters at a distance of 1.761. Group B consists of agricultural and forested sites and clusters at 0.958. Pearson distance and Ward joining algorithm were used.

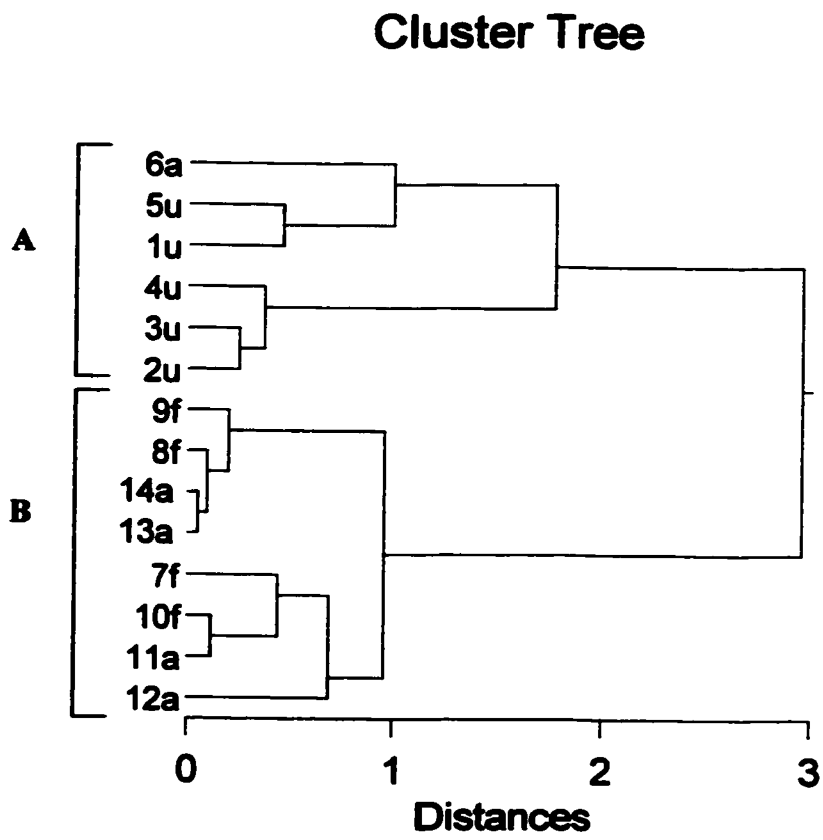

Cluster Tree
A
B
6a
5u
1u
4u
3u
2u
9f
8f
14a
13a
7f
10f
11a
12a
0
1
2
3
Distances

Fig. 16:
Sampling sites along the Rideau River clustered by the relative abundance of piscivorous fish species present at 3 or more sites. The YOY were removed from the data. Group A consists of all urban sites and two forested sites, they cluster at a distance of 0.492. Group B consists of all agricultural sites and one forested site and clusters at 0.593. Pearson distance and complete joining algorithm were used.

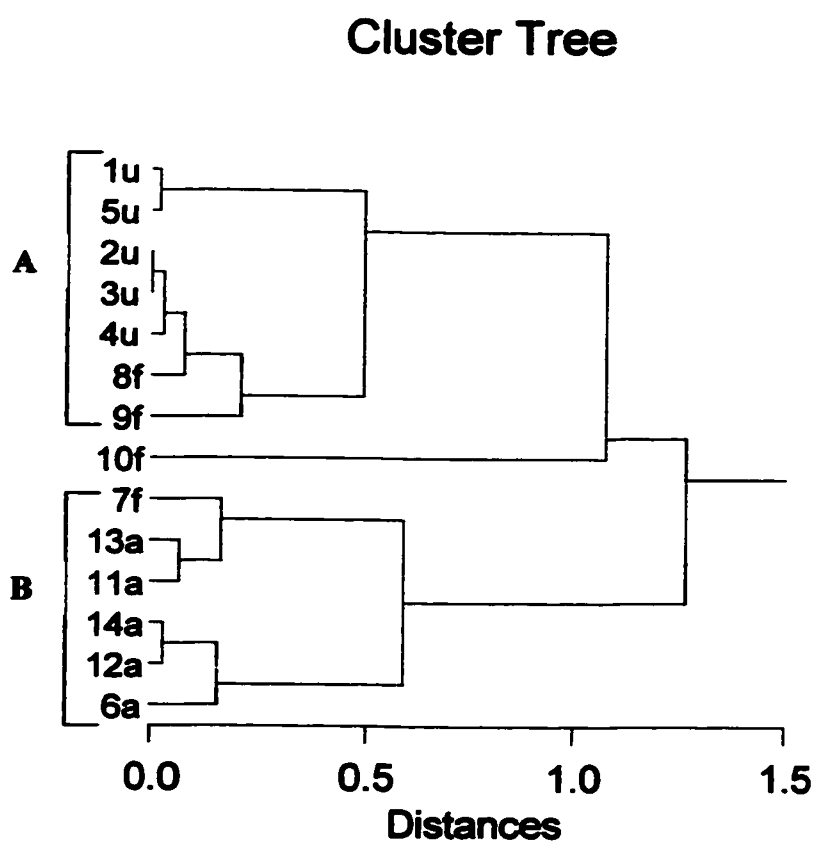

Cluster Tree
A
B
1u
5u
2u
3u
4u
8f
9f
10f
7f
13a
11a
14a
12a
6a
0.0
0.5
1.0
1.5
Distances

Fig. 17:
Sampling sites along the Rideau River clustered by the relative abundance of insectivorous fish species present at 3 or more sites. The YOY were removed from the data. Group A consists of all urban sites clustered at a distance of 3.62. Groups B and C each consist of two agricultural sites and two forested sites, clustered at 4.616 and 3.198 respectively. Euclidean distance and complete joining algorithm were used.

Cluster Tree

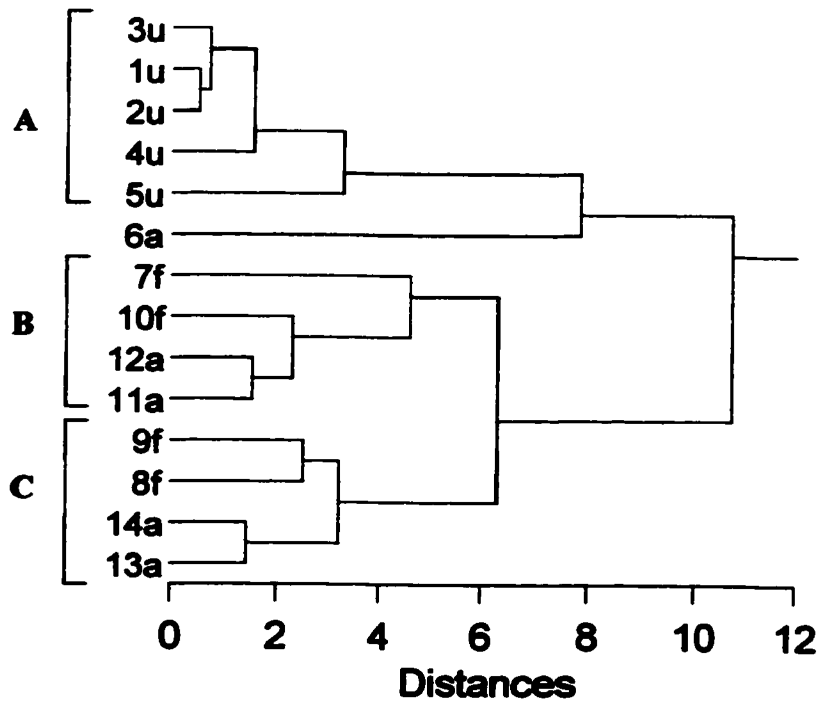


Fig. 18:
Sampling sites along the Rideau River clustered by the relative abundance of YOY fish species present at 3 or more sites. The YOY were removed from the data. Group A consists of four urban sites and an agricultural and forested site clustered at a distance of 1.440. Groups B consists of a mixture of agricultural and forested sites and one urban site clustered at1.332. Pearson distance and complete joining algorithm were used.

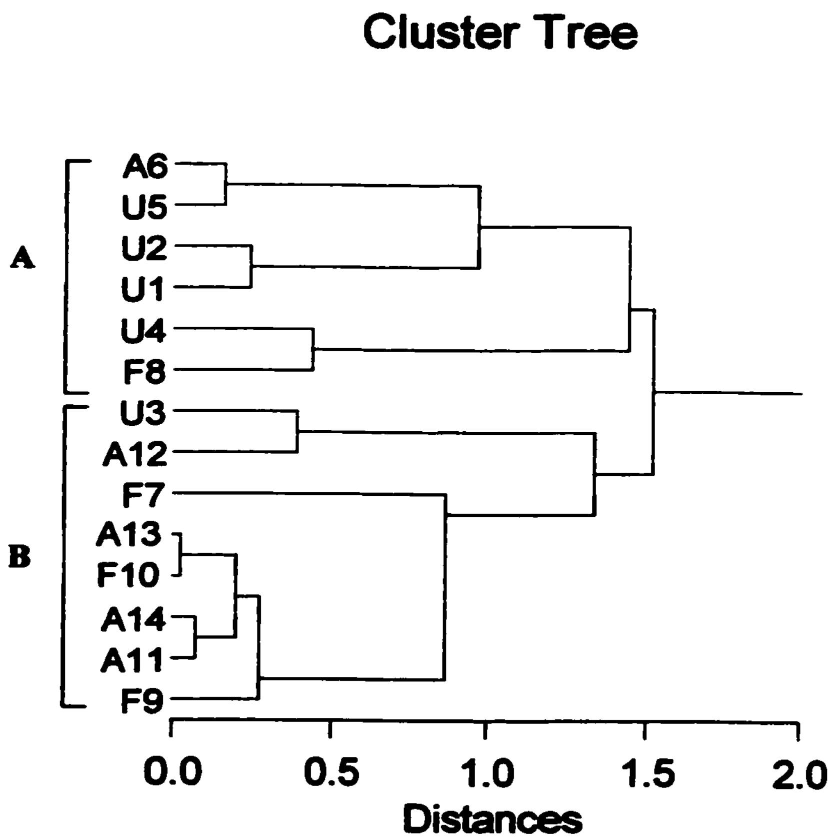

Cluster Tree
A
B
A6
U5
U2
U1
U4
F8
U3
A12
F7
A13
F10
A14
A11
F9
0.0
0.5
1.0
1.5
2.0
Distances

Fig. 19:
Sampling sites along the Rideau River clustered by the relative abundance of small-bodied fish species present at 3 or more sites. The YOY were removed from the data. Group A consists of a mixture of urban, agricultural, and a forested site clustered at a distance of 2.101. Group B consists of a mixture of agricultural and forested sites clustered at 0.527. Group C consists of three urban sites with two forested sites clustered at 0.173. Pearson distance and Ward joining algorithm were used.

Cluster Tree

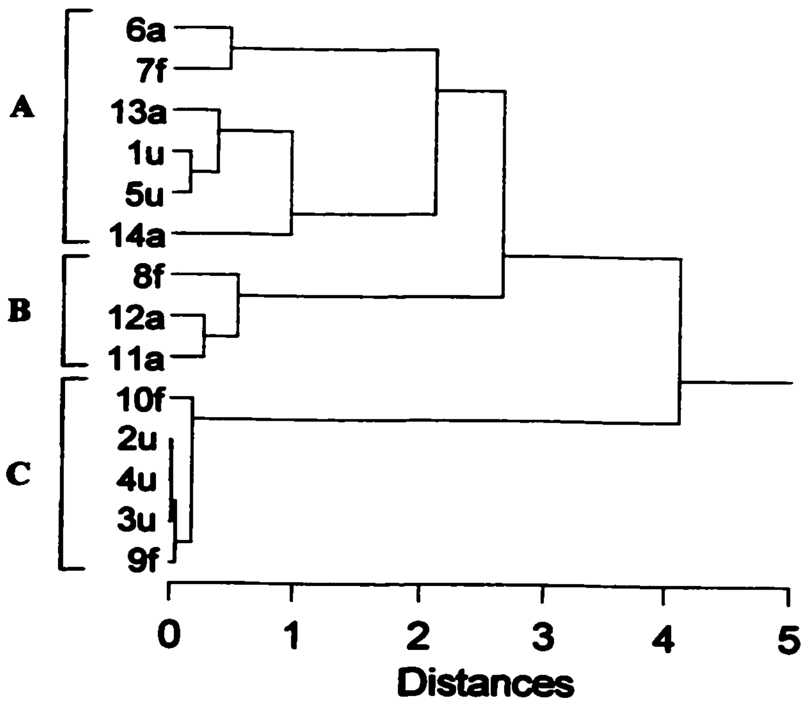


Fig. 20:
Sampling sites along the Rideau River clustered by the relative abundance of deep and shallow aquatic vegetation and substrate type. Group A consists of all urban sites with forested sites. It clustered at a distance of 0.901. Group B consists of agricultural sites and one forested site clustered at 1.367. Sites 14 and 8 were removed from the dataset because no shallow aquatic vegetation was present at these sites. Pearson distance and Ward joining algorithm were used.

Cluster Tree

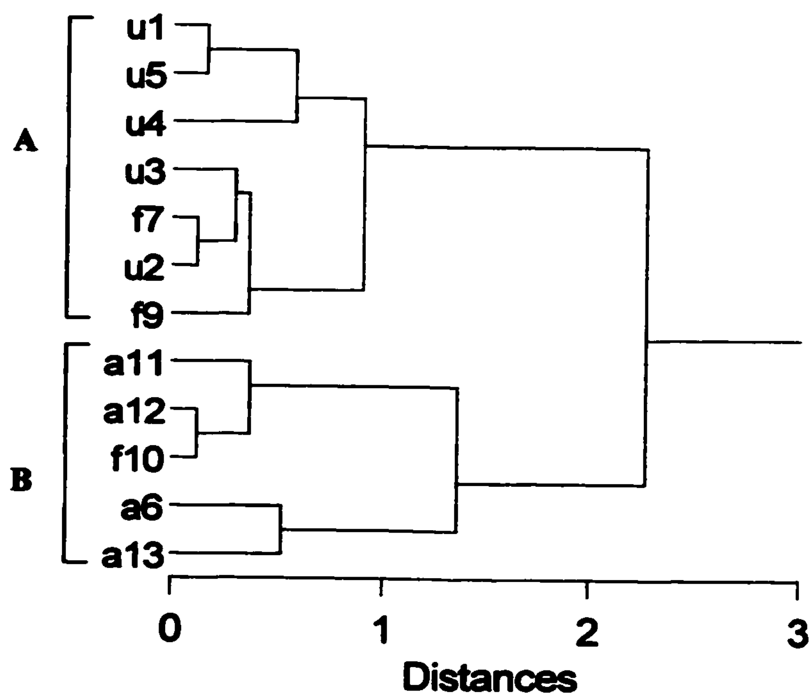


Fig. 21:
Sampling sites along the Rideau River clustered by the relative abundance of shallow aquatic vegetation. Group A clustered at a distance of 0.079, group B clustered at 0.133, and group C clustered at 0.187. Sites 14 and 8 were removed from the dataset because no shallow aquatic vegetation was present at these sites. Euclidean distance and Ward joining algorithm were used.

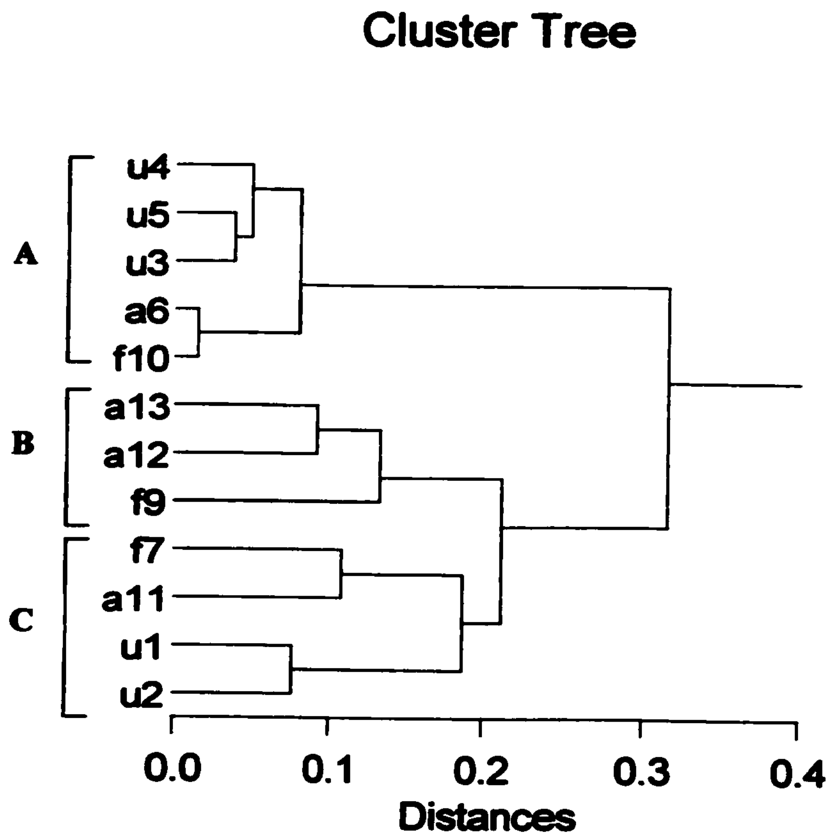

Cluster Tree
A
B
C
u4
u5
u3
a6
f10
a13
a12
f9
f7
a11
u1
u2
0.0
0.1
0.2
0.3
0.4
Distances

Fig. 22:
Sampling sites along the Rideau River clustered by the relative abundance of deep aquatic vegetation. Group A clustered at a distance of 0.200 and group B clustered at 0.137. Euclidean distance and Ward joining algorithm were used.

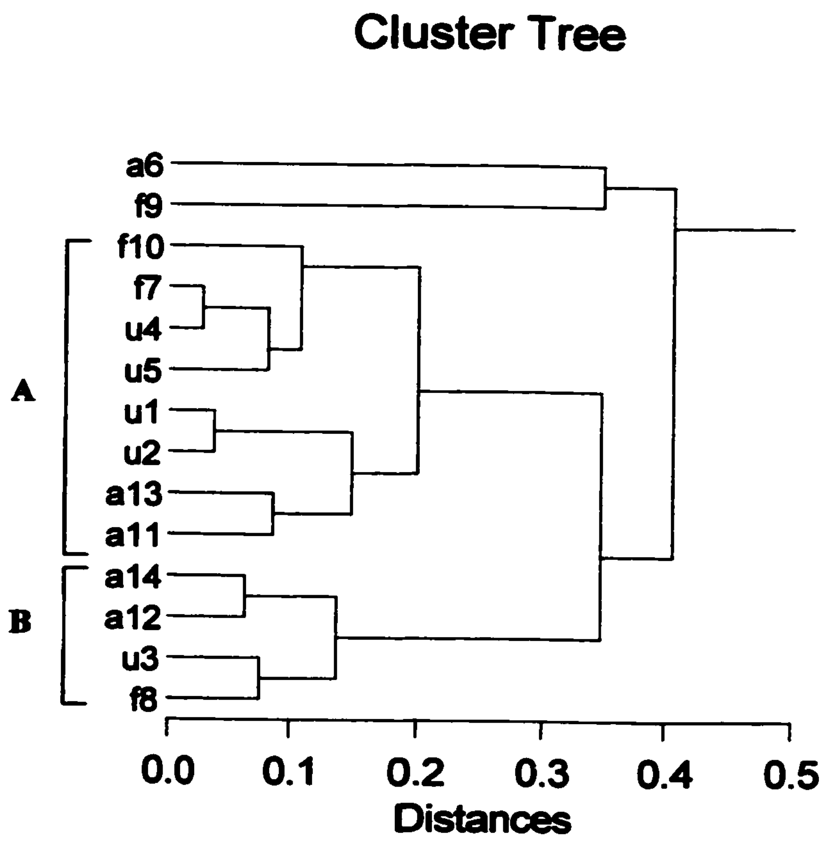

Cluster Tree
a6
f9
f10
f7
u4
u5
u1
u2
a13
a11
a14
a12
u3
f8
A
B
0.0
0.1
0.2
0.3
0.4
0.5
Distances

Fig. 23:
Sampling sites along the Rideau River clustered by the relative abundance of substrate type. Group A clustered at a distance of 0.973 and group B clustered at 0.742. Pearson distance and complete joining algorithm were used.

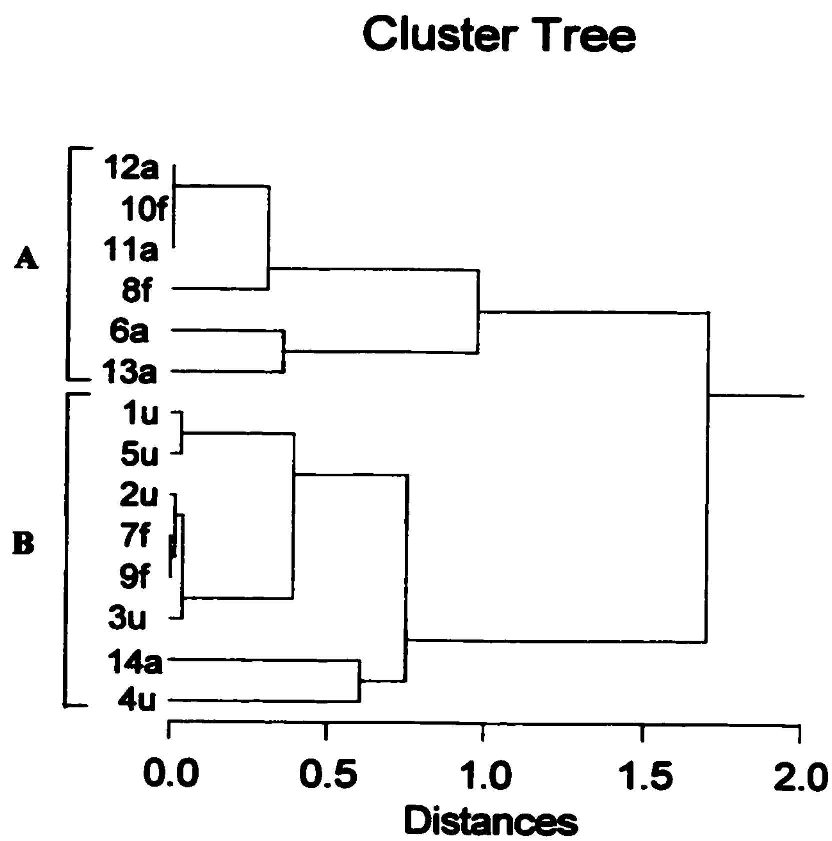

Cluster Tree
A
B
12a
10f
11a
8f
6a
13a
1u
5u
2u
7f
9f
3u
14a
4u
0.0
0.5
1.0
1.5
2.0
Distances

Table 6:
Habitat characteristics for fish species captured in the Rideau River, Ontario (Scott and Crossman 1973, McAllister and Coad 1974, Stern and Stickle 1978, Bernatchez and Giroux 1991, Lane *et al.* 1996, Cook and Bunt 1999, and Portt *et al.* 1999).

Fish Species	Spawning Season	Spawning Temperature (°C)	Spawning Substrate	Spawnin g Flow	Non-Spawning Habitat	Tolerance Suspended Sediment
Northern Pike	Spring (April-May)	4-11	Silt, sand with vegetation	Stagnant	In cover (weeds, wood, cobble	Sensitive
Muskellunge	Spring (May)	9.4-15.0	Mud, sand	Slow	In cover (weeds, wood, cobble)	Sensitive
Minnows	Spring-Summer (April-July)	~9-20	Varied	Varied	Open water to dense vegetation	Sensitive
Brook silverside	Spring-Summer (May-July)	20-23	Vegetation, rubble, gravel	Slow	Sand or gravel	Sensitive
White sucker	Spring (April-May)	~10.0	Gravel	Turbulent	Shallow warm water	Tolerant
Silver redhorse	Spring (May)	~13	Gravel, cobble	Turbulent	Slow current & deep channels	Unknown
Greater redhorse	Spring (June)	13-17	Sand, gravel	Turbulent	Slow current & deep channels	Unknown
Brown bullhead	Spring (May-June)	21.1	Sand, clay with vegetation	Turbulent	Shallow warm water	Tolerant
Banded killifish	Spring (June)	~23	Sand, rubble, gravel with veg	Slow	Moderate to slow current, weeds,	Unknown
Mottled sculpin	Spring (May)	~10	Boulder, cobble	Turbulent	Moderate current	Sensitive
Rock bass	Spring-Summer (June)	15.6-21.1	Cobble,rubble, and gravel	Varied	Shallow warm water, cobble	Tolerant
Pumpkinseed	Spring-Summer (June-July)	~20.0	Mud, sand, gravel, lots vegetation	Stagnant to slow	Shallow warm water weeds	Tolerant
Bluegill	Summer (July-August)	20-24.5	Sand, gravel and clay, veg	Stagnant	Shallow warm water weeds	Tolerant
Smallmouth bass	Spring (May-June)	16.1-18.3	Sand, gravel	Slow	Boulder	Sensitive
Largemouth bass	Spring-Summer (June-July)	18-26	Rocks, boulder in Ontario publications. Sand, silt and clay in Ottawa area publications	Slow to medium	Abundant vegetation, rocks, boulders, slow-med current	Unknown
Black crappie	Spring-Summer (June-July)	19-20	Sand, silt, gravel, veg	Slow	Sand, rocks, boulders	Unknown
Tesselated darter	Spring (May-June)	14-17	Rubble, cobble, gravel, sand	Stagnant to slow	Sand to clay bottom shallow water	Sensitive
Yellow perch	Spring (April-May)	8.9-12.2	Sand, gravel, veg, dead trees	Turbulent	Open water, vegetation	Tolerant
Logperch	Late spring (June)	unknown	Sand, mud, gravel	Slow to medium	Sand mud substrate, slow to med current	Unknown
Walleye	Spring (April)	6.7-11.1	Cobble, boulder	Turbulent	Shallow to deep water with cover (weeds & rocks)	Sensitive

Table 7:

A summary of the four data matrices used to describe the fish community and habitat characteristics. Fish species present at two or fewer sites were removed from the dataset. * Yellow perch were classified as insectivores even though individuals larger than 15 cm in total length consume fish. This is because only 9% of the yellow perch captured in the Rideau River were larger than 15 cm; the majority of individuals were insectivores.

Group	Fish species	Group	Fish species
Piscivores	Northern pike	Insectivores	White sucker
	Rock bass		Silver redhorse
	Black crappie		Greater redhorse
	Smallmouth bass		Brown bullhead
	Largemouth bass		Pumpkinseed
	Walleye		Bluegill
			Yellow perch*
Small-bodied fish	Common shiner	YOY	Golden shiner
	Golden shiner		Rock bass
	Blacknose shiner		Pumpkinseed
	Spottail shiner		Bluegill
	Bluntnose minnow		Smallmouth bass
	Fallfish		Largemouth bass
	Banded killifish		Black crappie
	Brook silverside		Yellow perch
	Tessellated darter		
	Logperch		

Table 8:
Sizes below which young-of-the-year fishes were eliminated from the dataset, as determined from length-frequency histograms.

Common Name	Scientific Name	Size(mm)	Number of YOY removed		
			Urban	Forested	Agricultural
Golden shiner	*Notemigonus crysoleucas*	≤ 60	23	15	136
Rock bass	*Ambloplites rupestris*	≤ 60	244	5	48
Pumpkinseed	*Lepomis gibbosus*	≤ 60	2	250	126
Bluegill	*Lepomis macrochirus*	≤ 60	11	143	199
Smallmouth bass	*Micropterus dolomieu*	≤ 100	11	26	16
Largemouth bass	*Micropterus salmoides*	≤ 100	0	49	11
Black crappie	*Pomoxis nigromaculatus*	≤ 80	46	96	62
Yellow perch	*Perca flavescens*	≤ 80	118	83	168
		Total	455	667	766

Table 9:
Mantel tests were conducted between the relative abundance of piscivorous dissimilarity matrix and the matrices of the relative abundance of YOY and small-bodied fish. Z distributions were created from 1000 randomizations. Fish species present at two or fewer sites were removed from the dataset prior to the analysis. *Z* is the observed *Z*-statistic, *p* is the p-value, $\alpha = 0.05$.

Relative Abundance	Relative Abundance of Piscivorous Fish		
	Z	**p**	**Result**
YOY	2922.149	0.000	**+ correlation**
Small-bodied fish	3771.225	0.000	**+ correlation**

Table 10:
Summary of total suspended solids measured from the Rideau River during the 1998 sampling season. Averages and standard deviations were calculated from all raw data collected by the RRBP and RMOC for each site, pooled over the entire sampling period.

Area	RRBP and RMOC Sites	Average (mg/L)	Number of samples	Standard deviation
Rideau Falls to Hogs Back	103A, 103B, 108A, 108B	0.86	18	0.42
Mooneys Bay to Blacks Rapids	167A, 167B, 118A, 188B	1.81	20	1.08
Blacks Rapids to Long Island	13A, 13B, 12A, 12B, 119A, 199B	0.91	42	0.55
Long Island to Burritts Rapids	09A, 09B, 08A, 08B, 121A, 121B	2.10	40	0.82
Burritts Rapids to Merrickville	05A, 05B	1.33	18	0.50

Table 11:

Spatial autocorrelation was assessed through the use of Mantel tests conducted between habitat or fish community dissimilarity matrices and a matrix of geographic distances among sites. *Z* distributions were created from 1000 randomizations. Fish species present at two or fewer sites were removed from the dataset prior to the analysis. *Z* is the observed *Z*-statistic, *p* is the p-value, α adjusted Bonferroni value.

	Geographic distance			
	Z	p	Adjusted α	Result
Fish Community				
Relative Abundance				
all species	18068.560	0.199	0.0083	no correlation
piscivores	5025.315	0.002	0.0062	+ correlation
insectivores	17589.890	0.000	0.0055	+ correlation
small-bodied fish	20259.550	0.425	0.0167	no correlation
Habitat Abundance				
deep aquatic plants	432.602	0.457	0.025	no correlation
shallow aquatic plants	305.229	0.483	0.05	no correlation
substrate	3853.405	0.012	0.0071	no correlation
depth	4568.095	0.390	0.0125	no correlation
overhanging vegetation	828.212	0.277	0.01	no correlation

Table 12:
Seven reaches of Rideau River separated by locks (Legget 1986). (u) identifies urban sites, (a) identifies agricultural sites, and (f) identifies forested sites.

Reach	Approximate Length (km)	Sites
Rideau Falls – Hogs Back	9	1, 2, 3, 4 (u)
Hogs Back – Blacks Rapids	6.5	5 (u)
Blacks Rapids – Long Island	8	6 (a)
Long Island – Burritts Rapids	40	7 (f), 8 (f), 11 (a), 12 (a)
Burritts Rapids – Andrewsville	4.5	13 (a), 14 (a)
Andrewsville – Merrickville	4.5	-
Merrickville – Kilmarnock	8	9(f), 10 (f)

Table 13:
Levene's test results. There are no significant differences in variability between land-use types along the Rideau River. *Z* is the observed *Z*-statistic, *p* is the p-value, α adjusted Bonferroni value.

Characteristics		F-ratio	p-value	Adjusted α	Result
Habitat Variables	Deep aquatic plant abundance	1.880	0.200	0.0125	Not significant
	Shallow aquatic plant abundance	0.290	0.750	0.05	Not significant
	Depth	2.060	0.170	0.01	Not significant
Fish Relative Abundance	Piscivores	0.576	0.578	0.025	Not significant
	Insectivores	3.938	0.051	0.00714	Not significant
	Small-bodied fish	2.341	0.142	0.00833	Not significant
	YOY	1.333	0.303	0.0167	Not significant

Table 14:
Mantel tests were conducted between habitat dissimilarity matrices and fish community dissimilarity matrices. *Z* distributions were created from 1000 randomizations. Fish species present at two or fewer sites were removed from the dataset prior to the analysis. *Z* is the observed *Z*-statistic, *p* is the p-value, α adjusted Bonferroni value.

	All Fish Species Presence/Absence				All Fish Species Relative Abundance			
	Z	p	Adjusted α	Result	Z	p	Adjusted α	Result
Habitat Diversity								
(Presence/Absence)								
deep aquatic plants	26.804	0.017	0.0042	no correlation	509.773	0.000	0.0031	+ correlation
shallow aquatic plants	32.709	0.156	0.0071	no correlation	613.583	0.260	0.0167	no correlation
substrate	29.324	0.015	0.0038	no correlation	519.946	0.001	0.0033	+ correlation
Habitat								
(Relative Abundance)								
deep aquatic plants	48.138	0.802	0.05	no correlation	111.719	0.000	0.00357	+ correlation
shallow aquatic plants	59.351	0.168	0.0125	no correlation	61.840	0.156	0.0083	no correlation
substrate	58.027	0.158	0.01	no correlation	805.735	0.037	0.0045	no correlation
Habitat								
(Physical characteristics)								
depth	59.702	0.074	0.005	no correlation	933.762	0.237	0.025	no correlation
overhanging vegetation	-15.610	0.115	0.0062	no correlation	9.816	0.097	0.0055	no correlation

Table 15:
Mantel tests between habitat dissimilarity matrices and fish community dissimilarity matrices. Z distributions were created from 1000 randomizations. Fish species present at two or fewer sites were removed from the dataset prior to the analysis. *Z* is the observed *Z*-statistic, *p* is the p-value, α adjusted Bonferroni value.

	Piscivore Presence/Absence				Piscivore Relative Abundance			
	Z	p	Adjusted α	Result	Z	p	Adjusted α	Result
Habitat Diversity								
(Presence/Absence)								
deep aquatic plants	20.944	0.056	0.0046	no correlation	95.857	0.038	0.0042	no correlation
shallow aquatic plants	25.574	0.373	0.025	no correlation	114.589	0.021	0.0036	no correlation
substrate	22.290	0.496	0.05	no correlation	105.554	0.062	0.005	no correlation
Habitat								
(Relative Abundance)								
deep aquatic plants	5.314	0.244	0.01	no correlation	23.770	0.254	0.0125	no correlation
shallow aquatic plants	3.745	0.202	0.0055	no correlation	17.744	0.021	0.0033	no correlation
substrate	8.490	0.212	0.0071	no correlation	40.561	0.218	0.0083	no correlation
Habitat								
(Physical Characteristics)								
depth	60.441	0.011	0.0031	no correlation	240.903	0.033	0.0038	no correlation
overhanging vegetation	10.000	0.204	0.0062	no correlation	48.451	0.338	0.0167	no correlation

	Insectivore Presence/Absence				Insectivore Relative Abundance			
	Z	p	Adjusted α	Result	Z	p	Adjusted α	Result
Habitat Diversity								
(Presence/Absence)								
deep aquatic plants	24.200	0.207	0.0062	no correlation	321.829	0.000	0.0031	+ correlation
shallow aquatic plants	30.362	0.427	0.025	no correlation	392.499	0.052	0.0041	no correlation
substrate	27.053	0.055	0.0045	no correlation	349.832	0.000	0.0033	+ correlation
Habitat								
(Relative Abundance)								
deep aquatic plants	6.138	0.339	0.0083	no correlation	82.893	0.004	0.0038	+ correlation
shallow aquatic plants	4.222	0.090	0.005	no correlation	54.691	0.436	0.05	no correlation
substrate	10.232	0.423	0.0167	no correlation	138.000	0.000	0.0036	+ correlation
Habitat								
(Physical Characteristics)								
depth	67.851	0.264	0.0071	no correlation	829.811	0.404	0.0125	no correlation
overhanging vegetation	11.822	0.173	0.0055	no correlation	156.462	0.360	0.01	no correlation

	Small-bodied Fish Presence/Absence				Small-bodied Fish Relative Abundance			
	Z	p	Adjusted α	Result	Z	p	Adjusted α	Result
Habitat Diversity								
(Presence/Absence)								
deep aquatic plants	34.063	0.015	0.0045	no correlation	490.682	0.000	0.0031	+ correlation
shallow aquatic plants	41.461	0.006	0.0042	no correlation	512.730	0.203	0.0125	no correlation
substrate	37.572	0.031	0.0055	no correlation	519.781	0.001	0.0038	+ correlation
Habitat								
(Relative Abundance)								
deep aquatic plants	8.518	0.129	0.01	no correlation	142.063	0.000	0.0033	+ correlation
shallow aquatic plants	5.929	0.043	0.0062	no correlation	73.767	0.206	0.0167	no correlation
substrate	14.366	0.425	0.05	no correlation	228.548	0.000	0.0036	+ correlation
Habitat								
(Physical Characteristics)								
depth	88.340	0.026	0.005	no correlation	1095.503	0.243	0.025	no correlation
overhanging vegetation	16.492	0.070	0.0083	no correlation	248.543	0.068	0.0071	no correlation

Appendix 1:
Relative abundance of fish captured in the Rideau River during the 1998 sampling season.

APPENDIX 1

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13	SITE 14
Fallfish	0	0	0	0	0.143	0.571	0	0.167	0	0	0	0.167	0	0
Bluegill	0	0.5	2	1.571	0.429	0.571	22.5	15	16.833	14.667	11.833	2.833	27.667	31.375
Pumpkinseed	0.571	2	0.5	4	2	0.429	53.333	13.167	11.5	17.833	20.333	26.667	17.167	15.625
Yellow perch	0	0.5	0	1.857	25.714	40	20.167	10	1	10.833	2	2.667	7.833	4.625
Black crappie	0	0.5	0.667	2.286	5.143	14.429	5.667	5.667	1	0.167	2	7	4.167	3.125
Northern pike	0.143	0	0.167	0.286	0.143	0.286	0	0.333	0	0.5	0.833	0.5	0.167	0.125
Muskellunge	0	0	0	0.143	0	0	0	0.167	0	0	0	0	0	0
Walleye	0	0	0	0	0.143	0.143	0.167	0	0	0	0	0.167	0	0
Logperch	3.857	0	0.333	0	8.857	22.571	1.667	0.333	0.667	0	0	0	5.5	0.625
Mottled sculpin	0	0	0.167	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	3.857	1.833	1.833	1.429	2	3.143	3.833	0	0	0	1.833	1.333	0.167	0.375
Largemouth bass	0	0	0	0.143	0	0.429	7.167	3.5	2.333	2.667	3.667	2.167	3	1.25
Brown bullhead	0	0.333	0	0	0	0.143	1	3	4.5	0.667	1.833	1	0.167	0
Spottail shiner	0	2.333	0	0	4.571	3.429	1.167	0	0	0	0	0.833	0	0
Brook silverside	0	0	0	0	0.429	0.143	15.167	1.167	0	0.833	1.5	0	3	0
Blackchin shiner	0	1.5	0	0	0	0.143	0	0	0	0	0	0	0	0
Tadpole madtom	0	0	0	0	0	0	0	0	0	0	0	0.167	0	0
Blacknose shiner	0	0	0	0	0	0	1.667	0.333	1.333	0.5	4	9.5	0.167	0.125
Bluntnose minnow	0	0	0	0	0	0	2.333	1.667	1.167	0	3.167	15.667	2.667	0.25
White sucker	0	0	0	0	0.143	0	0	0	0	0	0.167	0.167	0	0
Rockbass	4.857	27.333	5.333	4.571	20.143	8.857	2.5	2	1.667	0.333	1	3.667	1.333	1.625
Banded killifish	0	24.5	3.333	3.143	0	0	2.833	0.5	7	2	1.5	1.167	0.5	0.125
Tesselated darter	0.714	0.667	0	0	0.571	1	2.333	0.833	0.167	0.167	0.5	1.5	0	0.125
Common carp	0	0	1.333	0	0	1	0.5	0.167	0	0	0.167	0.167	0.333	0.375
Greater redhorse	0	0	0	0	0	0.429	0	0	0	0	0	0.5	0.833	0
Silver redhorse	0	0	0.167	0	0.143	0.857	0	0	0	0	0	0	0	0.125
Freshwater drum	0	0	0.167	0	0	0	0	0	0	0	0	0	0	0
Common shiner	0	0	0	0.143	0	90.857	13.333	0	0	0	0	0	0	0
Emerald shiner	0	0	0	0	0	0.143	0	0	0	0	0	0	0	0
Golden shiner	0	1	3.667	0.143	0.286	0.143	0	2.833	0.333	0	2.167	28.5	0	1.125

	YOY Relative Abundance			
	Z	p	Adjusted α	Result
Habitat Diversity				
(Presence/Absence)				
deep aquatic plants	386.594	0.405	0.01	no correlation
shallow aquatic plants	489.499	0.498	0.025	no correlation
substrate	423.776	0.301	0.00833	no correlation
Habitat				
(Relative Abundance)				
deep aquatic plants	96.452	0.039	0.0071	no correlation
shallow aquatic plants	75.429	0.007	0.0062	no correlation
substrate	167.473	0.427	0.0125	no correlation
Habitat				
(Physical Characteristics)				
depth	107.317	0.500	0.05	no correlation
overhanging vegetation	199.442	0.489	0.0167	no correlation

Appendix 2:
List of fish species reported in the Rideau River and Canal according to literature records (technical reports and unpublished sources), since 1883. Scientific names are written according to the spelling at the time of capture. Current names are written according to Robins *et al.* (1991).

RMOC 1996	RMOC 1997	RMOC 1998	CMN-U of O 1998	Current Name	Family
Moxostoma valenciennesi	*Moxostoma valenciennesi*	*Moxostoma valenciennesi*	*Moxostoma valenciennesi*	*Moxostoma valenciennesi*	Catostomidae
				Ameiurus natalis	Ictaluridae
Ameiurus nebulosus	*Ameiurus nebulosus*	*Ameiurus nebulosus*	*Ameiurus nebulosus*	*Ameiurus nebulosus*	Ictaluridae
Ictalurus punctatus				*Ictalurus punctatus*	Ictaluridae
				Noturus flavus	Ictaluridae
			Noturus gyrinus	*Noturus gyrinus*	Ictaluridae
Lota lota				*Lota lota*	Gadidae
				Percopsis omiscomaycus	Percopsidae
	Fundulus diaphanus	*Fundulus diaphanus*	*Fundulus diaphanus*	*Fundulus diaphanus*	Cyprinodontida[illegible]
Labidesthes sicculus	*Labidesthes sicculus*		*Labidesthes sicculus*	*Labidesthes sicculus*	Atherinidae
Ambloplites rupestris	*Ambloplites rupestris*	*Ambloplites rupestris*	*Ambloplites rupestris*	*Ambloplites rupestris*	Centrarchidae
Lepomis gibbosus	*Lepomis gibbosus*	*Lepomis gibbosus*	*Lepomis gibbosus*	*Lepomis gibbosus*	Centrarchidae
Lepomis macrochirus	*Lepomis macrochirus*	*Lepomis macrochirus*	*Lepomis macrochirus*	*Lepomis macrochirus*	Centrarchidae
Micropterus dolomieu	*Micropterus dolomieu*	*Micropterus dolomieu*	*Micropterus dolomieu*	*Micropterus dolomieu*	Centrarchidae
Micropterus salmoides	*Micropterus salmoides*	*Micropterus salmoides*	*Micropterus salmoides*	*Micropterus salmoides*	Centrarchidae
Pomoxis nigromaculatus	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	Centrarchidae
				Etheostoma exile	Percidae
	Etheostoma nigrum	*Etheostoma nigrum*		*Etheostoma nigrum*	Percidae
Etheostoma olmstedi			*Etheostoma olmstedi*	*Etheostoma olmstedi*	Percidae
Perca flavescens	*Perca flavescens*	*Perca flavescens*	*Perca flavescens*	*Perca flavescens*	Percidae
Percina caprodes	*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	Percidae
				Stizostedion canadense	Percidae
Stizostedion vitreum	*Stizostedion vitreum*	*Stizostedion vitreum*	*Stizostedion vitreum*	*Stizostedion vitreum*	Percidae
		Cottus bairdi	*Cottus bairdi*	*Cottus bairdi*	Cottidae
		Culaea inconstans		*Culaea inconstans*	Gasterosteidae
			Aplodinotus grunniens	*Aplodinotus grunniens*	Sciaenidae

RMOC 1996	RMOC 1997	RMOC 1998	CMN-U of O 1998	Current Name	Family
				Ichthyomyzon unicuspis	Petromyzontidae
				Lepisosteus osseus	Lepisosteidae
Anguilla rostrata				*Anguilla rostrata*	Anguillidae
Alosa pseudoharengus				*Alosa pseudoharengus*	Clupeidae
				Oncorhynchus mykiss	Salmonidae
				Salmo trutta	Salmonidae
Esox lucius	*Esox lucius*	*Esox lucius*	*Esox lucius*	*Esox lucius*	Esocidae
Esox masquinongy	*Esox masquinongy*	*Esox masquinongy*	*Esox masquinongy*	*Esox masquinongy*	Esocidae
				Umbra limi	Umbridae
				Phoxinus eos	Cyprinidae
				Phoxinus neogaeus	Cyprinidae
Cyprinus carpio	*Cyprinus carpio*	*Cyprinus carpio*	*Cyprinus carpio*	*Cyprinus carpio*	Cyprinidae
				Hybognathus hankinsoni	Cyprinidae
Hybognathus regius				*Hybognathus regius*	Cyprinidae
Notemigonus crysoleucas	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	Cyprinidae
		Notropis atherinoides	*Notropis atherinoides*	*Notropis atherinoides*	Cyprinidae
Luxilus cornutus	*Luxilus cornutus*	*Luxilus cornutus*	*Luxilus cornutus*	*Luxilus cornutus*	Cyprinidae
	Notropis heterodon	*Notropis heterodon*	*Notropis heterodon*	*Notropis heterodon*	Cyprinidae
	Notropis heterolepis	*Notropis heterolepis*	*Notropis heterolepis*	*Notropis heterolepis*	Cyprinidae
Notropis hudsonius	*Notropis hudsonius*	*Notropis hudsonius*	*Notropis hudsonius*	*Notropis hudsonius*	Cyprinidae
				Notropis rubellus	Cyprinidae
				Notropis stramineus	Cyprinidae
Notropis volucellus				*Notropis volucellus*	Cyprinidae
Pimephales notatus	*Pimephales notatus*	*Pimephales notatus*	*Pimephales notatus*	*Pimephales notatus*	Cyprinidae
				Pimephales promelas	Cyprinidae
				Rhinichthys cataractae	Cyprinidae
				Semotilus atromaculatus	Cyprinidae
		Semotilus corporalis	*Semotilus corporalis*	*Semotilus corporalis*	Cyprinidae
				Margariscus margarita	Cyprinidae
Catostomus commersoni	*Catostomus commersoni*	*Catostomus commersoni*	*Catostomus commersoni*	*Catostomus commersoni*	Catostomidae
Moxostoma anisurum	*Moxostoma anisurum*	*Moxostoma anisurum*	*Moxostoma anisurum*	*Moxostoma anisurum*	Catostomidae
Moxostoma macrolepidotum				*Moxostoma macrolepidotum*	Catostomidae

City of Gloucester March 1991	City of Gloucester March 1992	RMOC 1995	RMOC 1995 Gore & Story	Current Name	Family
	Moxostoma valenciennesi	*Moxostoma valenciennesi*		*Moxostoma valenciennesi*	Catostomidae
				Ameiurus natalis	Ictaluridae
Ictalurus nebulosus	*Ictalurus nebulosus*	*Ictalurus nebulosus*	*Ameiurus nebulosus*	*Ameiurus nebulosus*	Ictaluridae
	Ictalurus punctatus	*Ictalurus punctalus*		*Ictalurus punctatus*	Ictaluridae
				Noturus flavus	Ictaluridae
				Noturus gyrinus	Ictaluridae
				Lota lota	Gadidae
Percopsis omiscomaycus	*Percopsis omiscomaycus*			*Percopsis omiscomaycus*	Percopsidae
Fundulus diaphanus	*Fundulus diaphanus*			*Fundulus diaphanus*	Cyprinodontidae
Labidesthes sicculus	*Labidesthes sicculus*	*Labidesthes sicculus*	*Labidesthes sicculus*	*Labidesthes sicculus*	Atherinidae
Ambloplites rupestris	*Ambloplites rupestris*	*Ambloplites rupestris*	*Ambloplites rupestris*	*Ambloplites rupestris*	Centrarchidae
Lepomis gibbosus	*Lepomis gibbosus*	*Lepomis gibbosus*	*Lepomis gibbosus*	*Lepomis gibbosus*	Centrarchidae
Lepomis macrochirus	*Lepomis macrochirus*	*Lepomis macrochirus*	*Lepomis macrochirus*	*Lepomis macrochirus*	Centrarchidae
Micropterus dolomieui	*Micropterus dolomieui*	*Micropterus dolomieui*	*Micropterus dolomieui*	*Micropterus dolomieu*	Centrarchidae
Micropterus salmoides	*Micropterus salmoides*	*Micropterus salmoides*	*Micropterus salmoides*	*Micropterus salmoides*	Centrarchidae
Pomoxis nigromaculatus	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatis*	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	Centrarchidae
			Etheostoma exile	*Etheostoma exile*	Percidae
Etheostoma nigrum	*Etheostoma nigrum*		*Etheostoma nigrum*	*Etheostoma nigrum*	Percidae
		Etheostomam olmstedi	*Etheostoma olmstedi*	*Etheostoma olmstedi*	Percidae
Perca flavescens	*Perca flavescens*	*Perca flavescens*	*Perca flavescens*	*Perca flavescens*	Percidae
Percina caprodes	*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	Percidae
				Stizostedion canadense	Percidae
Stizostedion vitreum	*Stizostedion vitreum*	*Stizostedion vitreum*	*Stizostedion vitreum*	*Stizostedion vitreum*	Percidae
		Cottus bairdii	*Cottus bairdi*	*Cottus bairdi*	Cottidae
		Culaea inconstans		*Culaea inconstans*	Gasterosteidae
				Aplodinotus grunniens	Sciaenidae

City of Gloucester March 1991	City of Gloucester March 1992	RMOC 1995	RMOC 1995 Gore & Story	Current Name	Family
				Ichthyomyzon unicuspis	Petromyzontidae
				Lepisosteus osseus	Lepisosteidae
				Anguilla rostrata	Anguillidae
	Alosa pseudoharengus			*Alosa pseudoharengus*	Clupeidae
				Oncorhynchus mykiss	Salmonidae
				Salmo trutta	Salmonidae
Esox lucius	*Esox lucius*	*Esox lucius*	*Esox lucius*	*Esox lucius*	Esocidae
Esox masquinongy	*Esox masquinongy*	*Esox masquinongy*		*Esox masquinongy*	Esocidae
				Umbra limi	Umbridae
				Phoxinus eos	Cyprinidae
				Phoxinus neogaeus	Cyprinidae
		Cyprinus carpio		*Cyprinus carpio*	Cyprinidae
	Hybognathus hankinsoni			*Hybognathus hankinsoni*	Cyprinidae
	Hybognathus regius		*Hybognathus regius*	*Hybognathus regius*	Cyprinidae
Notemigonus crysoleucas	*Notemigonus crysoleucas*	*Notropis crysoleucas*	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	Cyprinidae
Notropis atherinoides	*Notropis atherinoides*			*Notropis atherinoides*	Cyprinidae
Notropis cornutus	*Notropis cornutus*			*Luxilus cornutus*	Cyprinidae
	Notropis heterodon			*Notropis heterodon*	Cyprinidae
				Notropis heterolepis	Cyprinidae
Notropis hudsonius	*Notropis hudsonius*	*Notropis hudsonius*	*Notropis hudsonius*	*Notropis hudsonius*	Cyprinidae
				Notropis rubellus	Cyprinidae
				Notropis stramineus	Cyprinidae
Notropis volucellus	*Notropis volucellus*			*Notropis volucellus*	Cyprinidae
Pimephales notatus	*Pimephales notatus*			*Pimephales notatus*	Cyprinidae
Pimephales promelas	*Pimephales promelas*			*Pimephales promelas*	Cyprinidae
	Rhinichthys cataractae		*Rhinichthys cataractae*	*Rhinichthys cataractae*	Cyprinidae
Semotilus atromaculatus	*Semotilus atromaculatus*			*Semotilus atromaculatus*	Cyprinidae
	Semotilus corporalis			*Semotilus corporalis*	Cyprinidae
				Margariscus margarita	Cyprinidae
Catostomus commersoni	*Catostomus commersoni*	*Catostomus commersonii*	*Catostomus commersoni*	*Catostomus commersoni*	Catostomidae
Moxostoma anisurum	*Moxostoma anisurum*	*Moxostoma anisurum*		*Moxostoma anisurum*	Catostomidae
	Moxostoma macrolepidotum	*Moxostoma macrolepdotum*		*Moxostoma macrolepidotum*	Catostomidae

OMNR 1975-1983	Coad 1983	OMNR 1984-1987	Coad 1987	Current Name	Family
Moxostoma valenciennesi				*Moxostoma valenciennesi*	Catostomidae
				Ameiurus natalis	Ictaluridae
Ameiurus nebulosus		*Ameiurus nebulosus*		*Ameiurus nebulosus*	Ictaluridae
				Ictalurus punctatus	Ictaluridae
				Noturus flavus	Ictaluridae
				Noturus gyrinus	Ictaluridae
				Lota lota	Gadidae
Percopsis omiscomaycus				*Percopsis omiscomaycus*	Percopsidae
				Fundulus diaphanus	Cyprinodontidae
Labidesthes sicculus		*Labidesthes sicculus*	*Labidesthes sicculus*	*Labidesthes sicculus*	Atherinidae
Ambloplites rupestris		*Ambloplites rupestris*		*Ambloplites rupestris*	Centrarchidae
Lepomis gibbosus		*Lepomis gibbosus*		*Lepomis gibbosus*	Centrarchidae
Lepomis macrochirus			*Lepomis macrochirus*	*Lepomis macrochirus*	Centrarchidae
Micropterus dolomieu		*Micropterus dolomieu*		*Micropterus dolomieu*	Centrarchidae
				Micropterus salmoides	Centrarchidae
Pomoxis nigromaculatus				*Pomoxis nigromaculatus*	Centrarchidae
		Etheostoma exile		*Etheostoma exile*	Percidae
				Etheostoma nigrum	Percidae
Etheostoma olmstedi				*Etheostoma olmstedi*	Percidae
Perca flavescens		*Perca flavescens*		*Perca flavescens*	Percidae
Percina caprodes				*Percina caprodes*	Percidae
Stizostedion canadense				*Stizostedion canadense*	Percidae
Stizostedion vitreum				*Stizostedion vitreum*	Percidae
Cottus bairdi				*Cottus bairdi*	Cottidae
				Culaea inconstans	Gasterosteidae
				Aplodinotus grunniens	Sciaenidae

OMNR 1975-1983	Coad 1983	OMNR 1984-1987	Coad 1987	Current Name	Family
				Ichthyomyzon unicuspis	Petromyzontidae
		Lepisosteus osseus		*Lepisosteus osseus*	Lepisosteidae
Anguilla rostrata				*Anguilla rostrata*	Anguillidae
Alosa pseudoharengus	*Alosa pseudoharengus*		*Alosa pseudoharengus*	*Alosa pseudoharengus*	Clupeidae
				Oncorhynchus mykiss	Salmonidae
				Salmo trutta	Salmonidae
Esox lucius				*Esox lucius*	Esocidae
Esox masquinongy			*Esox masquinongy*	*Esox masquinongy*	Esocidae
Umbra limi				*Umbra limi*	Umbridae
				Phoxinus eos	Cyprinidae
				Phoxinus neogaeus	Cyprinidae
Cyprinus carpio		*Cyprinus carpio*		*Cyprinus carpio*	Cyprinidae
Hybognathus hankinsoni				*Hybognathus hankinsoni*	Cyprinidae
Hybognathus regius				*Hybognathus regius*	Cyprinidae
Notemigonus crysoleucas		*Notemigonus crysoleucas*		*Notemigonus crysoleucas*	Cyprinidae
Notropis atherinoides				*Notropis atherinoides*	Cyprinidae
Notropis cornutus				*Luxilus cornutus*	Cyprinidae
				Notropis heterodon	Cyprinidae
				Notropis heterolepis	Cyprinidae
Notropis hudsonius		*Notropis hudsonius*		*Notropis hudsonius*	Cyprinidae
Notropis rubellus				*Notropis rubellus*	Cyprinidae
				Notropis stramineus	Cyprinidae
				Notropis volucellus	Cyprinidae
Pimephales notatus				*Pimephales notatus*	Cyprinidae
				Pimephales promelas	Cyprinidae
				Rhinichthys cataractae	Cyprinidae
Semotilus atromaculatus				*Semotilus atromaculatus*	Cyprinidae
Semotilus corporalis				*Semotilus corporalis*	Cyprinidae
				Margariscus margarita	Cyprinidae
Catostomus commersoni		*Catostomus commersoni*		*Catostomus commersoni*	Catostomidae
Moxostoma anisurum			*Moxostoma anisurum*	*Moxostoma anisurum*	Catostomidae
		Moxostoma macrolepidotum		*Moxostoma macrolepidotum*	Catostomidae

Dymond 1939	OMNR 1957-1965	OMNR 1966-1974	McAllister and Coad 1974	Current Name	Family
Ichthyomyzon unicuspis			*Ichthyomyzon unicuspis*	*Ichthyomyzon unicuspis*	Petromyzontidae
Lepisosteus osseus			*Lepisosteus osseus*	*Lepisosteus osseus*	Lepisosteidae
				Anguilla rostrata	Anguillidae
				Alosa pseudoharengus	Clupeidae
Salmo gairdneri			*Salmo gairdnerii*	*Oncorhynchus mykiss*	Salmonidae
Salmo fario			*Salmo trutta*	*Salmo trutta*	Salmonidae
Esox lucius	*Esox lucius*		*Esox lucius*	*Esox lucius*	Esocidae
Esox masquinongy		*Esox masquinongy*	*Esox masquinongy*	*Esox masquinongy*	Esocidae
Umbra limi	*Umbra limi*		*Umbra limi*	*Umbra limi*	Umbridae
	Chrosomus eos		*Chrosomus eos*	*Phoxinus eos*	Cyprinidae
	Chrosomus neogaeus		*Chrosomus neogaeus*	*Phoxinus neogaeus*	Cyprinidae
	Cyprinus carpio	*Cyprinus carpio*	*Cyprinus carpio*	*Cyprinus carpio*	Cyprinidae
	Hybognathus hankinsoni	*Hybognathus hankinsoni*	*Hybognathus hankinsoni*	*Hybognathus hankinsoni*	Cyprinidae
	Hybognathus nuchalis	*Hybognathus nuchalis*	*Hybognathus nuchalis*	*Hybognathus regius*	Cyprinidae
Notemigonus crysoleucas	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	*Notemigonus crysoleucas*	Cyprinidae
	Notropis atherinoides		*Notropis atherinoides*	*Notropis atherinoides*	Cyprinidae
Notropis cornutus	*Notropis cornutus*		*Notropis cornutus*	*Luxilus cornutus*	Cyprinidae
	Notropis heterodon		*Notropis heterodon*	*Notropis heterodon*	Cyprinidae
Notropis heterolepis			*Notropis heterolepis*	*Notropis heterolepis*	Cyprinidae
Notropis hudsonius	*Notropis hudsonius*	*Notropis hudsonius*	*Notropis hudsonius*	*Notropis hudsonius*	Cyprinidae
	Notropis rubellus		*Notropis rubellus*	*Notropis rubellus*	Cyprinidae
		Notropis stramineus		*Notropis stramineus*	Cyprinidae
				Notropis volucellus	Cyprinidae
Hyborhynchus notatus	*Pimephales notatus*	*Pimephales notatus*	*Pimephales notatus*	*Pimephales notatus*	Cyprinidae
	Pimephales promelas		*Pimephales promelas*	*Pimephales promelas*	Cyprinidae
Rhinichthys cataractae	*Rhinichthys cataractae*	*Rhinichthys cataractae*	*Rhinichthys cataractae*	*Rhinichthys cataractae*	Cyprinidae
Semotilus atromaculatus				*Semotilus atromaculatus*	Cyprinidae
Leucosomus corporalis	*Semotilus corporalis*	*Semotilus corporalis*	*Semotilus corporalis*	*Semotilus corporalis*	Cyprinidae
	Semotilus margarita		*Semotilus margarita*	*Margariscus margarita*	Cyprinidae
Catostomus commersonii	*Catostomus commersonii*	*Catostomus commersonii*	*Catostomus commersonii*	*Catostomus commersoni*	Catostomidae
Moxostoma anisurum	*Moxostoma anisurum*	*Moxostoma anisurum*	*Moxostoma anisurum*	*Moxostoma anisurum*	Catostomidae
Moxostoma lesueurii	*Moxostoma macrolepidotum*	*Moxostoma macrolepidotum*	*Moxostoma macrolepidotum*	*Moxostoma macrolepidotum*	Catostomidae

Dymond 1939	OMNR 1957-1965	OMNR 1966-1974	McAllister and Coad 1974	Current Name	Family
	Moxostoma valenciennesi		*Moxostoma valenciennesi*	*Moxostoma valenciennesi*	Catostomidae
	Ameiurus natalis		*Ictalurus natalis*	*Ameiurus natalis*	Ictaluridae
Ameiurus nebulosus	*Ameiurus nebulosus*	*Ameiurus nebulosus*	*Ictalurus nebulosus*	*Ameiurus nebulosus*	Ictaluridae
			Ictalurus punctatus	*Ictalurus punctatus*	Ictaluridae
	Noturus flavus		*Noturus flavus*	*Noturus flavus*	Ictaluridae
				Noturus gyrinus	Ictaluridae
Lota maculosa				*Lota lota*	Gadidae
Percopsis omisco-maycus	*Percopsis omiscomaycus*		*Percopsis omiscomaycus*	*Percopsis omiscomaycus*	Percopsidae
	Fundulus diaphanus	*Fundulus diaphanus*	*Fundulus diaphanus*	*Fundulus diaphanus*	Cyprinodontidae
Labidesthes sicculus	*Labidesthes sicculus*	*Labidesthes sicculus*	*Labidesthes sicculus*	*Labidesthes sicculus*	Atherinidae
Ambloplites rupestris	*Ambloplites rupestris*	*Ambloplites rupestris*	*Ambloplites rupestris*	*Ambloplites rupestris*	Centrarchidae
Eupomotis gibbosus	*Lepomis gibbosus*	*Lepomis gibbosus*	*Lepomis gibbosus*	*Lepomis gibbosus*	Centrarchidae
Helioperca macrochira	*Lepomis macrochirus*	*Lepomis macrochirus*	*Lepomis macrochirus*	*Lepomis macrochirus*	Centrarchidae
Micropterus dolomieu	*Micropterus dolomieu*	*Micropterus dolomieu*	*Micropterus dolomieui*	*Micropterus dolomieu*	Centrarchidae
Aplites salmoides	*Micropterus salmoides*	*Micropterus salmoides*	*Micropterus salmoides*	*Micropterus salmoides*	Centrarchidae
Pomoxis sparoides	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	*Pomoxis nigromaculatus*	Centrarchidae
	Etheostoma exile	*Etheostoma exile*	*Etheostoma exile*	*Etheostoma exile*	Percidae
Boleosoma nigrum				*Etheostoma nigrum*	Percidae
	Etheostoma olmstedi	*Etheostoma olmstedi*	*Etheostoma olmstedi*	*Etheostoma olmstedi*	Percidae
Perca flavescens	*Perca flavescens*	*Perca flavescens*	*Perca flavescens*	*Perca flavescens*	Percidae
Percina caprodes	*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	Percidae
Stizostedion canadense				*Stizostedion canadense*	Percidae
Stizostedion vitreum	*Stizostedion vitreum*	*Stizostedion vitreum*	*Stizostedion vitreum*	*Stizostedion vitreum*	Percidae
	Cottus bairdii	*Cottus bairdii*	*Cottus bairdii*	*Cottus bairdi*	Cottidae
	Culaea inconstans		*Culaea inconstans*	*Culaea inconstans*	Gasterosteidae
				Aplodinotus grunniens	Sciaenidae

Small 1883	Prince et al. 1906	OMNR 1914-1919	OMNR 1932-1934	Current Name	Family
				Moxostoma valenciennesi	Catostomidae
				Ameiurus natalis	Ictaluridae
	Ameiurus nebulosis	*Ameiurus nebulosus*		*Ameiurus nebulosus*	Ictaluridae
				Ictalurus punctatus	Ictaluridae
				Noturus flavus	Ictaluridae
				Noturus gyrinus	Ictaluridae
	Loto maculosa			*Lota lota*	Gadidae
				Percopsis omiscomaycus	Percopsidae
				Fundulus diaphanus	Cyprinodontidae
			Labidesthes sicculus	*Labidesthes sicculus*	Atherinidae
	Ambloplites rupestris		*Ambloplites rupestris*	*Ambloplites rupestris*	Centrarchidae
			Eupomotis gibbosus	*Lepomis gibbosus*	Centrarchidae
				Lepomis macrochirus	Centrarchidae
Micropterus Dolomien			*Micropterus dolomieu*	*Micropterus dolomieu*	Centrarchidae
Micropterus Salmoides				*Micropterus salmoides*	Centrarchidae
			Pomoxis sparoides	*Pomoxis nigromaculatus*	Centrarchidae
				Etheostoma exile	Percidae
				Etheostoma nigrum	Percidae
				Etheostoma olmstedi	Percidae
		Perca flavescens		*Perca flavescens*	Percidae
Percina Caprodes		*Percina caprodes*	*Percina caprodes*	*Percina caprodes*	Percidae
Stizostedion Canadense/ Stizostedion Griseum				*Stizostedion canadense*	Percidae
Stizostedion Vitreum				*Stizostedion vitreum*	Percidae
		Cottus bairdii		*Cottus bairdi*	Cottidae
				Culaea inconstans	Gasterosteidae
				Aplodinotus grunniens	Sciaenidae

Small 1883	Prince et al. 1906	OMNR 1914-1919	OMNR 1932-1934	Current Name	Family
Icthyomyzon Argenteus				*Ichthyomyzon unicuspis*	Petromyzontidae
				Lepisosteus osseus	Lepisosteidae
				Anguilla rostrata	Anguillidae
				Alosa pseudoharengus	Clupeidae
				Oncorhynchus mykiss	Salmonidae
				Salmo trutta	Salmonidae
				Esox lucius	Esocidae
Esox Nobilior				*Esox masquinongy*	Esocidae
Umbra Limi				*Umbra limi*	Umbridae
				Phoxinus eos	Cyprinidae
				Phoxinus neogaeus	Cyprinidae
				Cyprinus carpio	Cyprinidae
				Hybognathus hankinsoni	Cyprinidae
				Hybognathus regius	Cyprinidae
			Notemigonus crysoleucas	*Notemigonus crysoleucas*	Cyprinidae
				Notropis atherinoides	Cyprinidae
		Notropis cornutus		*Luxilus cornutus*	Cyprinidae
				Notropis heterodon	Cyprinidae
				Notropis heterolepis	Cyprinidae
			Notropis hudsonius	*Notropis hudsonius*	Cyprinidae
				Notropis rubellus	Cyprinidae
				Notropis stramineus	Cyprinidae
				Notropis volucellus	Cyprinidae
			Hyborhynchus notatus	*Pimephales notatus*	Cyprinidae
				Pimephales promelas	Cyprinidae
				Rhinichthys cataractae	Cyprinidae
Erimyzon Sucetta (misidentification sensu Dymond (1939))				*Semotilus atromaculatus*	Cyprinidae
				Semotilus corporalis	Cyprinidae
				Margariscus margarita	Cyprinidae
			Catostomus commersonii	*Catostomus commersoni*	Catostomidae
				Moxostoma anisurum	Catostomidae
				Moxostoma macrolepidotum	Catostomidae

Appendix 3:
Relative abundance of fish captured in Kemptville Creek (KC), Jock River (JR) and Steven Creek (SC). Site 1 is located at the confluence of the tributary and the Rideau River, site 2 is located halfway between the confluence and site 3, which is located as close to the source as possible to navigate.

APPENDIX 3

	KC3	KC2	KC1	JR3	JR2	JR1	SC3	SC2	SC1
yellow perch	1	2	3.25	0	0	0	1.25	0	2.75
rock bass	0.8	0.25	7.75	13.25	12.5	4	0.5	0.5	0.25
largemouth bass	7.8	2	0.75	0	0	0	0	0	0
central mudminnow	1.4	0.25	0	0	0	0	0.75	0.5	0
log perch	1.8	0	0	4.25	2.5	0.25	0	0	0
pumpkinseed	3	1.75	8	32	84.5	0.25	7	4	4.5
bluegill	15	11	9.75	0.25	16.5	0	0	0	3.5
sunfish	0.2	0	0	0.25	0	0	0.25	0.25	2
tadpole madtom	0.2	0	0	0	0	0	0.25	0.75	0
silver redhorse	2.4	0	0	0	0	0	0	0	0
fallfish	1.4	0	0	0	0	0	0	0	0
smallmouth bass	2	1.75	3.25	0	0.5	2.75	0	0	0.5
brook silverside	1.8	0	0	0	0	51.5	0	0	0.75
banded killifish	1.4	0.5	50.75	0.5	5	0	1.25	0.25	0.5
bluntnose minnow	0.4	0	3.75	2.5	16	0	2.5	23.25	0
rosyface shiner	0.2	0	0	0.5	1.75	0	0.25	0	0
blacknose shiner	0.2	0	26.75	0	0	0	0.5	0	0
common shiner	0.2	0	0	10.25	2.25	0	0.25	1	0
mudpuppy	0.2	0	0	0	0	0	0	0	0
northern pike	0	0.25	0	0	0.25	0	0	0.25	0
blackchin shiner	0	0.25	0.25	0	0.25	0	0	0	0
black crappie	0	0.5	0	0	0.75	0	0.25	0	0
brown bullhead	0	0	0.25	0	0	0	0.25	0.5	0
white sucker	0	0	0.25	0	0	0	0.25	0	0
tesselated darter	0	0	0	0.25	1.5	0	0.75	1.25	0
mimic shiner	0	0	0	0.5	1	0	0	0	0
muskellunge	0	0	0	0	0.25	0.25	0	0	0
spottail shiner	0	0	0	0	5.25	0	0	0	0

Appendix 4:
Habitat characteristics for the Rideau River sampled during 1998. Percent cover of deep and shallow water vegetation and substrate are listed for each site. SWI is the Shannon-Weiner Diversity Index.

APPENDIX 4

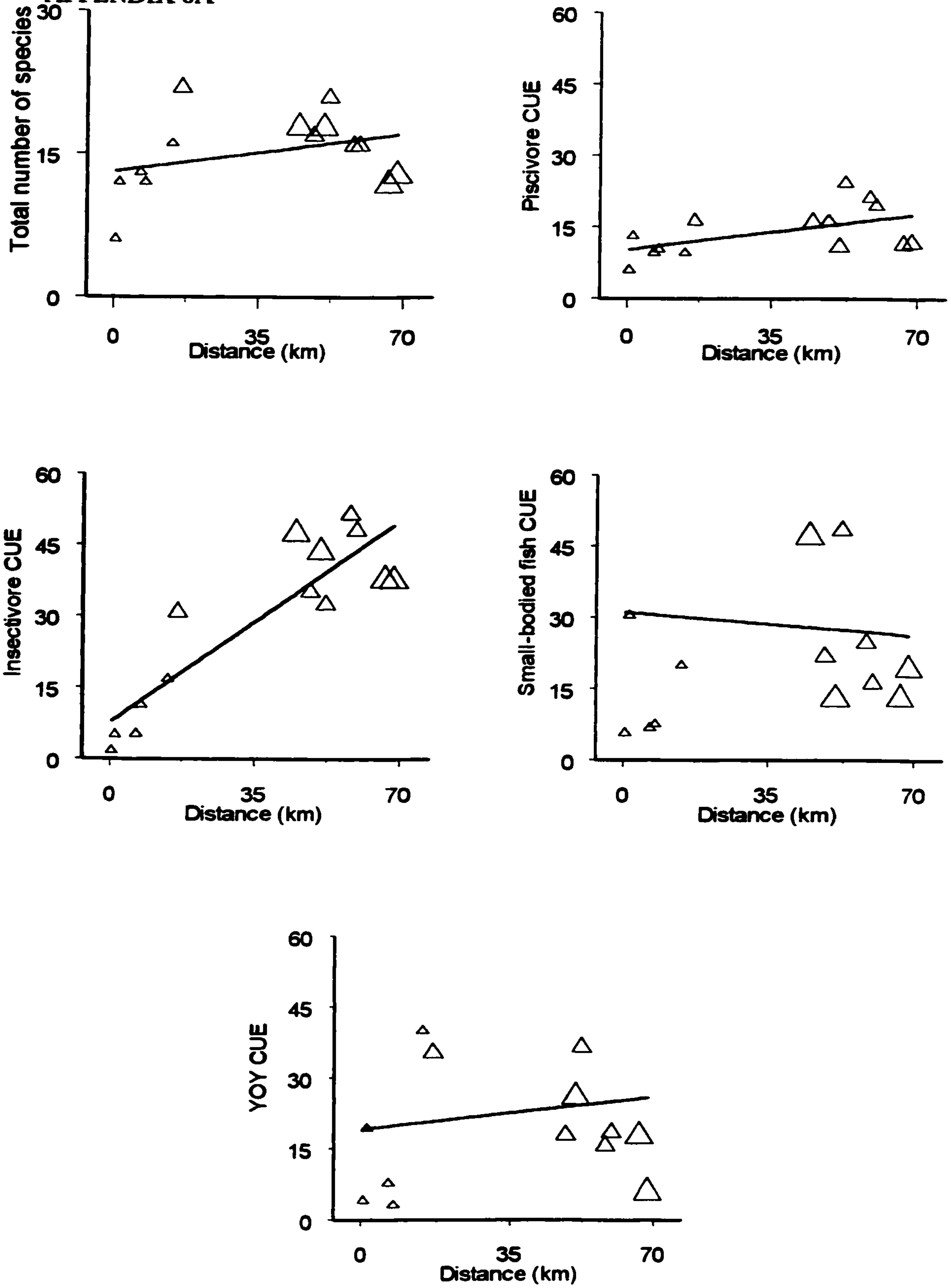
	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13	SITE 14
Deep Vall	0.10	0.20	0.70	0.38	0.25	0.00	0.36	0.60	0.25	0.42	0.28	0.52	0.18	0.48
Deep Milfoil	0.00	0.00	0.10	0.00	0.00	0.00	0.06	0.20	0.00	0.00	0.28	0.03	0.15	0.16
Deep Coontail	0.00	0.00	0.10	0.00	0.13	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Deep Potamogeton	0.00	0.00	0.10	0.13	0.13	0.60	0.15	0.20	0.00	0.04	0.04	0.03	0.00	0.00
Deep Lily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.04	0.07	0.18	0.16
Deep Duckweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.18	0.04	0.00	0.00	0.00
Deep Elodea	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.04	0.04	0.00	0.00	0.00
Shallow Vall	0.21	0.30	0.00	0.10	0.06	0.00	0.48	0.00	0.30	0.00	0.25	0.24	0.00	0.00
Shallow Milfoil	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.10	0.00	0.25	0.03	0.00	0.00
Shallow Potamogeton	0.03	0.15	0.00	0.08	0.00	0.00	0.20	0.00	0.00	0.00	0.21	0.03	0.00	0.00
Shallow Lily	0.03	0.05	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00
Shallow Duckweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.07	0.00	0.00	0.00
Shallow Wood Debris	0.03	0.15	0.00	0.05	0.00	0.10	0.00	0.00	0.20	0.14	0.07	0.24	0.30	0.00
Shallow Elodea	0.03	0.05	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0.00
Shallow Algae	0.21	0.30	0.00	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shallow Cattails	0.00	0.00	0.12	0.05	0.05	0.00	0.00	1.00	0.15	0.06	0.00	0.00	0.00	0.00
Shallow Rush	0.03	0.00	0.30	0.05	0.03	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shallow Arrowhead	0.03	0.00	0.12	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shallow Lustrife	0.00	0.00	0.06	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SAND	0.40	0.80	0.85	0.20	0.50	0.00	1.00	0.50	1.00	0.35	0.35	0.35	0.00	0.50
BOULDER	0.40	0.10	0.00	0.20	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
BEDROCK	0.10	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
RUBBLE	0.10	0.00	0.15	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRAVEL	0.00	0.10	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CLAY	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.50	0.00	0.30	0.30	0.30	0.50	0.00
DETRITUS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.35	0.35	0.00	0.00
DEPTH	3.60	3.00	3.45	1.20	4.75	1.75	1.00	1.00	0.75	1.00	3.00	3.75	3.75	4.75
OVERHANG TREES	0.50	0.75	0.25	0.25	0.75	0.00	0.25	0.75	0.13	0.13	0.50	0.25	0.13	0.75
BANKHEIGHT	0.86	5.18	2.21	1.44	4.03	2.60	0.20	0.30	0.28	0.86	1.72	4.00	1.29	3.38
SWI-DEEP VEG	0.00	0.00	0.54	0.29	0.41	0.00	0.61	0.48	0.48	0.75	0.76	0.46	0.48	0.42
SWI-SHALLOW VEG	0.67	0.73	0.65	0.82	0.58	0.30	0.00	0.00	0.70	0.30	0.76	0.68	0.00	0.00
SWI-SUBSTRATE	0.00	0.55	0.45	0.52	0.28	0.00	0.00	0.30	0.00	0.48	0.55	0.48	0.30	0.46

Appendix 5:
Visual Basic macro written for use in MS Excel 97 to perform Mantel tests (Francis 2000).

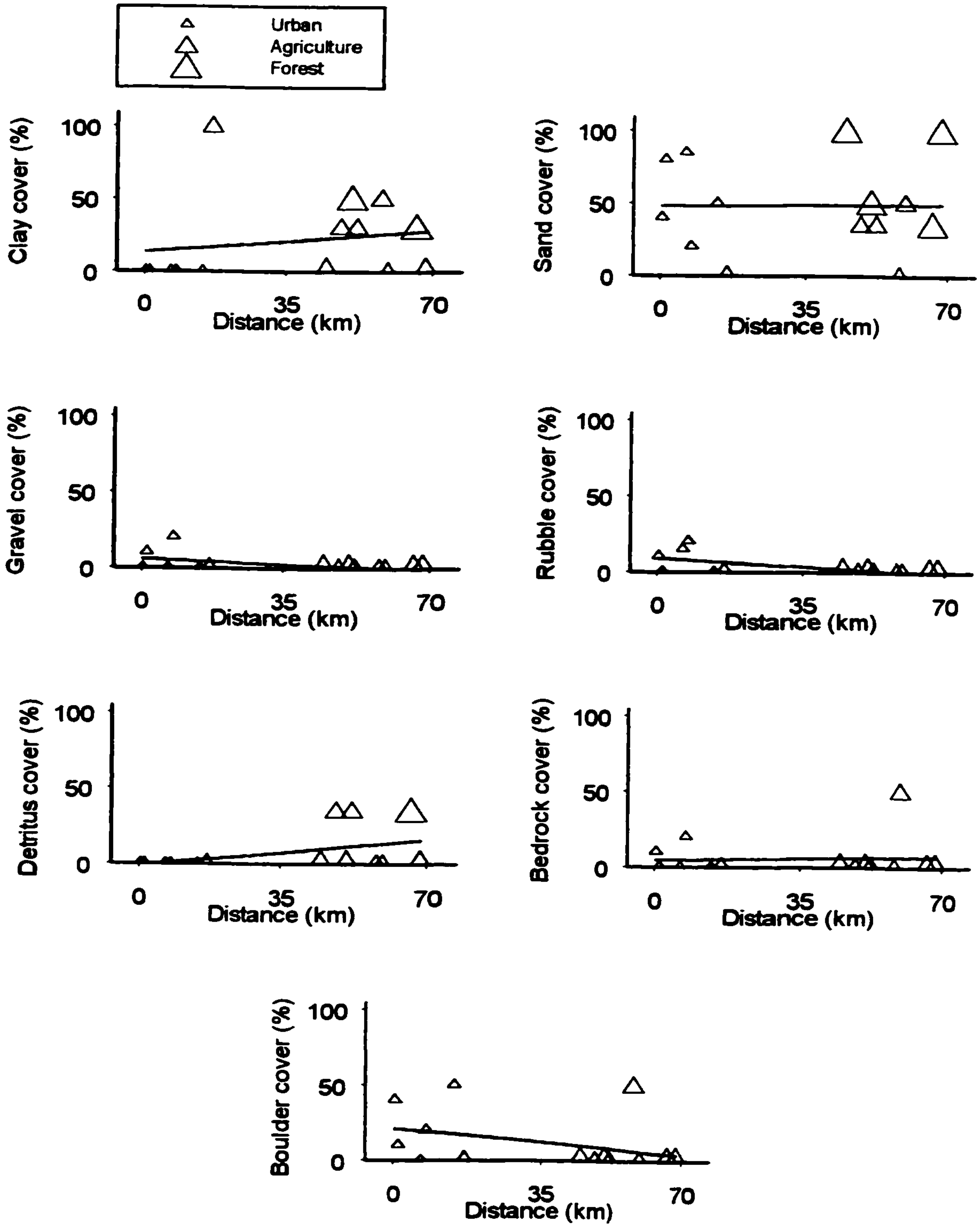
```
Mantel Macro
' Macro recorded 20/01/00 by Anthony Francis
'
'
Sub Mantel()

'Calculate Z
    Sheets("Matrix E(r)").Select
    Range("C2:E106").Select
    Selection.Sort Key1:=Range("C2"), Order1:=xlAscending, Header:= _
        xlGuess, OrderCustom:=1, MatchCase:=False, Orientation:= _
        xlTopToBottom

    Range("G108").Select
    Selection.Copy

    Sheets("Z and Z distribution").Select
    Range("A2").Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False

'Randomize and Recalculate Z

For n = 1 To 100 Step 1
    Sheets("Matrix E(r)").Select
    Range("C2:E106").Select
    Selection.Sort Key1:=Range("D2"), Order1:=xlAscending, Header:= _
        xlGuess, OrderCustom:=1, MatchCase:=False, Orientation:= _
        xlTopToBottom

    Range("G108").Select
    Selection.Copy

    Sheets("Z and Z distribution").Select
    Cells(n, 3).Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
Next n

End Sub
```

Appendix 6:
Diversity (presence /absence) and relative abundance (CUE) of the fish community and the habitat characteristics for each site were plotted against the distance of each site from the confluence of the Rideau and Ottawa Rivers.

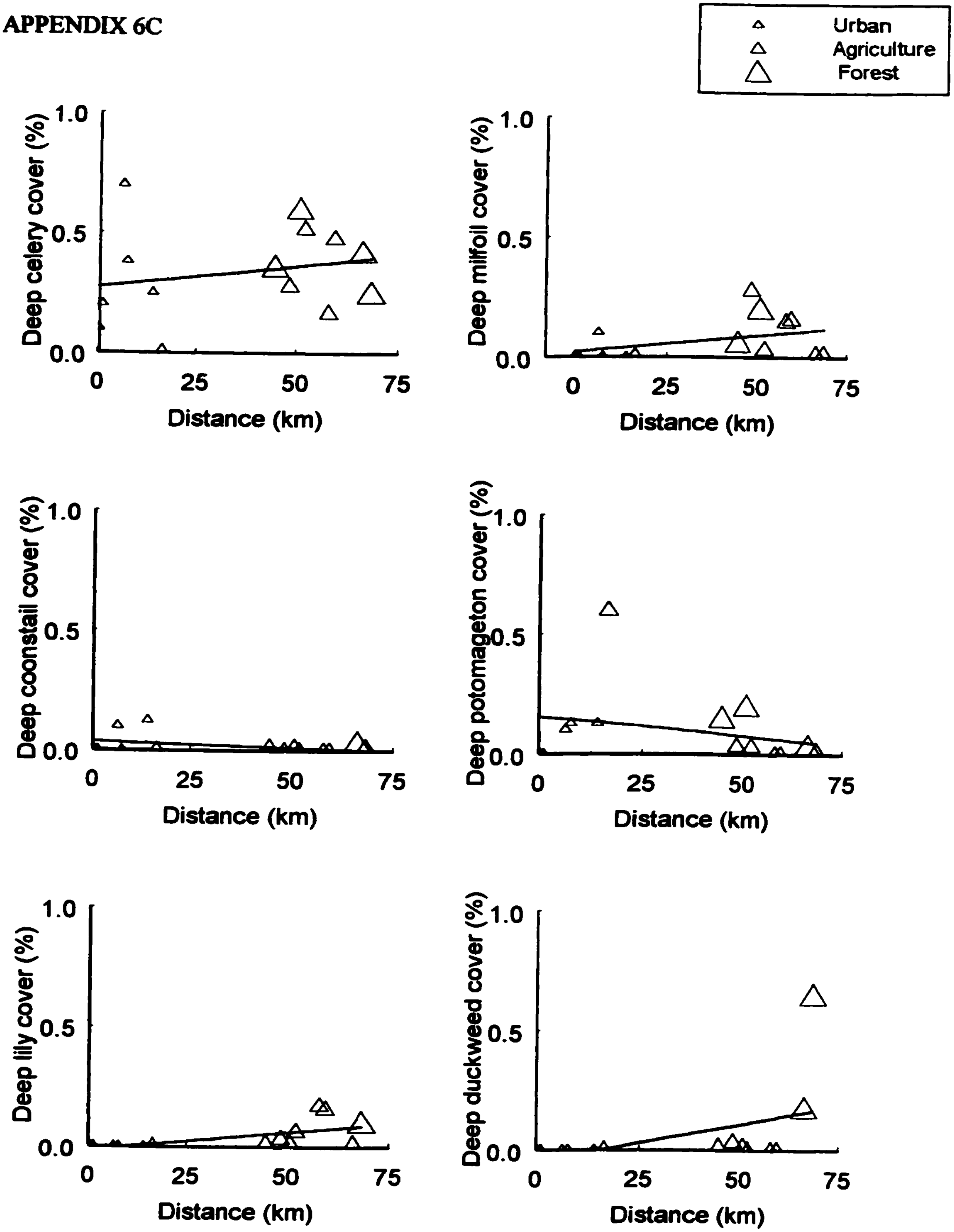
APPENDIX 6A


Total number of species
30
15
0
0
35
70
Distance (km)
Piscivore CUE
60
45
30
15
0
0
35
70
Distance (km)
Insectivore CUE
60
45
30
15
0
0
35
70
Distance (km)
Small-bodied fish CUE
60
45
30
15
0
0
35
70
Distance (km)
YOY CUE
60
45
30
15
0
0
35
70
Distance (km)

APPENDIX 6B

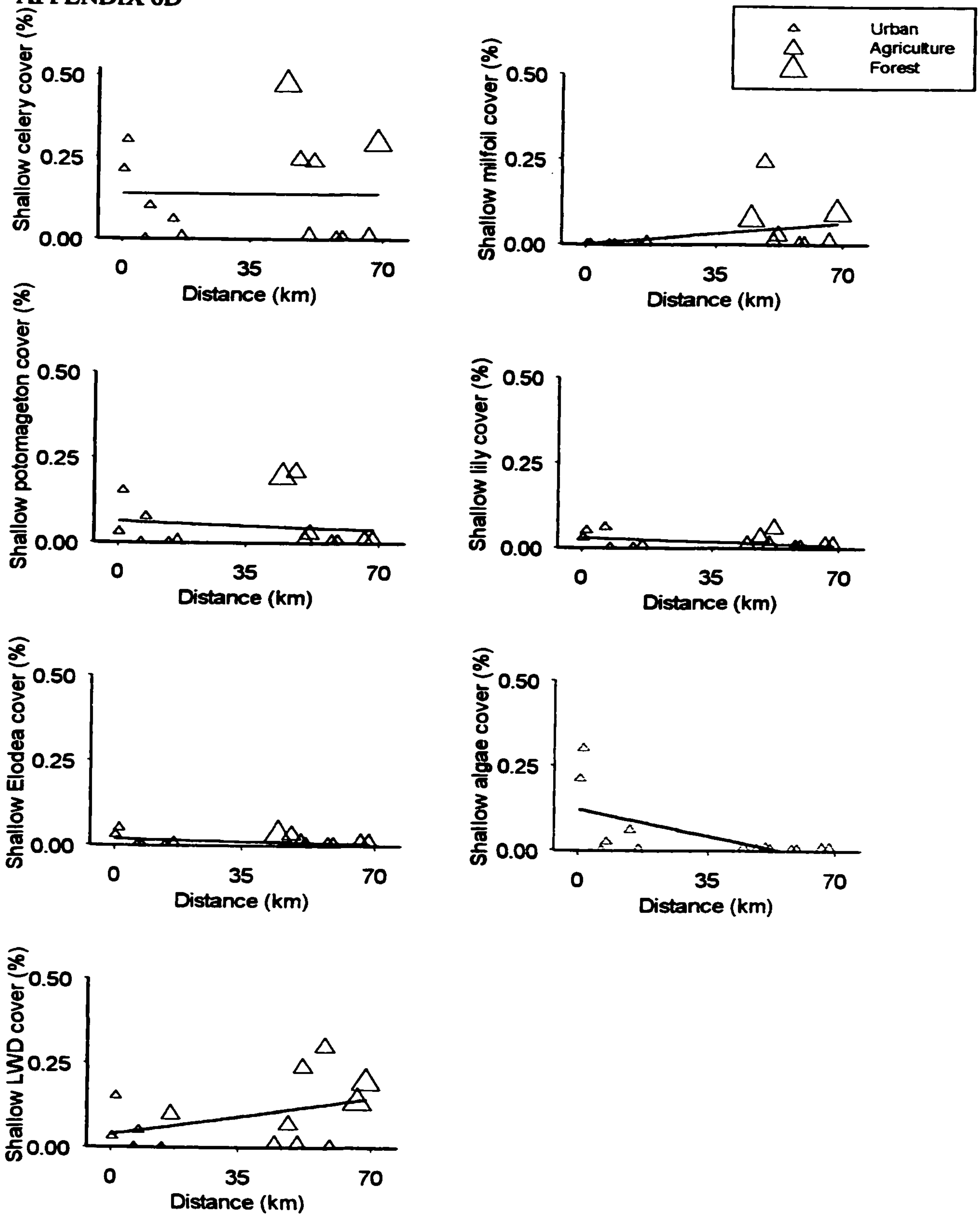

Urban
Agriculture
Forest
Clay cover (%)
Sand cover (%)
Gravel cover (%)
Rubble cover (%)
Detritus cover (%)
Bedrock cover (%)
Boulder cover (%)
0
50
100
0
35
70
Distance (km)

APPENDIX 6C



Urban
Agriculture
Forest
Deep celery cover (%)
Deep milfoil cover (%)
Deep coonstail cover (%)
Deep potomageton cover (%)
Deep lily cover (%)
Deep duckweed cover (%)
1.0
0.5
0.0
0
25
50
75
Distance (km)

APPENDIX 6D



Urban
Agriculture
Forest
Shallow celery cover (%)
Shallow milfoil cover (%)
Shallow potomageton cover (%)
Shallow lily cover (%)
Shallow Elodea cover (%)
Shallow algae cover (%)
Shallow LWD cover (%)
0.50
0.25
0.00
0
35
70
Distance (km)

Appendix 7:
Table of raw data.

APPENDIX 1

Site 1

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
BG									0
PS		2	2						4
YP									0
BC									0
NP			1						1
M									0
W									0
LP			4	8	15				27
SMB	12	1	1		2	7		4	27
LMB									0
BBH									0
ST									0
BSS									0
BCHIN									0
BKN									0
BN									0
WS									0
RB	1		14		13	3		3	34
KILL									0
TD								5	5
C									0
GRH									0
SRH									0
CS									0
GS									0
TOTAL	13	3	22	8	30	10	0	12	98

Site 2

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
BG				3					3
PS				11	1				12
YP					3				3
BC	1							2	3
NP									0
M									0
W									0
LP									0
SMB	9				2				11
LMB									0
BBH				1				1	2
ST				13	1				14
BSS									0
BCHIN				9					9
BKN									0
BN									0
WS									0
RB			4	135	10			15	164
KILL				100	3			44	147
TD								4	4
C									0
GRH									0
SRH									0
CS									0
GS				2	4				6
TOTAL	10	0	4	274	24	0	0	66	378

Site 3

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL	
SF					5				5	
BG					12				12	
PS		3							3	
YP									0	
BC				4					4	
NP	1								1	
M									0	
W									0	
LP								2	2	
MS								1	1	
SMB	5	2	2					2	11	
LMB									0	
BBH									0	
ST									0	
BSS									0	
BCHIN									0	
BKN									0	
BN									0	
WS									0	
RB	2	17	2		4			7	32	
KILL					20				20	
TD									0	
C	8								8	
GRH									0	
SRH	1								1	
FWD	1								1	
CS									0	
GS					22				22	
TOTAL	18	22	4	4	63	0	0	12		123

Site 4

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL	
BG				11					11	
PS			8	12	8				28	
YP					12			1	13	
BC	1			13	2				16	
NP	2								2	
M								1	1	
W									0	
LP									0	
MS									0	
SMB	2	1	1	2				4	10	
LMB				1					1	
BBH									0	
ST									0	
BSS									0	
BCHIN									0	
BKN									0	
BN									0	
WS									0	
RB		4	8	3	13			4	32	
KILL					22				22	
TD									0	
C									0	
GRH									0	
SRH									0	
FWD									0	
CS						1			1	
GS						1			1	
TOTAL	5	5	17	42	57	2	0	10		138

Site 5	Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
	FF				1					1
	SF				204	214	37			455
	BG	1							2	3
	PS			2	9	2	1			14
	YP				81	10	89			180
	BC				6	4	26			36
	NP	1								1
	M									0
	W						1			1
	LP				49	2	8		3	62
	MS									0
	SMB	7	2	2	1		2			14
	LMB									0
	BBH									0
	ST				8		24			32
	BSS					3				3
	BCHIN									0
	BKN									0
	BN									0
	WS			1						1
	RB		2	2	31	25	75		6	141
	KILL									0
	TD								4	4
	C									0
	GRH									0
	SRH	1								1
	FWD									0
	CS									0
	GS				2					2
TOTAL		10	4	7	392	280	283	0	15	951

Site 6	Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
	FF				4					4
	SF				48					48
	BG								4	4
	PS		2	1						3
	YP	3			51	177	48		1	280
	BC	3	1	1	9	51	36			101
	NP	1				1				2
	M									0
	W				1					1
	LP				30	31	90		7	158
	MS									0
	SMB	8	6			2	3		3	22
	LMB	1			1	1				3
	BBH								1	1
	ST				12	6	6			24
	BSS				1					1
	BCHIN					1				1
	BKN									0
	BN									0
	WS									0
	RB		1	2	9	24	26			62
	KILL									0
	TD						4		3	7
	C	6							1	7
	GRH	1					2			3
	SRH	5							1	6
	FWD									0
	CS				413	222	1			636
	ES					1				1
	GS					1				1
TOTAL		28	10	4	579	518	216	0	21	1378

Site 7

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
SF									0
BG	23		2	20	79			11	135
PS	11	6	4	210	88			1	320
YP	2	1		32	84			2	121
BC	5		2	24	3				34
NP									0
M									0
W			1						1
LP				10					10
MS									0
SMB	1			12	10				23
LMB	2		3	20	17			1	43
BBH	3			1				2	6
ST			1	6					7
BSS				26	65				91
BCHIN									0
BKN				9	1				10
BN				8	5			1	14
WS									0
RB				12	2			1	15
KILL				12				5	17
TD				2	2			10	14
C	2			1					3
GRH									0
SRH									0
FWD									0
CS				80					80
GS									0
TOTAL	49	7	13	485	356	0	0	34	944

Site 8

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
UK					2				2
FF								1	1
SF									0
BG	71	11	1		5			2	90
PS	11	10	7		44			7	79
YP	4	3		35	18				60
BC	10	2		4	18				34
NP	2								2
M	1								1
W									0
LP					2				2
MS									0
SMB									0
LMB	3	7	1	1	6			3	21
BBH	13	4			1				18
ST									0
BSS					7				7
BCHIN									0
BKN					2				2
BN				6	2			2	10
WS									0
RB			1		10			1	12
KILL					3				3
TD				1	4				5
C	1								1
GRH									0
SRH									0
FWD									0
CS									0
GS				12	2			3	17
TOTAL	116	37	10	59	128	0	0	19	387

Site 9

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
SF									0
BG	7	49	14	18	12			1	101
PS	2	33	4	10	19			1	69
YP		1		2	3				6
BC	4	1		1					6
NP									0
M									0
W									0
LP		4							4
MS									0
SMB									0
LMB			7		1			6	14
BBH	1	24	2						27
ST									0
BSS									0
BCHIN									0
BKN				8					8
BN					6			1	7
WS									0
RB				1	2			7	10
KILL				8	10			24	42
TD								1	1
C									0
GRH									0
SRH									0
FWD									0
CS									0
GS				2					2
TOTAL	14	112	27	50	53	0	0	41	297

Site 10

Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
SF									0
BG	2	14	1	6	58			7	88
PS	4	6	9	6	74			8	107
YP	1		9		55				65
BC					1				1
NP	3								3
M									0
W									0
LP									0
MS									0
SMB									0
LMB		2		1	8			5	16
BBH		2	1	1					4
ST									0
BSS					5				5
BCHIN									0
BKN					3				3
BN									0
WS									0
RB			1					1	2
KILL				7	4			1	12
TD					1				1
C									0
GRH									0
SRH									0
FWD									0
CS									0
GS									0
TOTAL	10	24	21	21	209	0	0	22	307

Site 11	Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL	
	SF									0	
	BG	3	8	1	39	15			5	71	
	PS		17	27	28	40			12	122	
	YP	1		2		9				12	
	BC	5		4		2			1	12	
	NP	3	1	1						5	
	M									0	
	W									0	
	LP									0	
	MS									0	
	SMB				8	3				11	
	LMB	3	3	3		10			3	22	
	BBH		11							11	
	ST									0	
	BSS					9				9	
	BCHIN									0	
	BKN				20	3			1	24	
	BN			5	7	3			4	19	
	WS								1	1	
	RB			1	3	1			1	6	
	KILL				8	1				9	
	TD								3	3	
	C								1	1	
	GRH									0	
	SRH									0	
	FWD									0	
	CS									0	
	GS			2	5	6				13	
TOTAL		15	40	48	116	102	0	0	32		351

Site 12	Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL	
	FF					1				1	
	BG	3	2	3	7	2				17	
	PS		5	22	113	17			3	160	
	YP		1	4	2	9				16	
	BC			18	18	6				42	
	NP				3					3	
	M									0	
	W	1								1	
	LP									0	
	SMB	4		2	2					8	
	LMB	2		2	7	2				13	
	BBH	3		1	1				1	6	
	ST				4	1				5	
	BSS									0	
	MT								1	1	
	BKN				40	17				57	
	BN				87	7				94	
	WS		1							1	
	RB			1	4	13			4	22	
	KILL				5	1			1	7	
	TD			1		1			7	9	
	C	1								1	
	GRH	3								3	
	SRH									0	
	GS				134	37				171	
TOTAL		17	9	54	427	114	0	0	17		638

	Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
Site 13	BG	2	21	6	59	75			3	166
	PS		5	3	56	37			2	103
	YP				36	11				47
	BC	2	1	1		21				25
	NP	1								1
	M									0
	LP				31				2	33
	SMB				1					1
	LMB	2	5		7	2			2	18
	BBH		1							1
	ST									0
	BSS				18					18
	BKN				1					1
	BN				15				1	16
	WS									0
	RB				1	5			2	8
	KILL				2	1				3
	TD									0
	C	2								2
	GRH	2			3					5
	SRH									0
	GS									0
TOTAL		11	33	10	230	152	0	0	12	448
Site 14	Gear	Trap	Hoop	Minnow	Seine A	Seine B	Seine C	Seine D	Electro	TOTAL
	BG	5			17	79	76	73	1	251
	PS	1		1	25	12	30	55	1	125
	YP				4	6	9	18		37
	BC	4		2	9	4	3	3		25
	NP						1			1
	M									0
	LP				1		1	2	1	5
	SMB	2							1	3
	LMB				2	3	3		2	10
	BBH									0
	ST									0
	BSS									0
	BKN				1					1
	BN				1	1				2
	WS									0
	RB				6	3	1	3		13
	KILL				1					1
	TD								1	1
	C	3								3
	SRH	1								1
	GS				4	5				9
TOTAL		16	0	3	71	113	124	154	7	488
GEAR TOTAL		332	306	242	2758	2177	615	154	320	TOTAL 6904

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