Spatial and Temporal Variation in Fish Assemblages in Three Small Unpolluted Estuarine Rivers and Associated Lagoons in Kouchibouguac National Park, Southern Gulf of St. Lawrence, Canada

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Estuaries have among the highest primary production rates of ocean waters and provide essential habitat for many organisms. Recognition of the need to conserve these critical habitats is coupled with the need for baseline data to allow assessment of ecosystem changes. This study compares natural variations in, and correlations between, the composition of fish assemblages and environmental factors at several sites over two years in three rivers emptying into estuaries in the southern Gulf of St. Lawrence, Canada. Fish diversity and abundance were determined by beach seining and related to water temperature, salinity, substrate, and vegetation. From May to September 2000 (14 sites) and May to August 2001 (15 sites), 20 fish species were collected, seven of which accounted for 98% of the total catch. The dominant species, Mummichog (*Fundulus heteroclitus*), represented 44% of the catch. Its abundance and that of the other dominant species — Threespine Stickleback (*Gasterosteus aculeatus*) 16%, Blackspotted Stickleback (*G. wheatlandi*) 13%, Banded Killifish (*F. diaphanus*) 12%, Fourspine Stickleback (*Apeltes quadracus*) 7%, Atlantic Silverside (*Menidia menidia*) 4%, and Ninespine Stickleback (*Pungitius pungitius*) 2% — differed significantly both spatially and temporally. Multidimensional scaling analysis showed a spatial gradient in abundance from upstream to lagoon sites and a temporal gradient from spring to fall. Upstream sites were low in salinity and had a higher organic content and a higher proportion of silt–clay in the sediment. Variation within fish populations was related to site and seasonal changes in environmental conditions and species' tolerance of water temperature, salinity, vegetation coverage, and fine sediments.

Key Words: Estuary; fish; fishes; spatial and temporal gradients; beach seine; *Fundulus heteroclitus*; Mummichog; *Gasterosteus aculeatus*; Threespine Stickleback; *Gasterosteus wheatlandi*; Blackspotted Stickleback; *Fundulus diaphanus*; Banded Killifish; *Apeltes quadracus*; Fourspine Stickleback; *Menidia menidia*; Atlantic Silverside; *Pungitius pungitius*; Ninespine Stickleback; multivariate analyses; Kouchibouguac National Park; Black River; Kouchibouguac River; Kouchibouguacis River

Introduction

Although fish assemblages in shallow temperate environments are naturally highly dynamic, anthropogenic processes bring about further change through habitat modification (Waite and Carpenter 2000), introduction of non-native species (Waite and Carpenter 2000), climate change (Genner *et al.* 2010), and exploitation of commercial and bycatch species (Rogers and Ellis 2000). These impacts, caused in large part by concentration of humans in coastal zones, have resulted in disturbance and the loss of entire estuaries, which have been long recognized as among the most productive ecosystems in the world (Kennish 2000, 2002). Invertebrates and numerous species of coastal fish depend on estuaries as migration corridors, spawning and feeding habitats, and nurseries that provide refuge from predation (Haedrich 1983; Deegan and Day 1984). Conservation of estuarine habitat is critically important before more is lost (Kennish 2000, 2002).

Only a handful of fish assemblage studies have been carried out in the coastal waters of Atlantic Canada (e.g., Macdonald *et al.* 1984; Black and Miller 1991; Methven

et al. 2001; Wroblewski *et al.* 2007; Melanson and Campbell 2012) despite the ecological and economic importance of estuaries there. Several additional studies from the southern Gulf of St. Lawrence (McKenzie 1959; Chaput 1995; Hanson and Courtenay 1995) have focused largely on the more anthropogenic influenced Miramichi River and estuary (47°5'N, 65°22'W). Research in the Miramichi estuary has concentrated on Atlantic Tomcod (*Microgadus tomcod*) as a potential indicator of the effects of pulp mill effluent (Courtenay *et al.* 1995). This estuary has important commercial and recreational fisheries for Atlantic Salmon (*Salmo salar*), American Eel (*Anguilla rostrata*), Atlantic Tomcod (*Microgadus tomcod*), Rainbow Smelt (*Osmerus mordax*), and Gaspereau (*Alosa* spp.) and contains approximately 78 species of fishes (McKenzie 1959; Chaput 1995; Hanson and Courtenay 1995). Robinson *et al.* (2001) collected 21 fish taxa using beach seine nets in the Kouchibouguac and Richibucto estuaries while looking for spawning grounds of Striped Bass (*Morone saxatilis*). Thériault *et al.* (2006, 2007) also sampled in the southern Gulf of St. Lawrence, collecting 18 species

adjacent to fish processing plants. The coastal fauna is further described by ichthyoplankton surveys of the Miramichi, Kouchibouguac, and Richibucto estuaries (Locke and Courtenay 1995; Robinson *et al.* 2001) and bottom trawling (< 40 m) in the Northumberland Strait (Bosman *et al.* 2011).

Our study examines the fish assemblages in a near-pristine environment, Kouchibouguac National Park in the southern Gulf of St. Lawrence. This is among the first studies undertaken in a shallow estuarine habitat where near-natural undisturbed conditions exist.

Although we acknowledge that it is difficult to characterize pristine conditions, given the long history of exploitation and habitat modification in estuaries (Blaber *et al.* 2000), anthropogenic impacts in the study area are limited to commercial fishing of a few species, notably *A. rostrata, O. mordax* (during winter), and *Alosa* spp. (Kalff 1998) and occasional dredging. There is no industry or fish processing facility, farming, pesticide use, wood cutting, or disposal of domestic sewage that would affect the estuary or nearby waters. The last shipyard for boat building and repair closed in 1868. Canneries closed in the 1950s, and sawmill operations ceased in 1964 (Beach 1988; Rudin 2011).

Our study is unique in that it reports changes in fish assemblages at upstream, downstream, and lagoon sampling sites during spring, summer, and fall in three relatively pristine rivers over 2 years. The objective was to describe variation in these assemblages among sites (15), rivers (3), seasons (3), and years (2) in relation to environmental and habitat variables.

Study Area

All sampling occurred in vegetated areas within or immediately adjacent to Kouchibouguac National Park on the east coast of New Brunswick, Canada, bordering on the southern Gulf of St. Lawrence. Kouchibouguac National Park is representative of the Maritime Lowland Ecoregion and includes bogs, salt marshes, tidal rivers, freshwater systems, sheltered lagoons, abandoned fields, and Acadian forests (Rowe 1972; Beach 1988). Aquatic habitat within the park is relatively undisturbed (Hauck *et al.* 2009), and the amount of disturbance has decreased each year since the park was established in 1979 (Beach 1988; Kalff 1998).

All sampling was confined to the Black, Kouchibouguac, and Kouchibouguacis Rivers and their associated estuaries and lagoons (Figure 1). These rivers
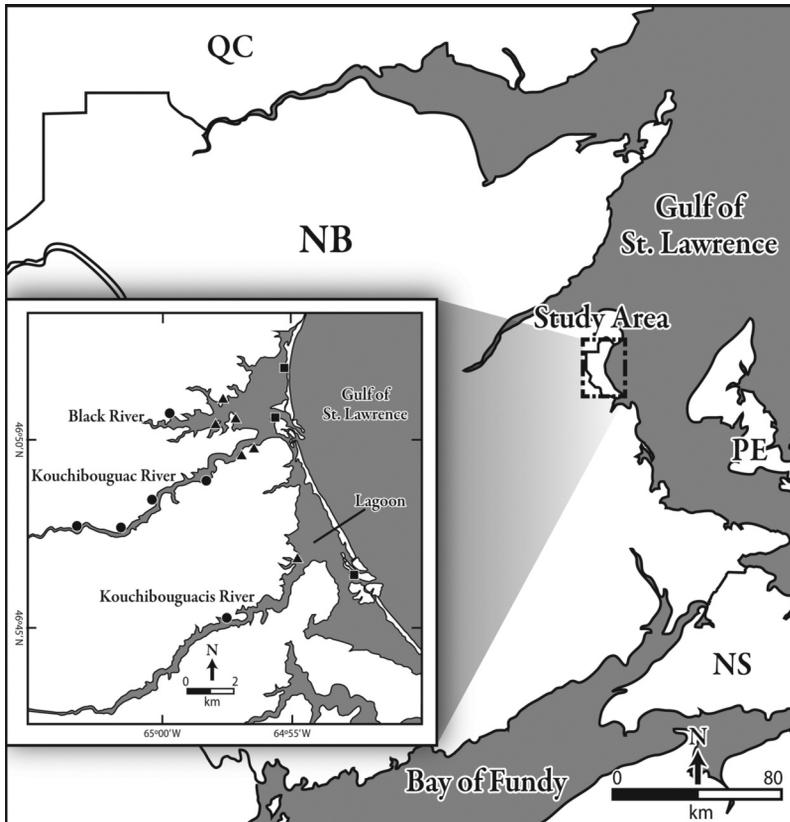

FIGURE 1. Location of the 15 sampling sites in the coastal waters of the southern Gulf of St. Lawrence, New Brunswick, in or adjacent to Kouchibouguac National Park, showing upstream (●), downstream (▲), and lagoon (■) sites. The lagoon site at the mouth of the Kouchibouguacis River was added in 2001. Note: NB = New Brunswick, NS = Nova Scotia, QC = Quebec, PE = Prince Edward Island.

form broad shallow (< 10 m) estuaries that are protected from the ocean by a series of barrier islands (Beach 1988; Hauck *et al.* 2009). Sediments vary from silt and mud upstream to sand in the lagoons. Vegetation also varies with distance from the ocean. Sea Ditchgrass (*Ruppia maritima*) dominates upstream areas, and Common Eelgrass (*Zostera marina*) is characteristic of the parts of the rivers and lagoons affected by tides (Beach 1988). The mixed semi-diurnal tides that characterize the region have an amplitude of approximately 3 m (Miller *et al.* 1991; Robinson *et al.* 2001). Hauck *et al.* (2009) has described the study area in more detail. The Kouchibouguac River lagoon site has been studied previously (Joseph *et al.* 2006).

The salinity of upstream sampling sites ($n = 6$), greater than 2 km from the mouth of the river, was less than 10 ppt. That of downstream sites ($n = 6$), which were less than 2 km from the mouth of the river, was 10–25 ppt. Lagoon sites ($n = 3$), located on the western side of the barrier islands were characterized by salinities greater than 25 ppt.

Methods

Fish sampling

Fourteen sites were sampled from May to September 2000. In 2001, sampling was repeated from May to August with the addition of a 15th site: the southernmost lagoon site on the Kouchibouguacis River (Figure 1). Sites were sampled once a month to minimize impact on beds of eelgrass and fish mortality. Each site was sampled using a 30 m × 1.3 m beach seine (6-mm mesh throughout), with 69 hauls in 2000 and 60 in 2001 to a maximum depth of 1.2 m.

The beach seine was deployed by pulling half the net perpendicular to the shore until the collection bag was in the water, then pulling it parallel to the shore against the current until the entire seine was in the water. The deep end of the seine was then brought back to shore 10 m from the starting point. The seine was hauled out of the water simultaneously by two people who gradually approached each other to close the seine. When the seine was deployed from a boat (at the nine lagoon sites), the same procedure was employed; however, the seine was pulled into the boat rather than onto the shore. The catch efficiency was judged to be consistent given that the vast majority of the catch was confined to the centrally located collection bag, making it easy to retain the catch and haul it into the boat.

The catch was carefully emptied into a plastic tub (51 cm × 43 cm × 25 cm) filled with water from the collection site. Fish were identified and counted, and the vast majority were returned to the water alive. Fish were identified to species using Scott and Crossman (1973) and Scott and Scott (1988). In the few cases where a seine haul captured more than 300 individuals of one species (in 2000, 9 of 69 hauls; in 2001, 6 of 60 hauls), a dip net was used to subsample 300 individuals to minimize handling and holding stress.

Environmental variables

Data on salinity, temperature, organic content, silt–clay content, and plant and algae cover were collected at each site to examine relationships with seasonal and spatial variability. Vegetation coverage was determined by random toss of a metal quadrat (54 cm × 54 cm), repeated three times at each sampling site. The quadrat was divided into four equal quadrants, and plant and algal cover were estimated separately for each quadrant through a viewing box with a plexiglass bottom. The percentage cover was calculated as the average of the 12 quadrants.

Approximately 200 mL of sediment was collected at each site, using a garden trowel, to determine percentage organic content and percentage silt–clay. Sediment samples were placed in a plastic bag and frozen (−20°C) until lab analysis was conducted as described by Higgins and Thiel (1988) and Thériault *et al.* (2006). Water temperature and salinity were measured at a depth of 0.5 m approximately 2 m from shore.

Data analyses

Univariate and multivariate analyses were used to determine variation in catches of fishes and environmental variability (salinity, temperature, organic content, silt–clay, plant and algae cover) among sampling locations (upstream, downstream, lagoon), rivers (Black, Kouchibouguac, Kouchibouguacis), seasons (spring [May], summer [June, July], fall [late August, September]), and years (2000, 2001).

Significant differences among rivers, sampling locations, seasons, and years were determined using the global nonparametric Kruskal–Wallis test for species richness and total abundance (SAS 2000). Significant differences among sampling locations and seasons were determined using the nonparametric Kruskal–Wallis test for the seven most abundant species (i.e., those representing more than 1% of the total catch) and the six environmental variables (SAS 2000). This test is an analysis of variance of ranked data used to compare more than two samples (Zar 1996). It was followed by the Wilcoxon paired test to determine where significant differences occurred between upstream and downstream, upstream and lagoon, downstream and lagoon locations and between spring and summer, spring and fall, and summer and fall, for the mean species richness, mean total abundance, mean abundance of each dominant fish species, and the six environmental variables. Because only 2 years were sampled, the Wilcoxon test was used to test for differences between years.

All fish assemblage data were submitted to multidimensional scaling (MDS) analysis (Clarke and Warwick 2001) based on the Bray–Curtis similarity index to identify patterns in abundance by site and season. The Bray–Curtis similarity index was chosen over other common indices because it is recommended for species data and depends only on those species that are present (it does not take into account joint absences) (Clarke 1993).

MDS analysis was based on relative species abundance for each site and month, i.e., species abundance was expressed as a percentage of the total abundance for that site and month. We used relative abundance because of the unequal number of samples collected in different years, months, and locations. Species data were square root transformed. Environmental data were analyzed using correlation-based principal components analysis (PCA) with normalized Euclidean distance as the measure of distance between samples (Clarke and Warwick 2001). This analysis is the most appropriate for mixed measurement scales characteristic of environmental data (e.g., organic content as a percentage, salinity as parts per thousand, etc.). For the multivariate analyses, rivers and years were pooled because no significant differences were found in mean species richness and mean total abundance among the rivers or between years.

Correlations between ranked mean species abundances and ranked environmental variables were determined using the Spearman correlation test (SAS 1999). All analyses were conducted with $\alpha = 0.05$.

Results

Fish assemblage

More than 21 000 fish (11 022 in 2000 and 10 131 in 2001) representing 20 taxa from 13 families were collected in the 129 samples taken from the three estuarine rivers and associated lagoons (Table 1). Seven estuarine species accounted for 98% of the catch: *Fundulus heteroclitus* (44%) was the most abundant, followed by four species of sticklebacks, *Gasterosteus aculeatus* (16%), *G. wheatlandi* (13%), *Apeltes quadracus* (7%), and *Pungitius pungitius* (2%), in addition to *F. diaphanus* (12%) and *Menidia menidia* (4%). All fishes were small bodied (usually less than 30 cm in

TABLE 1. Number of fishes (*n* = 21 153) caught in three estuaries in Kouchibouguac National Park, southern Gulf of St. Lawrence, in spring, summer, and fall 2000 and 2001.

Species	Abundance	
	Number	%
Mummichog (*Fundulus heteroclitus*)	9313	44.03
Threespine Stickleback (*Gasterosteus aculeatus*)	3302	15.61
Blackspotted Stickleback (*G. wheatlandi*)	2784	13.16
Banded Killifish (*Fundulus diaphanus*)	2615	12.36
Fourspine Stickleback (*Apeltes quadracus*)	1522	7.20
Atlantic Silverside (*Menidia menidia*)	849	4.01
Ninespine Stickleback (*Pungitius pungitius*)	489	2.31
Striped Bass (*Morone saxatilis*)	75	0.35
Smooth Flounder (*Liopsetta putnami*)	65	0.31
Winter Flounder (*Pseudopleuronectes americana*)	57	0.27
Atlantic Tomcod (*Microgadus tomcod*)	19	0.09
Brook Trout (*Salvelinus fontinalis*)	16	0.08
Golden Shiner (*Notemigonus crysoleucas*)*	13	0.06
Cunner (*Tautogolabrus adspersus*)	12	0.06
Gaspareau, Blueback, Shad (*Alosa* spp.)	9	0.04
Juvenile flounder (*Pleuronectes* spp.)	7	0.03
White Sucker (*Catostomus commersonii*)	3	0.01
Yellowtail Flounder (*Limanda ferrugina*)	1	0.00
Northern Pipefish (*Sygnathus fuscus*)	1	0.00
Longhorn Sculpin (*Myoxocephalus octodecemspinosus*)	1	0.00

*Identification tentative.

length) and these seven dominant species were represented by both juvenile and adult stages.

Species richness (Kruskal–Wallis test: $\chi^2 = 0.6413$, $P = 0.73$) and total catches (Kruskal–Wallis test: $\chi^2 = 1.6767$, $P = 0.43$) were not significantly different among the three rivers sampled. However, species richness (Kruskal–Wallis test: $\chi^2 = 28.7267$, $P < 0.0001$) and total catch (Kruskal–Wallis test: $\chi^2 = 21.8753$, $P < 0.0001$) did differ significantly among upstream, downstream, and lagoon locations (Figure 2). Species richness (Wilcoxon test: $\chi^2 = 1.7492$, $P = 0.20$) and total catches (Wilcoxon test: $\chi^2 = 0.1826$, $P = 0.68$) were

not significantly different between years. Species richness (Kruskal–Wallis test: $\chi^2 = 0.34$, $P = 0.84$) and total catches (Kruskal–Wallis test: $\chi^2 = 1.3380$, $P = 0.51$) were also not significantly different among seasons (Figure 2).

Abundance patterns of the dominant species differed significantly among sites and seasons (Figure 3). Catches of *P. pungitius*, *F. heteroclitus* and *F. diaphanus* decreased significantly from upstream to lagoon sites. Catches of *A. quadracus* between upstream and downstream sites were not significantly different, but they were significantly lower at lagoon sites. Mean catches
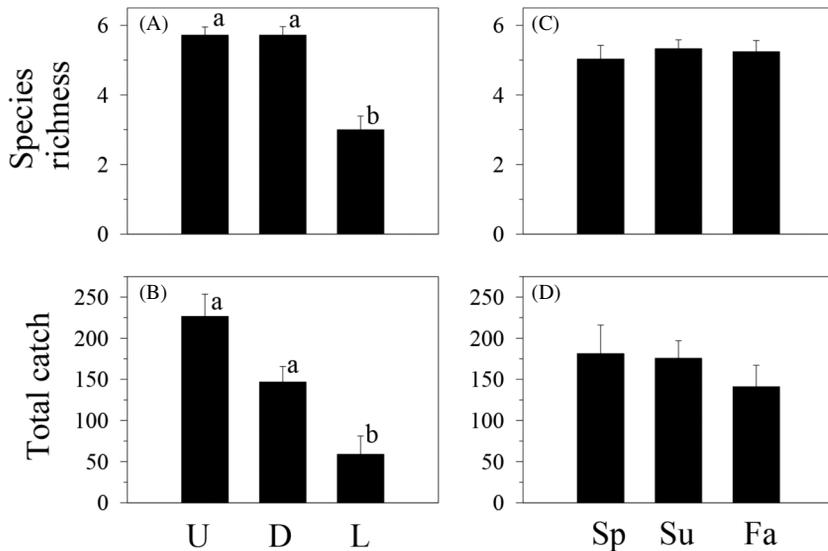
FIGURE 2. (A) Mean species richness and (B) mean total beach seine catch at upstream (U), downstream (D), and lagoon (L) sampling sites, and (C) mean species richness and (D) mean total beach seine catch in spring (Sp), summer (Su), and fall (Fa) in Kouchibouguac National Park estuaries, southern Gulf of St. Lawrence ($n = 129$). Significant differences are indicated by different letters (a, b).

of *G. aculeatus* and *M. menidia* were lower at upstream sites, peaked at downstream sites, and decreased slightly in the lagoon although not all these differences were significant. Relative abundances of *G. wheatlandi* did not vary among upstream, downstream, and lagoon sites (Figure 3).

Four patterns of species abundance were evident by season (Figure 3): catches of *G. aculeatus* and *G. wheatlandi* decreased significantly from spring to fall; catches of *A. quadracus* and *P. pungitius* increased significantly from spring to fall; catches of *F. heteroclitus* and *F. diaphanus* were lowest in spring and highest in summer, a trend that was only significant for *F. diaphanous*. *Mendia menidia* was less abundant in summer, although not significantly.

Environmental variables

Salinity (Kruskal–Wallis test: $\chi^2 = 29.6549$, $P < 0.0001$) was the single variable that differed significantly by river; it was lower in the Kouchibouguac River than in the Black and Kouchibouguacis Rivers. Organic content (Kruskal–Wallis test: $\chi^2 = 2.2614$, $P = 0.32$) and silt–clay content (Kruskal–Wallis test: $\chi^2 = 5.0094$, $P = 0.082$) of the sediment and algae coverage (Kruskal–Wallis test: $\chi^2 = 2.9104$, $P = 0.23$) were marginally (but not significantly) lower in the Black River. Temperature (Kruskal–Wallis test: $\chi^2 = 0.2923$, $P = 0.86$) and plant coverage (Kruskal–Wallis test: $\chi^2 = 1.1577$, $P = 0.56$) were relatively homogeneous in all three rivers.

Salinity was significantly higher (Wilcoxon test: $\chi^2 = 12.5276$, $P = 0.0004$) in 2001 than in 2000. Organic content (Wilcoxon test: $\chi^2 = 10.4476$, $P = 0.0012$) and plant coverage (Wilcoxon test: $\chi^2 = 10.8755$, $P = 0.0010$) were significantly lower in 2001. Temperature (Wilcoxon test: $\chi^2 = 1.9977$, $P = 0.17$), silt–clay content (Wilcoxon test: $\chi^2 = 0.0008$, $P = 0.99$), and algae coverage (Wilcoxon test: $\chi^2 = 0.2283$, $P = 0.63$) did not differ between years.

As expected, salinity increased significantly from upstream to lagoon sites (Figure 4). Salinity was lowest in spring when terrestrial runoff was highest and significantly higher in summer and fall. Water temperature ranged from 8° to 28°C (mean 20.1°C) throughout the study and differed significantly among seasons: lowest in spring, highest in summer, and intermediate in fall. Temperature did not differ significantly among upstream, downstream, and lagoon locations.

Organic content in the sediment ranged from 0.25% to 14.93% (mean 2.21%); it was highest upstream and decreased significantly toward lagoon sites (Figure 4). Organic content did not differ significantly among seasons. Silt–clay content of the sediment ranged from 0.04% to 32.23%, (mean 4.93%) and followed the same pattern as organic content: highest at upstream sites and lowest in the lagoon. Silt–clay content did not differ among seasons.

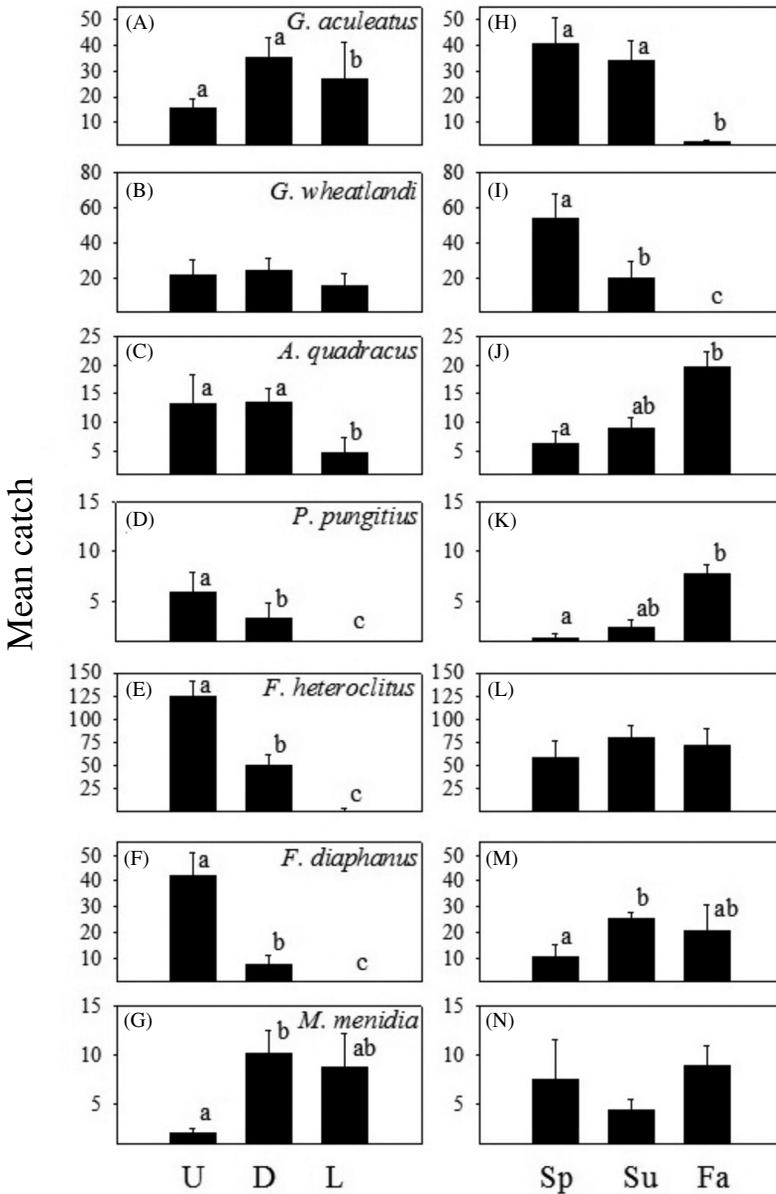Plant cover ranged from 0% to 95% (mean 33%). Coverage was highest at downstream sites and lowest

FIGURE 3. Mean catch of dominant fish (one standard error) (A–G) at upstream (U), downstream (D), and lagoon (L) sampling sites, and (H–N) in spring (Sp), summer (Su), and fall (Fa) in Kouchibouguac National Park estuaries, southern Gulf of St. Lawrence ($n = 129$). Significant differences are indicated by different letters (a, b, c).

in high–salinity lagoon sites (Figure 4). Plant coverage was significantly lower in spring than in summer or fall. Algal coverage reached a maximum of 65% (mean 9%) and was highest at upstream sites and lowest at lagoon sites, although this difference was not significant. Algal coverage was significantly lower in spring compared with summer and fall.

Linking fish assemblages to environmental variables

Two fish assemblage patterns, based on species composition and catches, were apparent from the MDS analysis: a spatial gradient from low salinity upstream sites to higher salinity lagoon sites (Figure 5a) and a temporal gradient from spring to fall (Figure 5b). PCA of all the environmental variables (salinity, temperature,
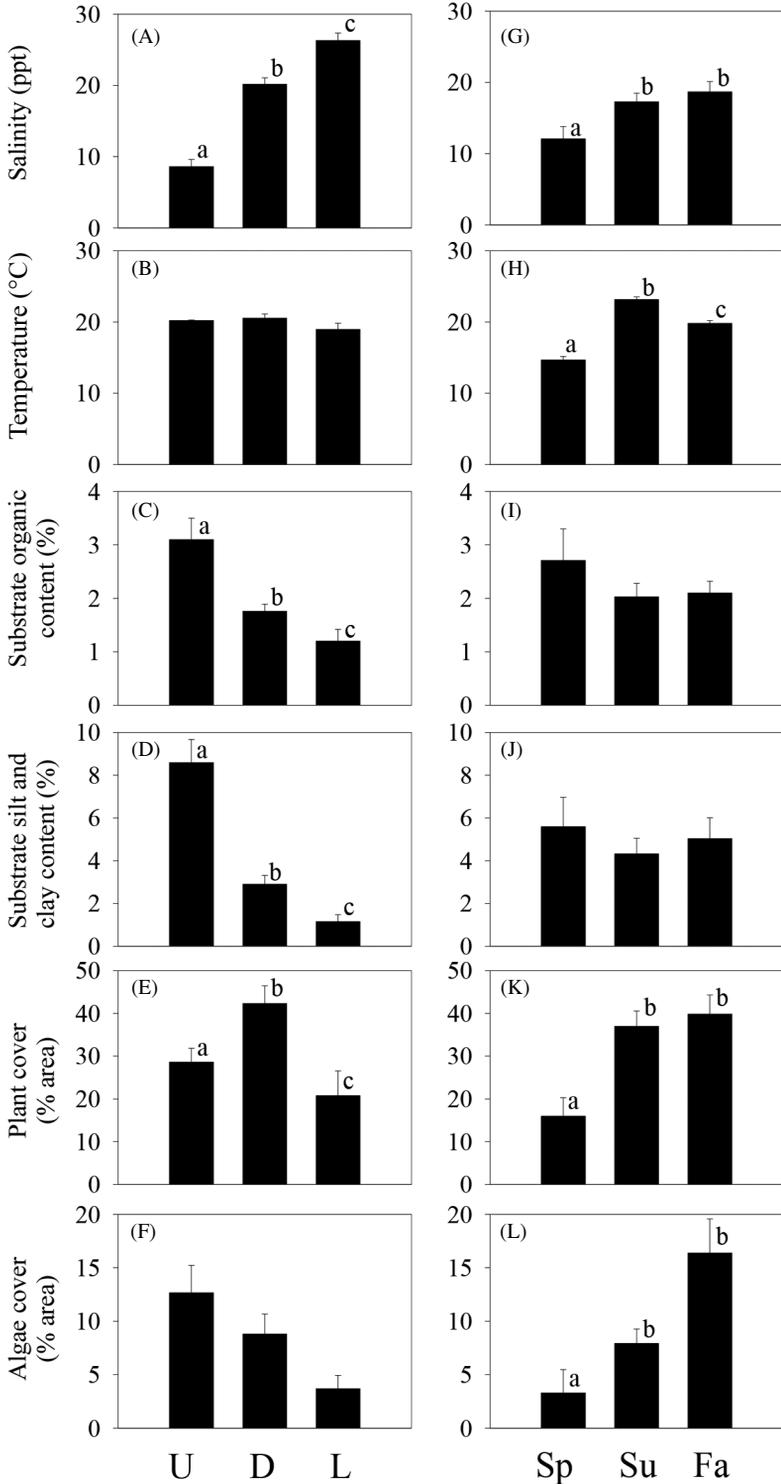
FIGURE 4. Environmental variables (mean and one standard error) (A–F) at upstream (U), downstream (D), and lagoon (L) sampling sites and (G–L) in spring (Sp), summer (Su), and fall (Fa) in Kouchibouguac National Park estuaries, southern Gulf of St. Lawrence (*n* = 129). Significant differences are indicated by different letters (a, b, c).
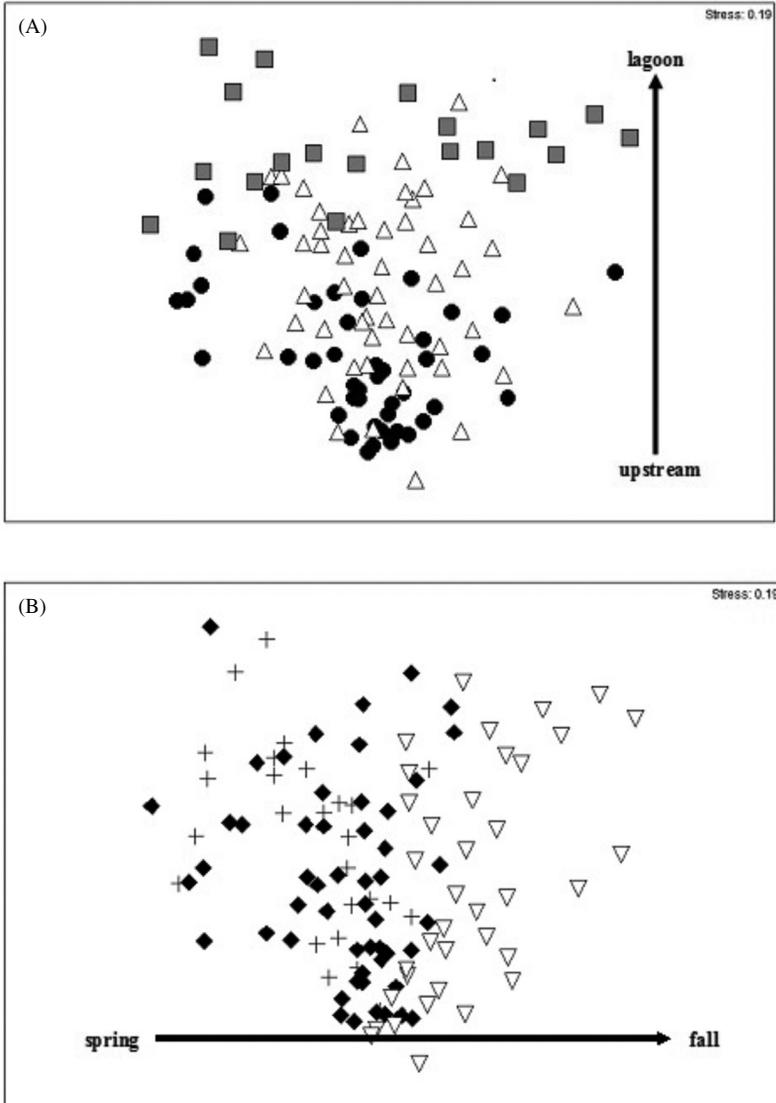
FIGURE 5. Multidimensional scaling (MDS) ordination plots of fish assemblage data showing spatial gradient from (A) upstream (●), downstream (△), and lagoon (■) sites and temporal gradient from (B) spring (+), summer (♦), and fall (▽) samples in Kouchibouguac National Park estuaries, southern Gulf of St. Lawrence (*n* = 129).

organic content, silt–clay content, plant coverage and algae coverage) showed two similar gradients: from upstream to lagoon sites on axis 1 (Figure 6a, 34.9% variation) and from spring to fall on axis 2 (Figure 6b, 24.5% of the variation). The remaining PCA axes did not contribute significantly in the analysis.

Significant correlations were detected between catches of the seven dominant fishes and the six environmental variables. Catches were significantly correlated with salinity, except those of *G. wheatlandi* and *A.*

quadracus (Table 2). These correlations were negative for all species except *M. menidia*. Temperature was significantly correlated with catches of *G. wheatlandi* (negative) and both *Fundulus* species (positive).

The catches of *P. pungitius, F. heteroclitus,* and *F. diaphanus* were positively correlated with organic and silt–clay content. Catches of *M. menidia* were negatively correlated with silt–clay content (Table 2). The catches of all species except *G. wheatlandi* were positively correlated with vegetation coverage: *G. aculea-*
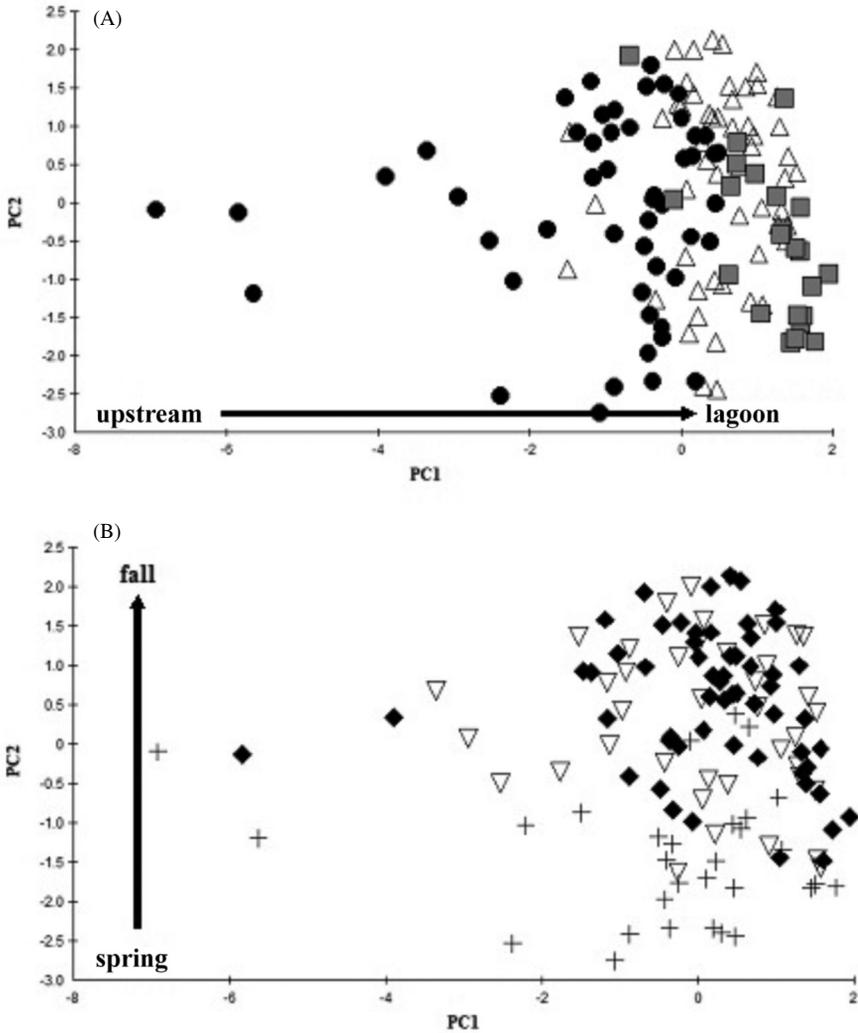
FIGURE 6. Principle component analysis (PCA) ordination plots of environmental data showing spatial gradient from (A) upstream (●), downstream (△), and lagoon (▦) sites and temporal gradient from (B) spring (+), summer (♦), and fall (▽) samples in Kouchibouguac National Park estuaries, southern Gulf of St. Lawrence (*n* = 129). Samples are plotted on the first two PCA axes, which capture 34.9% (axis 1) and 24.5% (axis 2) of variation.

TABLE 2. Spearman ranked correlations (range: -1 to 1) between environmental variables and fish species catches in Kouchibouguac National Park estuaries, southern Gulf of St. Lawrence. Significant correlations are in bold type.

Species	Salinity	Temperature	Organic content	Silt-clay content	Plant cover	Algae cover
Threespine Stickleback (*Gasterosteus aculeatus*)	**-0.205**	0.125	0.123	0.071	**0.178**	-0.087
Blackspotted Stickleback (*G. wheatlandi*)	-0.044	**-0.184**	-0.146	-0.031	-0.036	-0.023
Fourspine Stickleback (*Apeltes quadracus)*	-0.018	0.163	0.136	0.169	**0.418**	**0.228**
Ninespine Stickleback (*Pungitius pungitius*)	**-0.280**	0.002	**0.238**	**0.284**	**0.199**	0.030
Atlantic Silverside (*Menidia menidia*)	**0.241**	0.102	-0.068	**-0.275**	**0.237**	0.162
Mummichog (*Fundulus heteroclitus*)	**-0.197**	**0.286**	**0.227**	**0.486**	0.149	**0.267**
Banded Killifish (*Fundulus diaphanus*)	**-0.341**	**0.279**	**0.282**	**0.482**	0.069	0.116

tus, *A. quadracus*, *P. pungitius* and *M. menidia* showed a positive correlation with plant coverage, and *A. quadracus* and *F. heroclitus* showed a positive correlation with algae coverage.

Discussion

Conservation of estuarine habitats is essential, as these habitats are among the most productive in the ocean and provide essential nursery habitat for many organisms, including commercially important fish and species at risk. Our study of shallow estuarine habitats in near-undisturbed conditions in the southern Gulf of St. Lawrence differed from a survey of the more anthropogenically disturbed Miramichi Estuary, approximately 30 km to the north. There, Hanson and Courtenay (1995) reported 47 species (compared with our 20), 18 of which were found in this study. The Miramichi study covered a larger area, included both shallow and deep water, involved a variety of sampling equipment, and took place throughout the year, all of which resulted in greater species richness. Golden Shiner (*Notemigonus crysoleucas*) and Northern Pipefish (*Syngnathus fuscus*) were two rare species taken in our study that were not reported by Hanson and Courtenay (1995) but were reported previously from estuarine waters of the southern Gulf of St. Lawrence (Needler 1940 [as *Siphostoma fuscum*]; Robinson *et al.* 2001; Herrell and Methven 2009). Otherwise, all fish species collected in our study have been reported previously from shallow coastal waters of the southern Gulf of St. Lawrence (Beach 1988; Robinson *et al.* 2001; Joseph *et al.* 2006).

The relatively small number of species (20) captured by seining and the high catches of just a few species (seven species represent 98% of the fishes caught) in our study are typical of fish assemblages in temperate estuaries off eastern Canada and New England (Lazzari *et al.* 1999; Methven *et al.* 2001; Joseph *et al.* 2006; Thériault *et al.* 2006; Herrell and Methven 2009; Furey and Sulikowski 2011; Teather *et al.* 2012). Species richness in shallow waters such as those sampled by beach seine off Atlantic Canada south of Newfoundland and Labrador is typically less than 25, with most fish species belonging to the Fundulidae, Gasterosteidae, Gadidae, Pleuronectidae, Clupeidae, Cottidae, and Osmeridae. This fauna is a mixture of north temperate and boreal species (Haedrich 1983). Species richness generally increases with additional inshore habitats, sampling gear types, water depth, seasons, tide, and diel cycles (e.g., Hanson and Courtenay 1995). Nonetheless, the shallow water (beach seine) fish assemblages off eastern Canada from Newfoundland and Labrador to New England can be characterized by relatively small body size (less than approximately 30 cm total length), a high proportion of juveniles (that use the area as a nursery) and small adult fishes (that use the area for feeding and spawning), low species richness (< 25), and few species (typically < 7) contributing to more than 90% of the total catch. Many of these shallow water

fishes spawn demersal eggs (Pearcy and Richards 1962; Methven *et al.* 2001).

The environmental variables that differed significantly between years were salinity (higher in 2001) and the percentage of organic content and plant cover (both lower in 2001). The higher salinity was likely due to greater precipitation from October 1999 to April 2000 (776.3 mm) before the sampling season, causing greater freshwater runoff compared with precipitation from October 2000 to April 2001 (638.4 mm). The lower plant coverage in 2001 might be related to the lower organic content, as fewer nutrients in the substrate would limit plant growth. The lower level of organic content was probably related to the lower level of precipitation and less freshwater runoff.

The only environmental variable that differed significantly among rivers was salinity, which was lower in the Kouchibouguac River. Even though there were some significant differences in environmental variables between years and/or rivers, mean species richness and total fish abundance did not differ significantly.

The seven dominant fishes sampled in our study (two Fundulidae, four Gasterosteidae, and one Atherinopsidae) responded to a seasonal gradient and a spatial lagoon-to-upstream gradient (salinity was lower and organic content and proportion of silt–clay in the substrate were higher at upstream sites). Dominant species were present at all sites, except for *F. diaphanus* which was never captured in the high-salinity lagoon sites. *Fundulus diaphanus, P. pungitius,* and *F. heteroclitus* were all significantly negatively correlated with salinity. Salinity has a strong influence on abundance of *F. heteroclitus* and *F. diaphanus* (Fritz and Garside 1974). These three species, were also significantly and positively correlated with organic and silt–clay content and, consequently, decreased in abundance toward the lagoon. The high proportions of silt–clay and organic material at upstream sites contributed to softer and more easily disturbed sediments, which likely increased suspended sediment in the water column. *Fundulus heteroclitus* often occurs in muddy habitats where it tolerates low oxygen levels (Scott and Scott 1988; Halpin and Martin 1999; Collette and Klein-MacPhee 2002; Stierhoff *et al.* 2003).

Fundulus heteroclitus spawns during summer, at approximately 19°C (McMullin *et al.* 2009) when our catches were highest (although they were not significantly different from those in spring and fall). The available evidence indicates an absence of lunar spawning in *Fundulus heteroclitus macrolepidotus*, the subspecies characterizing the northern distribution of the Mummichog. The spawning process is likely largely regulated by temperature (McMullin *et al.* 2009). *Fundulus heteroclitus* is abundant in relatively protected sites in the southern Gulf of St. Lawrence, an observation that contrasts with studies from the coastal Bay of Fundy, where it is present but seldom reported in high abundance (Macdonald *et al.* 1984; Arens 2007), due

possibly to the more exposed nature and higher salinity of the Bay of Fundy sampling sites. McMullin *et al.* (2010) caught *F. heteroclitus* at relatively protected sites in low-salinity water (e.g., 6 ppt–22 ppt) in the lower St. John River, which empties into the Bay of Fundy.

We found *F. diaphanus* to be most abundant at upstream sites, where its presence was significantly correlated with salinity and temperature. The negative correlation with salinity is in keeping with previous studies: Murdy *et al.* (1997) observed that it rarely occurred where salinity was greater than 5 ppt; according to Griffith (1974) and Fritz and Garside (1974), it inhabits freshwater streams and lakes and only rarely invades brackish or marine waters. Catches of *F. diaphanus* were greatest during summer when it spawns (Fritz and Garside 1975). Eggs are reported to be suspended below the female by chorionic filaments, which can attach to aquatic vegetation once fertilized (Richardson 1939; Able and Fahay 2010). Although *F. diaphanus* inhabits upstream sites with aquatic vegetation, it was not significantly correlated with either plant or algae cover, in contrast with the findings of Scott and Crossman (1973: 633) who noted: "Small schools are usually found over sand, gravel, or detritus-covered bottom where there are patches of submerged aquatic plants." Instead, we observed a strong positive correlation with fine sediments, which have been reported as a suitable substrate for burrowing to escape from predation, as noted by Colgan and Costeloe (1980) in laboratory studies.

Menidia menidia is a short-lived (< 2 years) schooling species inhabiting coastal habitats with a sandy bottom and high salinity (Scott and Scott 1988; Able and Fahay 1998). It was most abundant in lagoon and downstream locations, where catches were highest in spring and fall. Low abundance in summer was consistent with observations by Arens (2007) at six sites in the Bay of Fundy. This seasonal pattern of small summer catches was interpreted by Doyle *et al.* (2011) as movement from nursery grounds in late spring and early summer to spawning grounds. Spawning grounds are apparently located in intertidal areas, including marsh creeks and tidal channels, where eggs (1–1.5 mm in diameter) are deposited at high tides on aquatic plants and algae by means of a tuft of adhesive filaments (Collette and Klein-MacPhee 2002). This pattern fits the available information on spawning time in the southern Gulf of St. Lawrence (June: Needler 1940), in the Annapolis River (late June to early July: Jessop 1983), and the vicinity of Saint John Harbour (early June: Doyle *et al.* 2011). Hence, if this interpretation is correct, sampling in nearby marsh creeks and tidal channels in June may yield mature *M. menidia* in the process of spawning.

The four remaining dominant fishes collected in our study belong to the Gasterosteidae. *Gasterosteus aculeatus* and *G. wheatlandi* are the dominant stick-leback species in the marine portions of estuaries in southern Labrador (Wroblewski *et al.* 2007), eastern Newfoundland (Methven *et al.* 2001), southern Gulf of St. Lawrence (Robinson *et al.* 2001; Joseph *et al.* 2006), and the Bay of Fundy (Arens 2007). These species also continue to be prominent members of the Gasterosteidae off northern New England, although *A. quadracus* and *P. pungitius* can also be abundant (Targett and McCleave 1974; Ayvazian *et al.* 1992; Lazzari *et al.* 1999). In our study, *G. aculeatus* and *G. wheatlandi* shared similar spatial and temporal distributions and were most abundant at downstream sites in spring during spawning (Scott and Crossman 1973) when temperature (mean 14.7°C) and salinity (12.1 ppt) were lowest. Catches of both species decreased throughout summer and were lowest in fall, possibly due to migration out of the estuary later in summer (Hanson and Courtenay 1995; Able and Fahay 2010). Judging by their silvery body colour and occasional very high catches, it appears that *G. aculeatus* and *G. wheatlandi* are more pelagic and schooling than either *A. quadracus* or *P. pungitius* which lacked silver body pigment and were typically taken in lower numbers, especially at higher-salinity lagoon sites. Catches of *A. quadracus* and *P. pungitius* increased from spring to fall, a pattern opposite that for *G. aculeatus* and *G. wheatlandi*. The abundance of *P. pungitius* at upstream sites is consistent with its tolerance of high concentrations of suspended sediments (Chiasson 1993).

This study has established baseline data for seven fish species and environmental conditions in the three largest estuaries of Kouchibouguac National Park. Regular monitoring of estuarine habitats is necessary to detect changes in fish assemblages in response to disturbance; however, meaningful assessment requires comparison with a baseline of natural variations across seasons. Additional sampling at new sites using different methods would determine the extent of migration and help explain seasonal fluctuations in abundance.

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