Are benthic exotic species helping or harming river food webs in the Waddington to Massena stretch of the St. Lawrence River ecosystem?

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Introduction

With the limited information we have on the benthos of the St. Lawrence River (mostly downstream near Montreal), our impression is that of a native community impacted by invasive species such as zebra mussels, amphipods, and round gobies (e.g., Ward & Ricciardi 2007). These species have also been documented upstream in Lakes Erie and Ontario (e.g., Mills et al. 1999, Baldwin et al. 2002, Osterling et al. 2007) and have been observed by scientists, scuba divers, and other residents from Cape Vincent to Massena, NY and beyond.

Because native species can be positively or negatively affected by such exotic species (Ward & Ricciardi 2007), both the abundance and the impacts of benthic exotics should be quantified to judge possible influences on river food webs that include sport fish and waterfowl. For example, zebra mussel filtration of plankton has increased water clarity in the river, and while this increases the aesthetic value of the river, it also promotes growth of benthic green algae and shoreline weed beds. Moreover, zebra mussels outcompete certain native benthos (e.g., clams, shadflies) but they also provide food and shelter for native amphipods that are important in the diet of many fish. And with the addition of round gobies, food energy that was traditionally locked up in plankton can now be routed through mussels to gobies and on into sport fish and waterfowl. Gobies are now one of the most abundant prey fish in Lake Ontario (Walsh et al. 2008) and are commonly consumed by sport fish (Klindt & Gordon 2008, McCullough et al. 2008) and cormorants (Johnson et al. 2008, B. Baldwin, personal observation) in the St. Lawrence River (SLR). Coincidentally, the recent increase in smallmouth bass growth rate is attributed in large measure to the abundance of goby prey (Klindt & Gordon 2008).

Are such impacts common, large and positive in this stretch of the SLR? Although many scientists feel that gobies, despite their negative impacts on native invertebrates and prey fish, have actually increased the prey base for sport fish and waterfowl such as cormorants, do gobies come with some "baggage" that compromises the populations of these managed species? For example, given their high populations and proficiency at eating eggs of native fishes (e.g. Roseman et al. 2006), do they exert significant control over the reproductive success of these natives? Also, scientists working in the Great Lakes suspect an increased transfer of toxic substances (e.g., PCBs, mercury) from zebra mussels and round gobies to game fish in the Great Lakes (Vanderploeg et al. 2002, Hogan et al. 2007). Are these exotics facilitating transfers of mercury or botulism toxin to game fish and waterfowl along the SLR? Could such transfer have lethal or sublethal effects on these valued species, which may limit or suppress their populations? Mercury levels in northern pike, bass, and walleye are high (B. Baldwin, unpublished data), and environmental botulism outbreaks in fish and birds have periodically been severe in the Great Lakes (Getchell & Bowser 2006). With the continued introduction of exotic species into the river and Great Lakes (e.g., Baldwin et al. 2002, Ward & Ricciardi 2007), the biodiversity and ecological function of river food webs have certainly been altered, but to an unknown extent.

Project Goals

My goals were to measure the abundance and composition of bottom dwelling (i.e., benthic) organisms such as zebra mussels and gobies, to assess major environmental conditions along the riverbed, and to investigate potential roles of exotic species in regulating mercury and botulism levels in the SLR ecosystem. My hypothesis was that populations of zebra mussels and particularly round gobies increase energy resources, but coincidentally biomagnify mercury in sport fish and birds to troublesome levels. In contrast, benthic oxygen conditions would remain high enough to prevent the development of botulism poisoning in river wildlife.

Methods

Site Descriptions

We sampled one nearshore and one to two offshore sites near both Waddington and Massena, NY. (Table 1). These sites (Figs. 1-5) were located in the riverbed that existed before the construction of the Robert Moses Power Dam in the 1950s. The riverbed substrate at most sites was a mixture of mud, sand, large rocks, and exposed bedrock. Water current was mild, generally less than 10-20 cm s^{-1}. Water clarity was generally 2-4 m.

Environmental Conditions

We sampled water temperature, pH, dissolved oxygen, specific conductivity, and suspended chlorophyll a levels at each site using a Hydrolab Datasonde 4a that was placed directly upon the riverbed. Measurements were recorded (logged internally) every 10 min for periods of 1-2 hrs during each visit.

Population Assessments

Zebra and quagga mussels were sampled while scuba diving by hand collecting all mussels within a 25-cm x 25-cm quadrat. At each site and visit, 6-8 quadrats were placed haphazardly on the riverbed along a 50-m transect. Sampled sites were marked to avoid resampling during future visits. Back in the laboratory, live mussels were counted after sorting to species and shell length categories (< 0.5 cm, 0.5-1 cm, >1-2 cm, >2 cm). The two small size categories indicate young of the year (YOY) mussels while the larger sizes include new and old adults that are likely reproductive (Baldwin, unpublished data). A portion of each sample was kept alive overnight in an aquarium so they could clear their digestive tracts of unabsorbed food. They were then frozen for future analyses of whole body (non-shell) mercury content.

Round gobies were counted using video analysis. At each site, a high-definition video camera was positioned atop a 0.5-m tall tripod to film an area of riverbed approximately 1-2 m^2 in front of the tripod. After 5 min of filming, a 50-cm x 50-cm quadrat was placed in the field of view and filmed for later area and scaling reference. This was repeated five to six times at each site and visit. Gobies were neither attracted nor scared away by this filming technique. Back in the lab, gobies were observed on a computer video screen that had been marked with the outline of the quadrat for that area and film clip. At distinct 1-min intervals, gobies were counted within a known area of substrate (0.25 m^2). At each site, gobies were collected using baited minnow traps anchored for 1-3 hrs on the riverbed. As with mussels, gobies were held in aquaria in the lab in order to clear their guts prior to being frozen for future mercury analyses.

Mercury Analysis

Mercury concentrations (ppm = $\mu g\ g^{-1}$ or ppb = $\mu g\ kg^{-1}$) were measured in zebra and quagga mussels as well as round gobies (and sport fish, from a separate study). Animals were sized (length and mass) and were freeze-dried for about 48 hrs until a constant, dry body mass was achieved. Mussel bodies were extracted from their shells and were minced into ~1mm pieces using a scalpel. Individual gobies were blended whole in a coffee grinder. Duplicate or triplicate subsamples of each individual organism were then measured on a LECO AMA254 Mercury Analyzer.

Results

Environmental Conditions

We periodically measured conditions near the riverbed over a span of 98 days during the 2008 field season. Water temperature was cooler and variable in June, peaked in August, and cooled again in September (Fig. 6). There were no statistical differences among sites (Kruskal-Wallis ANOVA on ranks, $p = 0.834$), but pooled data did show highest temperatures in August, followed by July and September, and then June (K-W ANOVA on ranks, $p < 0.001$, Dunn's multiple comparison tests $p < 0.05$). Trends and differences were virtually the same for pH, with values rising from June to August and dropping in September (Table 2). No differences were detected within datasets for specific conductivity, dissolved oxygen, or suspended chlorophyll (Table 2). In general, water was well mixed, well buffered, and oxygenated (always above the EPA recommended 5 mg L^{-1} minimum for fish health, Bain 1999), but of low productivity. Even so, water clarity remained modest (rarely exceeding 3 m), suggesting a high load of suspended detritus and inorganic particles.

Population Assessments

Benthic community structure was visibly dominated by dreissenid mussels and round gobies. Few other macroinvertebrates or demersal fishes were observed while scuba diving, filming, or sample processing in the lab.

Mean mussel density for all sites in summer 2008 was 2,236 individuals m^{-2}, although densities ranged from about 600 to 8,000 individuals m^{-2}. Mussels (exotic and native) were rarely observed in muddy embayment sites (densities not quantified). Generally, densities were not related to sampling time, but populations were most abundant (Kruskal-Wallis ANOVA on ranks, $p < 0.001$, Dunn's multiple comparison tests $p < 0.05$). at the Massena nearshore site (Fig. 7). Quagga mussels were numerically dominant at all sites and times except the nearshore Waddington site (Fig. 8), where zebra mussels were dominant (2-way ANOVA, $p < 0.05$). For both mussel species, large individuals (>1cm) were numerically dominant (Table 3), and there were negligible numbers of of small young-of year (<0.5cm) settling into the benthos by August (also observed in early September). Using relationships of dreissenid dry tissue mass to shell length (Baldwin et al. 2002), we estimate food availability to round goby predators of about 55g dry tissue mass m^{-2}.

Round gobies were observed everywhere we dove, from the littoral zone to about 30m depth, regardless of whether driessenid mussels were present. Based on video analyses, from June through August, the overall average density of gobies was 16.9 individuals m^{-2}. It is worth noting that we have observed feeding aggregations (apparently on mussels) estimated as high as 200-400 individuals m^{-2}. In summer 2008, densities of gobies were highest (Kruskal-Wallis ANOVA on ranks, $p < 0.001$, Dunn's multiple comparison tests $p < 0.05$) at the Waddington offshore site and lowest at the Waddington nearshore site (Fig. 9). There were marginal differences in certain site densities over time but not as the summer progressed, as expected given the appearance of young of year in August (estimated while diving to be as abundant as 200-400 individuals m^{-2}). However, these individuals could rarely be detected during video analysis. We detected no significant relationship between average density of round gobies and that of corresponding dreissenid mussel prey measured at set locations and times (Pearson Product Moment Correlation analysis, $p > 0.05$). Of the captured gobies, most fish were 3-6 cm in total length. This was also true of gobies seen on video. Using relationships of goby dry tissue mass to standard length, we estimate food availability of round gobies to game fish predators to be about 25g dry tissue mass m^{-2}.

Mercury Levels

Whole body mercury concentrations in zebra and quagga mussels (n = 85-120) ranged from 0.089 to 0.131 (ppm in dry mass), and were significantly lower (Kruskal-Wallis

ANOVA on ranks, $p < 0.001$, Dunn's multiple comparison tests $p < 0.05$) than levels in round gobies ($n = 73$), which had a range of 0.142 to 0.335 ppm. There were no detectable differences among zebra and quagga mussels or among sites or dates for any species.

Compared to data from a separate project (Baldwin et al., in prep.), sport fish from the SLR, which can forage on gobies, had increasingly higher Hg levels in fillet muscle tissues (Fig. 10). Feathers of common terns and cormorants from the SLR also had higher levels of Hg.

Discussion

The benthic community of this section of the SLR is clearly dominated by exotic dreissenid mussels and round gobies. Few other benthic macroinvertebrates were observed while diving or while enumerating hand collected samples of the benthos (e.g., amphipods). All native mussels (=clams) were dead and no larval shadflies were seen in our summer samples. The only native fish that we regularly observed while diving were smallmouth bass, with occasional sightings of logperch (littoral zone only), carp, and drum.

Although dreissenid mussels could form extensive, thick (2-4 cm) "carpets" over the riverbed in some locations (e.g., Massena nearshore), most locations only had patches of mussels attached to scattered rocks and outcrops. In stark contrast, round gobies were abundant in nearly all locations, whether there were high or low dreissenid densities, whether the riverbed was mud or rock, or whether it was stagnant or in high current. And unlike dreissenid mussels, for which we measured virtually no settlement of young-of-year (YOY), YOY gobies (1-2 cm long) were widespread by August and September.

While diving, we occasionally observed round gobies (mainly large 10 cm individuals) feeding on dreissenid mussels. And when we dislodged or crushed these mussels, feeding frenzies of gobies would ensue, with aggregations of nearly 400 individuals m^{-2}. Gobies also made quick work of insect larvae that were collected in the littoral zone and transplanted onto the riverbed at our dive sites. Although it is only speculation at this point, it would appear that round gobies may limit recruitment of dreissenid mussels and may have suppressed populations of other macroinvertebrates (e.g., shadflies). Because data are lacking on temporal trends in dreissenid mussel populations for this section of the SLR, it is unclear whether mussels have declined as a result of goby predation. However, there are many anecdotal accounts from the general public of mussel declines over the past ten years. Several times during this period, I have collected abundant YOY mussels in littoral zone habitats in July and August. Perhaps the lack of these YOY this year, even as late as September, was due to poor reproduction and/or heavy predation by gobies.

We never observed smallmouth bass preying on gobies, but gobies would scatter when these bass approached the riverbed, and based on Klindt & Gordon (2008), it appears that smallmouth bass at least are consuming these gobies and increasing their growth as a result. Clearly, there is also consumption of gobies by birds such as cormorants (Johnson et al. 2008). It is unclear whether the seemingly high population of gobies represents a significant increase in the forage base for native sport fish, as compared to the native river forage of pre-invasion years. However, I at least do not recall seeing nearly the same number of native logperch or other small forage fish along the riverbed when I began diving in the SLR about 1998, before the expansion of round gobies (Klindt & Gordon 2008). Seeing the vast number of gobies along the riverbed one can't help but conclude that piscivores such as bass, walleye, and even large yellow perch are not limited by food availability, which probably supports high rates of individual growth in these sport fish. From this standpoint, exotics such as dreissenids and gobies likely represent a positive impact on these important native species. And in the immediate future at least I would expect this pattern to hold, as the forage base for gobies – largely dreissenids – seems abundant with plenty of food of their own. Although our riverbed phytoplankton concentrations were low, flux of these food items is likely high given river currents. Additionally, as our modest diving visibility attests, there were high levels of suspended, non-pigmented organic particles near the bottom, which dreissenids are also known to consume (e.g., Baldwin et al. 2002).

But is the impact of these exotic species a net positive effect? Undoubtedly sport fish are deriving large amounts of energy and nutrients from gobies, but do they also assimilate troublesome levels of toxins like mercury (Hg) which may temper the perceived benefits, especially at the population level? Our data on dreissenids and gobies, when compared to data from separate studies of ours, suggests biomagnification of Hg in the SLR foodweb, from dreissenids on up (Fig. 10). Have these exotics worsened the situation with Hg uptake? This is unclear. Although gobies have higher Hg levels than native yellow perch forage (3-6 cm long), their levels are similar to other potential native forage like killifish (Fig. 11). So, depending on the diet of piscivores, it's possible that native sport fish and waterfowl normally had (i.e., pre-exotic invasions) mercury levels such as those shown in Figs 10 and 11. However, other work we have done on lab model fish (zebrafish and convict cichlids) shows that under similar body burdens of Hg, the fish experience negative behavioral and reproductive impacts, which may have implications for survival and population growth (Baldwin et al. 2009b). Thus it remains possible that the transfer of Hg from exotics to native piscivores has sublethal impacts that compromise the fitness of consumer populations. These exotics may also transfer botulism toxin to piscivores, and although we were unable to measure such levels directly (no separate funding was available), we assume the likelihood of such transfer is low in the SLR given the moderate to high concentrations of dissolved oxygen along the riverbed (Table 2).

Conclusions

Exotics such as dreissenids (especially quagga mussels) and gobies appear to be dominant members of the benthic community in this stretch of the SLR. Population estimates of these species are now available and might be tracked over time to judge whether their populations and impacts are stable or changing. Their routing of energy from the plankton to the benthos and then to managed populations of piscivores (via goby consumption) is probably significant and beneficial, at least in part. However, it remains unclear whether the large populations of gobies limit population fitness of certain native sport fish, either through predation of eggs/embryos or by facilitating the accumulation of toxic mercury – and its sublethal effects - on sport fish. While unproven, it is unlikely that these exotics are promoting botulism poisoning in this well-mixed, well-oxygenated stretch of the SLR.

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Table 1. Location and depth of scuba-surveyed sampling sites in Waddington and Massena, NY.

Township	Nearshore Site Site Name Lat-Long Depth range (m)	Offshore Site Site Name Lat-Long Depth range (m)
Waddington	Whittaker Park 44°52'-75 °12' 6-10	Ogden Island 44°52'-75 °14' 15-20
Massena	"The Ruins" 44°58'-74 °55' 20-30	Long Sault Island 44°59'-74 °56' 25-30
		Barnhart Island 45°01'-74 °50' 20-30

Table 2. Environmental conditions (temperature, pH, specific conductivity, dissolved oxygen, and chlorophyll a) on the riverbed in 2008, measured using a Hydrolab Sonde 4a. Monthly and summer means (n = 15-23) are reported, along with SD in brackets. Resultant p values of Kruskal-Wallis ANOVA on ranked data are given for comparisons by site (see Table 1) and by month.

Factor	June	July	August	Sept	Mean	By Site	By Month
Temp. (°C)	18.22	21.67	23.25	21.59	21.16	0.83	<0.001
	[2.06]	[0.83]	[0.25]	[0.38]	[2.16]		
pH	8.41	8.65	8.95	8.72	8.65	0.93	<0.001
	[0.10]	[0.12]	[0.01]	[0.02]	[0.18]		
SC (μS cm^{-1})	292.43	296.95	291.60	298.25	295.47	0.86	0.73
	[2.15]	[1.43]	[0.54]	[0.50]	[2.84]		
DO (mg L^{-1})	8.55	7.23	7.62	7.33	7.49	0.10	0.09
	[1.24]	[0.91]	[0.63]	[0.49]	[0.97]		
Chl a (μg L^{-1})	1.65	1.19	1.12	0.75	1.21	0.25	0.12
	[1.39]	[0.84]	[0.71]	[0.13]	[0.91]		

Table 3. Population size structure of dreissenid mussel populations.

LOCATION	SPECIES	<0.5cm	0.5-1cm	>1cm
Wadd Near	Zebra	0.0	0.1	99.9
	Quagga	0.8	5.2	94.0
Wadd Off	Zebra	0.0	0.0	100.0
	Quagga	0.0	9.2	90.8
Mass Near	Zebra	0.0	1.0	99.0
	Quagga	0.3	3.5	96.2
Mass Off LS	Zebra	0.0	0.0	100.0
	Quagga	0.7	2.7	96.6
Mass Off Barn	Zebra	0.0	3.8	96.2
	Quagga	0.0	2.7	97.3

Barn: Barnhart Island; LS: Long Sault Island; Mass: Massena; Wadd: Waddington

Figure 1. Location of sampling sites. Stretch of St. Lawrence River from Waddington to Massena, NY. Yellow line shows international border between the US and Canada.

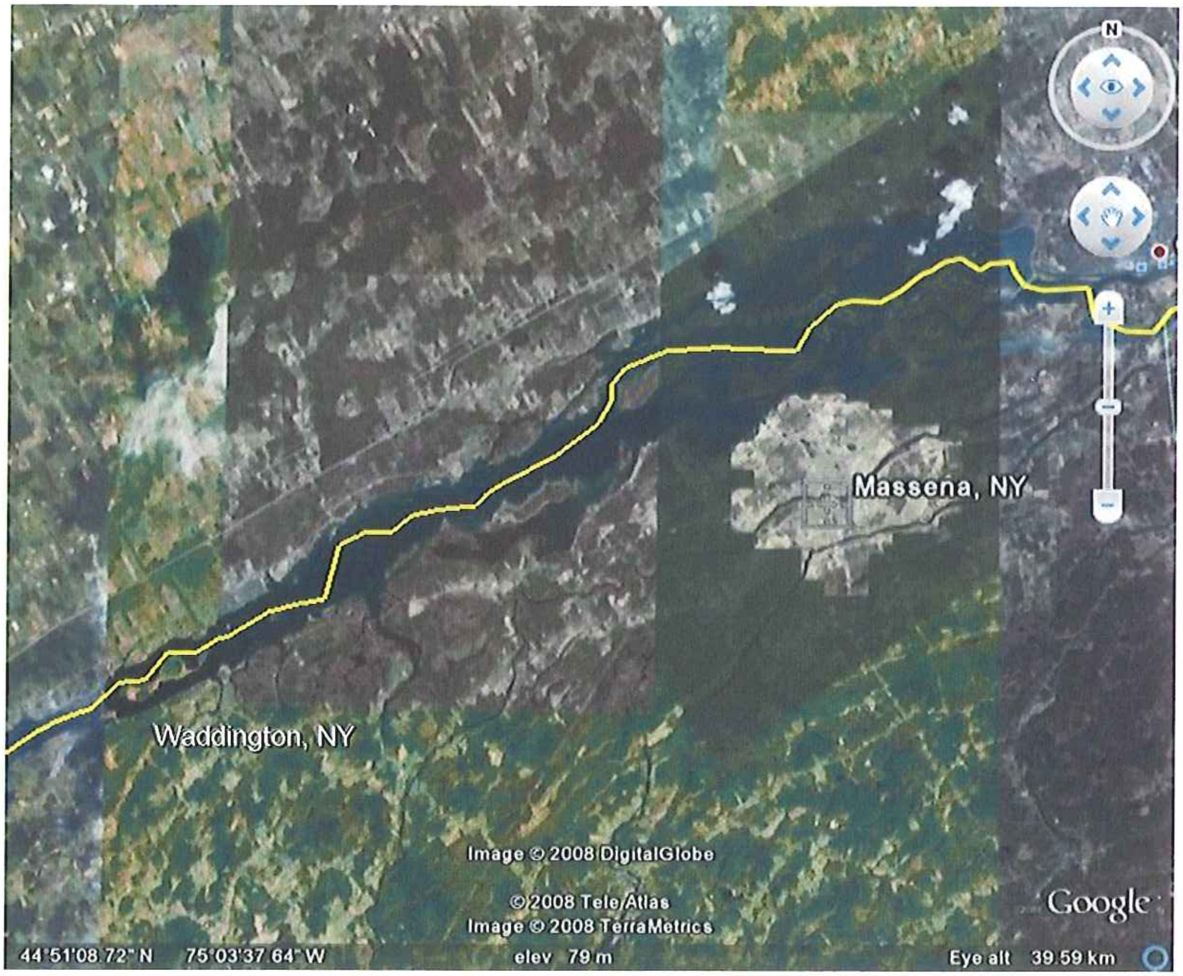


Figure 2. Location of Waddington sampling sites. A – offshore site, north of Ogden Island near shipping channel. B – nearshore site, north of Whittaker Park.

Figure 3. Location of Massena nearshore sampling site near a local area called "The Ruins" (A).

Figure 4. Location of Massena offshore sampling site in Lake St. Lawrence, north of Long Sault Island (A).

Figure 5. Location of Massena offshore sampling site in Lake St. Lawrence, north of Barnhart Island (A).

Figure 6. Benthic temperature trends during summer 2008. Box plots show median (line), 25 to 75% percentiles (grey box), 10 to 90% percentiles (whiskers), and outliers (dots). With the exception of July and September data (not different from each other), temperatures for each month were different from other months (KW ANOVA, Dunn's test on ranks, see Results). n = 15-23.

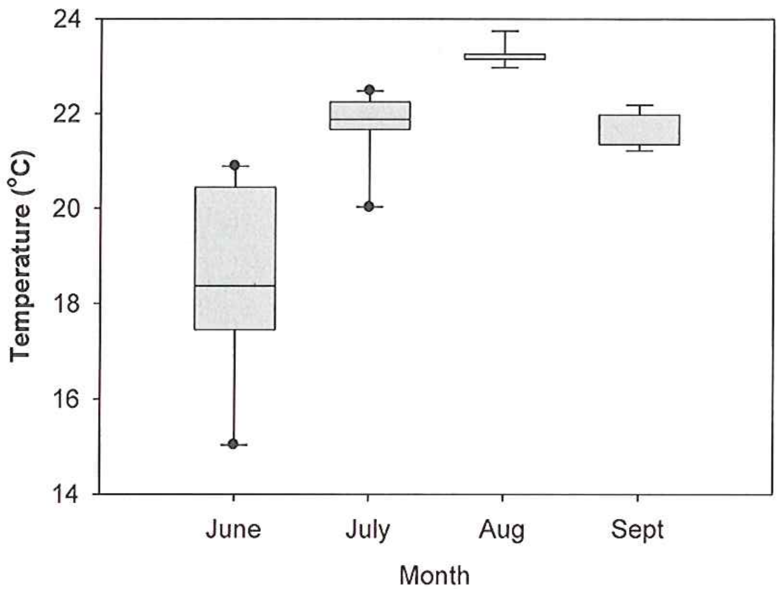


Figure 7. Population density of dreissenid mussels (zebra and quagga) in Waddington (W.) and Massena (M.) nearshore (Near) and offshore (Off) sites, summer 2008. Box plot parameters as described in Fig. 6. Different letters over bars indicate significant differences among sites ($p < 0.05$). n = 14-24.

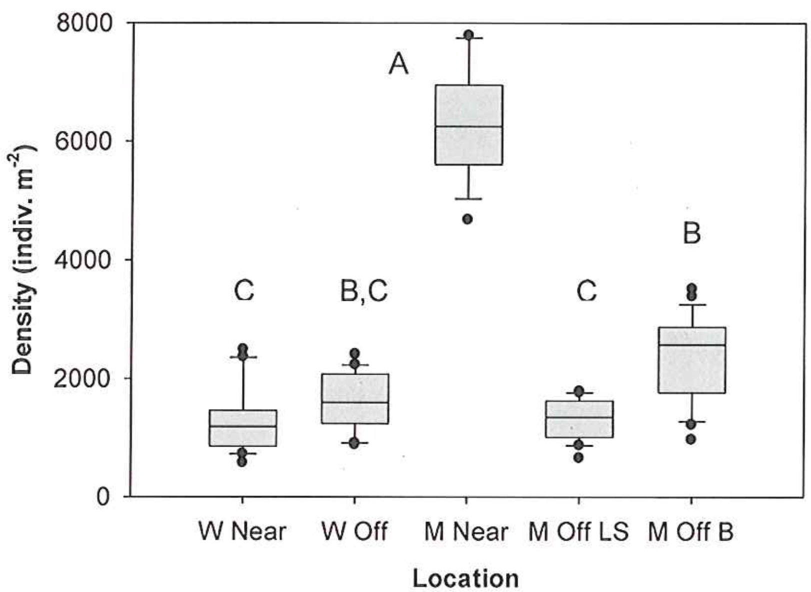


Figure 8. Mean ($\pm$ SD) percent composition of zebra and quagga mussels in benthic samples from Waddington (W.) and Massena (M.) nearshore (Near) and offshore (Off) sites, summer 2008. Quagga mussels were more abundant than zebra mussels at all locations except W. Near, where zebra mussels were more abundant (2-way ANOVA, $p < 0.05$).

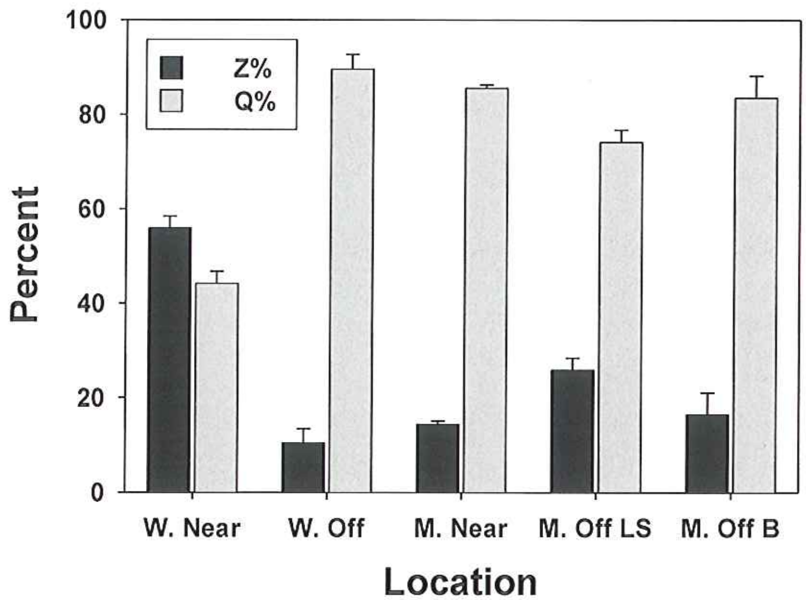


Figure 9. Population density of round gobies in Waddington (W.) and Massena (M.) nearshore (Near) and offshore (Off) sites, summer 2008. Box plot parameters as described in Fig. 6. Different letters over bars indicate significant differences among sites ($p < 0.05$). $n = 15\text{-}16$.

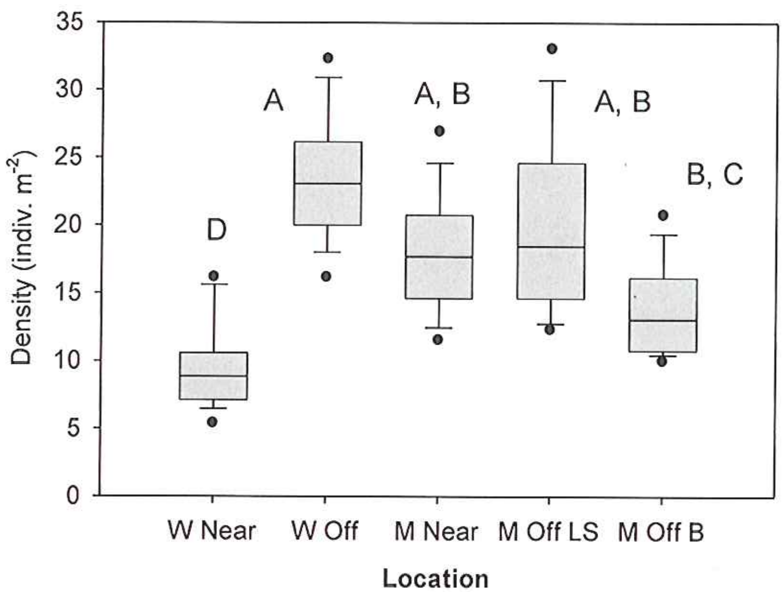


Figure 10. Mean (+ SD) mercury concentrations in exotic zebra and quagga mussels (ZQ), exotic round gobies (RG), and native game fish of the St. Lawrence River (collected in gillnets by the DEC), such as yellow perch (YP), small mouth bass (SMB), walleye (W), and northern pike (NP). Common terns (T) and double crested cormorants (DCC) are also shown. n = 5-120. From Baldwin et al. 2009a.

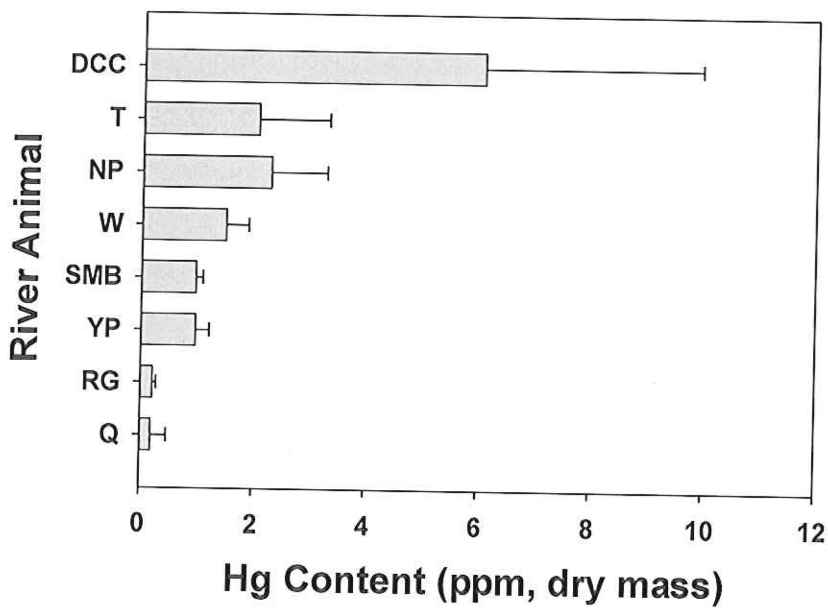
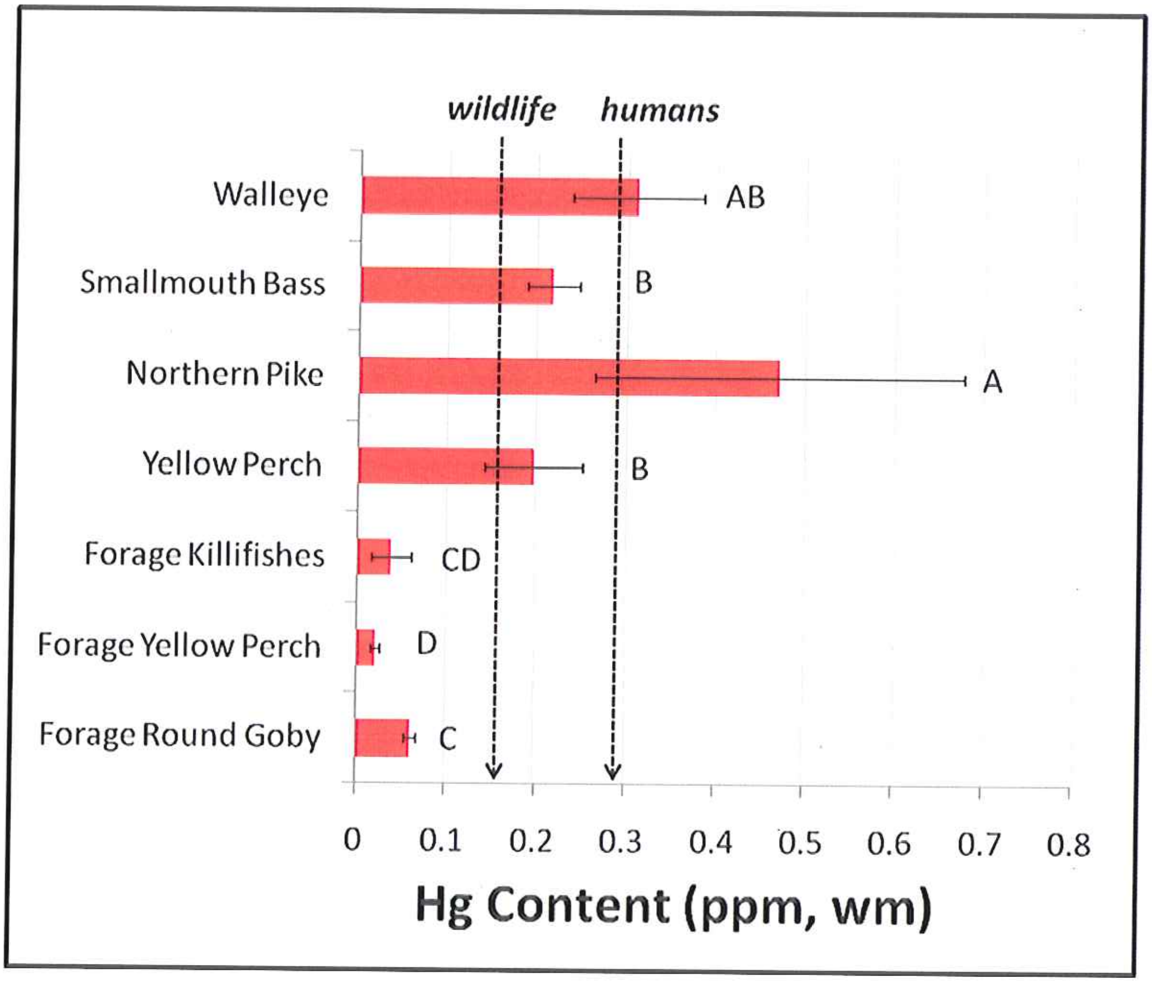


Figure 11. Mean (± SD) mercury concentrations (wet mass) in exotic round gobies, native forage fish (collected in littoral zone seines), and native game fish of the St. Lawrence River (collected in gillnets by the DEC). n = 10-120. Different letters over bars indicate significant differences among means. Thresholds (dashed lines) indicate health implications to natural piscivores ("wildlife") or humans eating prey with this level of Hg (explained in Evers et al. 2007). From Baldwin et al. 2009b.



SLRREF Grant Financial Report: June 2009
Are benthic exotic species helping or harming river food webs in the Waddington to Massena stretch of the St. Lawrence River ecosystem?

Budget Component	Grant Funds Spent to Date	SLU Cost Share
Salaries:		
PI Summer Salary	$ 7,500	
FICA on PI Salary	$ 574	
Student Researcher Stipend		$ 3,500
FICA on Student Salary		$ 268
Subtotal	**$ 8,074**	**$ 3,768**
Labor/Contractors:		
Safety Diver	$ 560	
Sample Processing & Mercury Analysis	$ 1,316	$ 1,300
Subtotal	**$ 1,876**	**$ 1,300**
Equipment/Material:		
Video Camera and Light	$ 3,344	
Scuba Airfills and Equipment	$ 2,177	$ 287
Subtotal	**$ 5,521**	**$ 287**
Other		
Research-related Travel	$ 386	
Boat Rental	$ 88	
Student Summer Housing		$ 945
Software	$ 514	
Subtotal	**$ 988**	**$ 945**
Project Total	**$ 16,459**	**$ 6,300**

Notes on the SLRREF Grant June 2009 Financial Report:

Institutional Cost Share: In addition to supporting a research student during the summer of 2008, St. Lawrence University provided $1,300 from the Biology Department to support the Senior Year Experience (SYE) projects of two additional students who worked on sample processing and mercury analysis.

Remaining Grant Funds: Approximately $4,600 in grant funds remain as of the date of this report, June 30, 2009. With the permission of the SLRREF, we propose to use $1,700 of these funds during the summer of 2009 to complete the mercury analysis of project samples.