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Trace Metal Levels in Benthic Biota from Four Tributaries to the St. Lawrence River, Quebec

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Lamprey ammocoetes (Agnatha: Petromyzontidae) and freshwater mussels (Bivalvia: Unionidae), two groups of organisms that are closely associated with sediments, were collected from the Châteauguay, Bécancour, Sainte-Anne and Saint-Maurice rivers in July 1992 and analyzed for residues of 13 metals in their tissues. The hypothesis that lamprey larvae and mussels would bioaccumulate comparable levels of metals due to similarities in their ecology was rejected. Lampreys (*Ichthyomyzon fossor* and *Lampetra appendix*) from the Châteauguay River (the only site where both lampreys and mussels were collected) accumulated significantly lower concentrations of Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Tl, V and Zn than mussels (*Elliptio complanata*), suggesting that lampreys may be capable of regulating these metals. Conversely, lampreys accumulated much higher concentrations of Hg than mussels (1748 to 6793 versus 579 to 982 ng/g dry weight, respectively), indicating that they may be suitable biomonitors for Hg. Organisms that are capable of regulating metals are not normally recommended for biomonitoring purposes. Nevertheless, significant differences among rivers were observed for many metals based on the lamprey data. As metals in the gut contents of three specimens of Sea lamprey (*Petromyzon marinus*) from the Saint-Maurice River accounted for a substantial portion of the whole body burden of metals, a gut content correction factor is recommended for these organisms. Further studies are required to properly evaluate lamprey ammocoetes as biomonitors for trace metals in freshwater systems.

Key words: **trace metals, lamprey larvae, freshwater mussels, biomonitors**

Introduction

Freshwater mussels and bony fishes have both been used as biomonitors for trace metals in the freshwater environment (Phillips and Rainbow 1993). Mussels meet many of the prerequisites for an ideal biomonitor as outlined by Phillips and Rainbow (1993), namely, they are sedentary and therefore representative of the study area; they are abundant and readily sampled, handled and identified; they provide sufficient tissue for analysis; they are hardy and relatively insensitive to pollution; they have high bioaccumulation capacities for most metals; and they are generally considered to be poor metal regulators, thus providing a direct measure of the bioavailability of metals in aquatic systems (see Metcalfe-Smith 1994 and Metcalfe-Smith et al. 1996). Conversely, fishes are not a good choice for most biomonitoring applications because they tend to be highly mobile and are capable of regulating many trace elements.

Lamprey larvae, or ammocoetes, share several ecological traits with freshwater mussels that suggest they may be suitable biomonitors for metals. First of all, both organisms are sedentary and are closely associated with the sediment for long periods of time. Lamprey larvae typically spend 5 to 7 years living in burrows in the sediment prior to transforming into short-lived adults (Scott and Crossman 1973), and most species of freshwater mussels live partially buried in the sediment for several decades (Clarke 1981). Also, both mussels and lamprey ammocoetes are filter-feeders that primarily consume phytoplankton and organic detritus (The Nature Conservancy 1986; Scott and Crossman 1973). In contrast to the large amount of information available on the use of mussels as biomonitors for metals, there have been very few studies on lampreys. Evans et al. (1972) and Kulikova et al. (1985) examined trace metal levels in adult lampreys from freshwater and marine environments, respectively. Holmes and Youson (1996) investigated the relationships between concentrations of metals in lamprey ammocoetes and those in their environment, and Renaud et al. (1995b) measured trace metal levels in preserved museum specimens of lamprey larvae from tributaries to the St. Lawrence River. The objectives of this study were to (a) compare concentrations of trace metals in freshwater mussels and lamprey ammocoetes from several tributaries to the St. Lawrence River, Quebec, in order to test the hypothesis that mussels and lampreys would accumulate comparable levels of metals in their tissues due to similarities in their ecology; and (b) compare levels of metal contamination among the tributaries, based on concentrations of metals in lampreys and mussels.

Materials and Methods

Field Methods

Lamprey ammocoetes and/or freshwater mussels were collected from four tributaries to the St. Lawrence River in Quebec; namely, the Châteauguay River, 1.4 km NNW of Athelstan; the Bécancour River, at Bécancour; the Sainte-Anne River, off the east and west banks at Sainte-Anne-de-la-Pérade; and the Saint-Maurice River, off the western shore of Saint-Christophe Island at Trois-Rivières (Fig. 1) between 19 and 23 July 1992. Lamprey ammocoetes were collected with a Smith-Root type VII DC-electrofisher and scooped with a dip-net, or simply dug up with a dip-net, whereas mussels were collected by hand. Upon collection, mussels were individually packaged in plastic freezer bags and placed on dry ice. Lampreys were preserved in a 5% double-distilled aqueous solution of formalin, using plastic storage containers that had previously been acid-washed and rinsed with double-distilled water. Care was taken to

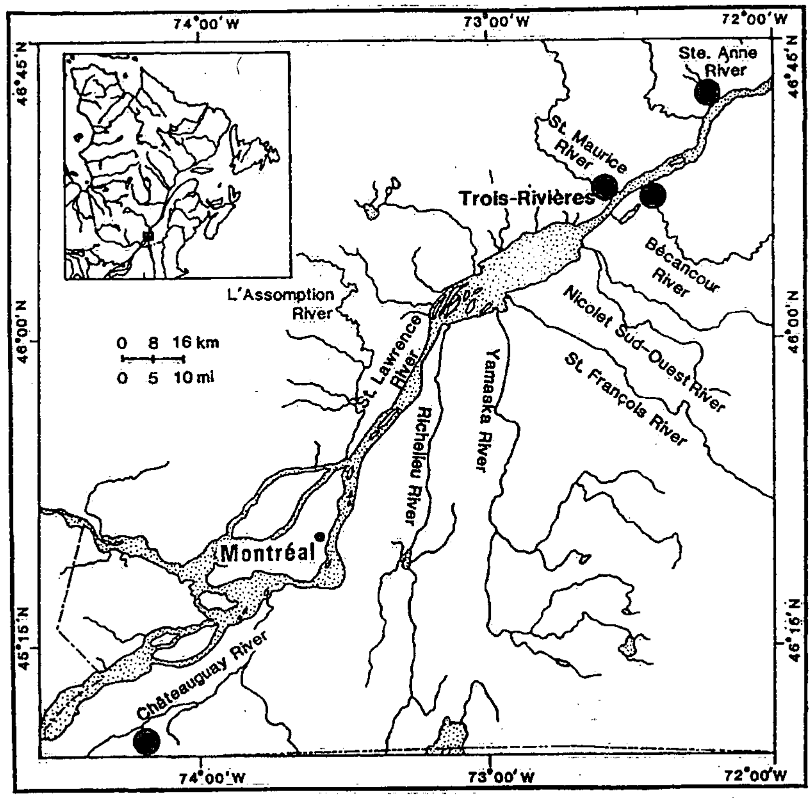

Fig. 1. Collection sites for lamprey ammocoetes and freshwater mussels from the Châteauguay, Bécancour, Sainte-Anne and Saint-Maurice rivers, St. Lawrence River Basin, Quebec.

avoid sample contamination as emphasized by Nriagu et al. (1993). The reason for preserving the lampreys in formalin was to permit comparisons of trace metal levels in these samples with levels in preserved museum specimens from the same region. It was subsequently found that the museum specimens could not be used for this purpose, due to many sources of sample contamination that could not be accurately measured (Renaud et al. 1995b).

Lamprey ammocoetes were identified to species using Vladykov (1950) and Lanteigne (1988), and their total lengths were measured to the nearest millimetre. Mussels were identified to species using Clarke (1981), and their shell lengths were measured to the nearest 0.05 mm. Water temperature, pH and conductivity were measured using a Hanna Instruments water tester with an accuracy of ±0.2°C for temperature, ±0.2 units for pH, and ±2% of the conductivity reading. Water temperature ranged from 20.1 to 21.0°C among sampling sites. Conductivity and pH in the Châteauguay, Bécancour, Sainte-Anne (west bank), Sainte-Anne (east bank) and Saint-Maurice rivers were 177 µS and 8.3, 201 µS and 7.9, 45 µS and 9.3, 24 µS and 7.4, and 26 µS and 11.9, respectively. The very high value for pH in the Saint-Maurice River (11.9) was considered anomalous, as a value of 7.2 had been recorded at the same site in 1990 (C.B. Renaud, unpublished data).

Analytical Methods

Sample preparation and analysis were performed in the Class 100 Clean Laboratory at the National Water Research Institute in Burlington, Ontario. This facility is described in detail in Nriagu et al. (1993). Under these ultraclean conditions, the preserved lamprey ammocoetes were rinsed with double-distilled water, and individually weighed and measured. They were then air dried for one week, after which their dry weights were recorded. The frozen mussels were partially thawed, then shucked using stainless steel scalpel blades and forceps. The soft tissues and associated body fluids from each mussel were placed in a precleaned 100-mL amber glass jar and weighed. This material was freeze-dried and reweighed to determine the dry weight. Each mussel sample was then homogenized for 1 minute in a Bel-Art Micro-Mill with stainless steel blades and grinding chamber. Stainless steel scissors were used to cut the sample into smaller pieces, if necessary.

For metals analyses, the whole dried lamprey ammocoetes and homogenized soft tissues of mussels were extracted with ultra-clean (Seastar) nitric acid, using the microwave technique (Renaud et al. 1995b). Extraction efficiency for all metals assayed was determined to be 96 ± 5% using a standard reference material (National Research Council of Canada DORM-1 dogfish muscle). Trace metals were assayed for each specimen individually, and included silver (Ag), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), thallium (Tl), vanadium (V) and zinc (Zn). Concentrations of Cd, Fe and Mn in the samples were determined by graphite-atomic absorption spectroscopy, with background correction (Renaud et al. 1995b); Hg was determined by cold-vapour-atomic absorption spectroscopy; and Ag, Co, Cr, Cu, Ni, Pb, Tl, V and Zn were determined by inductively coupled-plasma mass spectroscopy. Trace metal levels in method blanks were deducted from the levels in the biota samples.

A correction for gut sediment metal contents, as advocated by Chapman (1985), was not made for either the mussels or the lampreys. With reference to mussels, several studies have shown that concentrations of metals in the guts of undepurated freshwater mussels from both clean and contaminated environments are consistently lower than those in other organs, and that undigested material in the gut accounts for a negligible portion of the whole-body content of metals in these organisms (for a review, see Metcalfe-Smith 1994). Lamprey ammocoetes were generally too small (one-quarter of the specimens were less than 60 mm in total length) to permit the removal of the digestive tract and its contents.

However, in order to estimate the percent contribution of gut sediment metal contents to whole-body metal levels in lampreys, three of the larger specimens (108 to 122 mm total length) were dissected, and their digestive tracts were analyzed separately from the rest of their bodies for Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn.

Statistical Methods

Due to the small sample sizes obtained during this study and, consequently, our inability to determine the shape of the population distributions, nonparametric statistical methods were used to analyze the trace metal data. A two-tailed Mann-Whitney *U* test was used to compare concentrations of metals between and within taxa and sites, and a two-tailed Spearman rank correlation coefficient (r_s) test was used to determine the relationship between metal concentration and size in both mussels and lampreys. In all cases, the level of significance chosen was $p \leq 0.05$.

Results and Discussion

A total of 26 lamprey ammocoetes and 12 freshwater mussels were collected from the Châteauguay, Bécancour, Sainte-Anne and Saint-Maurice rivers (Table 1). Three species of lampreys (Northern Brook Lamprey, *Ichthyomyzon fossor*; American Brook Lamprey, *Lampetra appendix*; and Sea Lamprey, *Petromyzon marinus*) and two species of mussels (Eastern Elliptio, *Elliptio complanata*; and Eastern Lamp-Mussel, *Lampsilis radiata radiata*) were obtained. Sample sizes varied from 3 to 7 specimens for lampreys and 1 to 11 specimens for mussels. As sample sizes were small and unequal, and not all species were collected from all sites, a limited number of comparisons of metal concentrations between and within taxa and sites could be made.

Before metal concentrations in lampreys and mussels could be compared, it was necessary to demonstrate that the formalin used to preserve the lampreys had not contaminated the specimens with metals. In previous work, Renaud et al. (1995b) found that lamprey ammocoetes stored for 43 to 48 years in 4 to 5% formalin solution were contaminated by metals that had leached from the container walls, jar lids, sample tags, labels and strings over time. For example, concentrations of Cu in formalin from the storage jars ranged from 330 to 2300 µg/L. In the present study, trace metal levels were determined in freshly prepared 5% formalin, and in samples of formalin taken from two of the containers used to store the lampreys for approximately three years prior to analysis. Levels were found to be close to or less than the detection limits for Cd (<0.002 µg/L), Cu (<0.04 µg/L), Hg (<0.01 µg/L), Pb (<0.01 µg/L) and V (<0.01 µg/L) in both the fresh and used solutions, except that Hg was not determined in the used solutions. The other elements were not checked. Based on these results we conclude that formalin was not a source of contamination to the lampreys, and that concentrations of metals in lampreys and mussels

Table 1. Concentrations of 13 metals (ng/g dry weight) in lampreys (L) and mussels (M) collected from four tributaries to the St. Lawrence River, Quebec, in July 1992 (data are ranges of values for all specimens in a given sample)

NMC Catalog No.	Locality	Species	N	Total or shell length (mm)	Concentration per dry weight (ng/g)												
					Ag	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Tl	V	Zn
92-36	Châteauguay River	*Ichthyomyzon fossor* (L)	6	70–134	1.44–3.14[a]	2.6–43.7	5.9–10.0	53–85	147–295	483000–1004000	3189–5489	7250–11760	19–44	39.03–98.43	0.14–0.30[a]	0.14–46.68	651–2945
		Lampetra appendix (L)	7	102–173	0.98–1.61	0.6–6.7	8.8–14.6	57.3–85	75.6–117	458000–889000	1748–6793	9740–16130	12.9–38	31.7–60.1	0.14–0.28	29–47.55	893–1571
		Elliptio complanata (M)	11	76.0–102.3	30–198	349–1081	305–4315	2395–4634	5311–11022	837930–2530100	579–982	1624000–3706000	635–2069	729–4186	5.07–638.6[d]	315.1–759.7[f]	120464–944340
92-37	Bécancour River	*Lampsilis radiata* (M)	1	80.9	47	360	612	4586	6167	3467390	1611	4304000	1063	3235	ND	302.6	203766
92-38	Sainte-Anne River (west bank)	*Lampetra appendix* (L)	3	61–100	9.26–17.21	10.8–24.9	28.3–58.3	148–258	723–1052	1872000–3901000	1055–1862	24020–34420	70–597	181.43–530.59	0.96–1.4	125.38–251.43	3058–5143

(continued)

Table 1. *(concluded)*

		Petromyzon marinus (L)	4	35–110	12.51[b]	4.6–220.6	9.8–31.1	111–383	520–971	1176000–1670000	1000–2085	6000–17800	62–115[c]	146.17–416.67	1.58–14.83[e]	126.81–260.59	608–10750
92-39	Sainte-Anne River (east bank)	*Petromyzon marinus* (L)	3	38–46	8.01[b]	56.1–117.9	19.7–32.8	272–912	1059–1599	2244000–3504000	854–1981	7690–13140	196–281	408.3–1003.65	ND	145.83–452.55	2838–7044
92-41	Saint-Maurice River	*Petromyzon marinus* (L)	3	70–92	24.23–30.91	12.7–58.1	31.2–37	107–110	1450–1838	1638000–2053000	3705–4834	8050–9930	29–48	170.53–181.02	0.45–0.55[e]	110.74–131.9	1209–1275

Where some values were non-detectable, ranges were based on fewer specimens: [a]n = 5 specimens; [b]n = 1 specimen; [c]n = 3 specimens; [d]n = 7 specimens; [e]n = 2 specimens; [f]n = 10 specimens.

ND = no values above the instrument detection limit.

could therefore be directly compared. With the exception of As, Klusek and Heit (1982) also found no differences in the concentrations of 12 elements in marine mussels (*Mytilus edulis*) stored for one year in the freezer versus one year in a 10% formaldehyde solution. Some differences were observed for samples of fish muscle and liver, but these were attributed to analytical variability and nonhomogeneous distribution of the elements in the tissues rather than the preservation method. Klusek and Heit (1982) reported concentrations in the low ng/mL range for As, Cd, Cr, Hg, Ni, Pb, Se and Tl in the freshly prepared formaldehyde solution used in their study.

To determine if metals in the gut contents of lamprey ammocoetes constituted a significant proportion of the whole-body burden of metals in these animals, concentrations of eight elements were measured separately in the digestive tracts and bodies of three specimens of *P. marinus* from the Saint-Maurice River. The percentages of the whole-body metal burdens contributed by the gut contents were then calculated. As shown in Table 2, mean percentages varied from a low of 14.1% for Zn to a high of 54.2% for Fe. Chapman (1985) determined the percent contribution of gut sediment metal contents to whole-body levels of seven elements in lamprey ammocoetes (species not identified) from the lower Fraser River, British Columbia, using an indirect method. Undigested sediment from the peroxide-nitric acid digestion of lamprey tissue was collected, dried and weighed, and metal levels in this material were calculated based on levels in sediment from the site where the animals were collected. The percentages reported by Chapman (1985) are much higher than those reported in the present study (Table 2). The latter should be considered more reliable, because a direct method was used to determine these values. Nevertheless, the data show that metals in the gut contents introduce

Table 2. Percent contribution of metals in the gut contents to whole-body burdens of metals in lamprey ammocoetes

	Saint-Maurice River (this study)		Fraser River, B.C. (Chapman 1985)	
Metal	Mean ± SD	n	Mean	n
Cd	24.5 ± 16.0%	3	—	—
Co	15.9 ± 11.2%	3	80%	3
Cu	36.6 ± 1.9%	3	41%	8
Fe	54.2 ± 6.7%	3	97%	8
Mn	38.3 ± 6.0%	3	97%	8
Ni	32.5 ± 8.3%	3	77%	2
Pb	23.9 ± 10.6%	3	86%	7
Zn	14.1 ± 1.8%	3	35%	8

a significant source of error to the determination of whole-body metal levels in lamprey ammocoetes.

Concentrations of 11 metals in *P. marinus* collected from stations approximately 200 m apart on the east and west banks of the Sainte-Anne River did not differ significantly between stations (see Table 1). Silver and Tl could not be compared, because residues were below instrument detection limit in five of seven specimens for each element. Based on these results, we suggest that within-site differences in metal concentrations in lamprey ammocoetes of the same species are inconsequential. To determine if metal concentrations differed between species of lampreys collected from the same site, residues in *I. fossor* were compared with those in *L. appendix* from the Châteauguay River, and levels in *L. appendix* were compared with those in *P. marinus* from the Sainte-Anne River. Concentrations of Ag ($p = 0.014$) and Cu ($p = 0.006$) were significantly higher in *I. fossor* than *L. appendix* from the Châteauguay River, but there were no significant differences between the species for any other element. Similarly, there were no significant differences for any metal between *L. appendix* and *P. marinus* from the Sainte-Anne River except for significantly higher concentrations of Mn ($p = 0.03$) in *L. appendix*. Again, Ag and Tl could not be tested, because residues were below instrument detection limit in five of the seven specimens of *P. marinus*. These findings show that interspecific differences in the accumulation of metals by lampreys are insignificant for most metals.

Based on the above results, we assumed that intra- and interspecific site differences in metal concentrations in lamprey ammocoetes are relatively minor. Thus, metals data for all lampreys collected from a given river were combined and used to compare levels of contamination in the Châteauguay, Sainte-Anne and Saint-Maurice rivers. The Bécancour River could not be tested, because no lampreys were collected from that river. The Châteauguay and Sainte-Anne rivers were compared using $n = 13$ and $n = 10$ lampreys, respectively. Concentrations of Ag, Cd, Co, Cr, Cu, Fe, Ni, Pb, Tl, V and Zn were significantly higher in lampreys from the Sainte-Anne River, whereas Hg was higher in lampreys from the Châteauguay River. The Sainte-Anne and Saint-Maurice rivers were compared using $n = 7$ and $n = 3$ lampreys (all *P. marinus*), respectively. Levels of Cr and Ni were higher in lampreys from the Sainte-Anne River, whereas levels of Hg were higher in lampreys from the Saint-Maurice River. Some general conclusions regarding the relative pollution status (in terms of metal bioavailability) of the three rivers can be drawn from the lamprey data, i.e., the Sainte-Anne and Saint-Maurice rivers are more contaminated with Ag, Cd, Co, Cu, Fe, Pb, Tl, V and Zn than the Châteauguay River; the Châteauguay and Saint-Maurice rivers are more contaminated with Hg than the Sainte-Anne River; the Sainte-Anne River is more contaminated with Cr and Ni than either the Châteauguay or Saint-Maurice River; and there are no differences among rivers for Mn. According to Delisle (1978a; 1978b), sediments from the Châteauguay River are more contaminated with Hg (>1 mg/kg) than those from the Saint-Maurice

River (0.31 to 0.41 mg/kg). Laliberté (1990) reported a similar concentration of 0.32 mg/kg Hg in sediment from the Saint-Maurice River in 1987. Unfortunately, these are the only data available on metal levels in sediments from these three rivers.

Freshwater mussels were obtained from only two rivers; 11 specimens of *E. complanata* were taken from the Châteauguay River, and 1 specimen of *L. r. radiata* was collected from the Bécancour River. Concentrations of Fe, Hg and Mn in the single specimen of *L. r. radiata* from the Bécancour River exceeded concentrations of these metals in all specimens of *E. complanata* from the Châteauguay River (Table 1), suggesting that the former river may be more contaminated with these metals. Conversely, the concentrations of V in the *E. complanata* from the Châteauguay River exceeded the concentration of V in the specimen of *L. r. radiata* from the Bécancour River. However, Metcalfe-Smith et al. (1996) found that *E. complanata* and *L. r. radiata* collected sympatrically from a site on the St. Lawrence River at Sorel, Quebec, accumulated significantly different concentrations of 11 metals, including nine of the metals examined in the present study. Similar to the present study, residues of Mn were higher in *L. r. radiata*. In contrast, however, residues of Fe and Hg were higher in *E. complanata*. Due to these inconsistencies, as well as the small amount of data available for *L. r. radiata*, comparisons of metal contamination in mussels from the Bécancour and Châteauguay rivers were not considered meaningful.

One of the main objectives of this study was to determine if lamprey ammocoetes and freshwater mussels accumulated similar levels of trace metals from the same environment. Such a comparison was possible for the Châteauguay River, where 13 lampreys and 11 mussels were collected. Mussels were found to have non-overlapping higher concentrations of Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Tl, V and Zn and non-overlapping lower concentrations of Hg than lampreys, whereas concentration ranges for Fe overlapped between organisms (Table 1). The probability of falsely rejecting the null hypothesis of no difference between organisms was $p < 0.001$ for Ag, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Tl, V and Zn. Concentrations of most metals were considerably higher in mussels than lampreys, ranging from about 2.5 times as high (based on comparisons of mean concentrations) for Fe to 540 times as high for Tl; the modal value was 50 times. In contrast, Hg levels averaged 5 times as high in lampreys as mussels. Assuming a concentration of 1 mg/kg Hg in sediment from the Châteauguay River (Delisle 1978a), levels in lamprey ammocoetes were about 4 times those in the sediment. There is some evidence that lampreys may have a particularly high bioaccumulation capacity for Hg. Evans et al. (1972) analyzed the dorsal muscle of 57 preserved fish of 26 different species taken from the Lake St. Clair-Western Lake Erie region of the Great Lakes between 1920 and 1965, and found that only Muskellunge (*Esox masquinongy*) and adult Sea Lamprey (*P. marinus*) contained Hg levels above 0.5 ppm on a wet weight basis. Muskellunge and Sea Lampreys collected in 1970 contained approximately 3.0 µg/g Hg on a wet weight basis. Concentrations of Hg in *P. marinus* from the Sainte-Anne and Saint-

Maurice rivers appear to be much lower, ranging from 0.8 to 4.8 µg/g Hg on a dry weight basis; however, comparisons between levels in whole lamprey ammocoetes (this study) and the dorsal muscle of adult lampreys may not be valid especially in light of the different ecologies of the two life history stages. The results of this study clearly do not support the hypothesis that lamprey ammocoetes and freshwater mussels accumulate comparable levels of trace metals in their tissues, due to similarities in their ecology.

There are many possible reasons why the bioaccumulation of metals differed greatly between lampreys and mussels in this study. As concentrations of metals may differ by an order of magnitude or more between species of freshwater mussels (Metcalfe-Smith et al. 1992), it is not surprising that differences as great as or greater than this could be observed between mussels and fish. Length of exposure period could also be a factor. Specimens of *E. complanata* from the Châteauguay River were probably older than specimens of *I. fossor* and *L. appendix*; if so, they would have been exposed to trace metals for a longer period of time. Based on the relationship between shell length and age reported by Magnin and Stańczykowska (1971) *for E. complanata* from Lac des Deux Montagnes and Lac Saint-Louis in the Montréal area, mussels in the present study would have been at least 8 years old. Based on a length/age regression equation for 41 specimens of *E. complanata* of the same size range collected from the St. Lawrence River at Sorel, Québec, by Metcalfe-Smith et al. (1996), mussels from the Châteauguay River would have been between 7 and 17 years of age. In contrast, all specimens of *I. fossor* and *L. appendix* were certainly less than 7 years old, as the ammocoete period does not exceed 7 years in either species (Scott and Crossman 1973). Based on length-frequency data presented by Purvis (1970) for *I. fossor* from the Sturgeon River in the Lake Superior basin, and Thomas (1962) for *L. appendix* from Venison Creek in the Lake Erie basin, ages of specimens in the present study were estimated to be from 1+ to 4+ years. Longer exposure periods for mussels are consistent with the finding of higher concentrations of most metals in mussels. However, lamprey ammocoetes have higher filtration rates, and hence higher uptake rates, for contaminants than mussels (Renaud et al. 1995a), and this would tend to favour the accumulation of more elevated concentrations in lampreys.

Perhaps the most plausible explanation for the observed differences in metal concentrations between mussels and lampreys is that most metals, with the exception of Hg, are at least partially regulated in freshwater fish (Phillips and Rainbow 1993), whereas bivalves are generally considered to be poor metal regulators (Bryan 1979). Significant negative correlations between body size and trace metal concentration have been observed for various metals in the white muscle tissue of marine fish (Cross et al. 1973), in freshwater mussels (Metcalfe-Smith et al. 1996), and in *P. marinus* ammocoetes from tributaries to the St. John and St. Croix rivers, N.B. (Holmes and Youson 1996). Such negative relationships were attributed to the organisms' abilities to regulate metals. Metcalfe-Smith et al. (1996) observed significant negative correlations between age-size and soft tissue metal concentration for Al, Cr, Cu, Ni and Se in *L. r. radiata*, but only for Cu in *E. complanata*, and concluded that *L. r. radiata* was more capable of regulating metals.

Concentrations of metals in *E. complanata* from the Châteauguay River were compared with those in *E. complanata* of a similar size range collected from the St. Lawrence River at Sorel, Quebec (located directly below the mouth of the Richelieu River; see Fig. 1) by Metcalfe-Smith et al. (1996) in 1990 (Table 3). Mussels from the St. Lawrence River contained non-overlapping higher concentrations of Cr, Fe, Ni and Pb and non-overlapping lower concentrations of Hg than those from the Châteauguay River (see Table 1). The sampling site on the Châteauguay River was located near the headwaters, in an area remote from anthropogenic sources of metals. In contrast, the site near Sorel was located immediately downstream of the outfalls of several major metal-discharging industries. Loadings of Cr, Fe, Ni, Pb and Zn from these industries are particularly significant (Metcalfe-Smith et al. 1996), and these are the metals (with the exception of Zn) that were elevated in mussels from the St. Lawrence River relative to those from the Châteauguay River.

The only other data on metal levels in lamprey ammocoetes that are available for comparison with the present study are those of Holmes and Youson (1996) for Cu and Fe in *P. marinus* larvae from uncontaminated tributaries to the Saint John River, N.B. Only the data from the Keswick River and Long Creek were considered, because data from the other four streams had been corrected to a standard weight of the organism. These data are presented in Table 3 for comparison with levels of Cu and Fe in *P. marinus* from the Sainte-Anne River (Table 1). Lamprey ammocoetes from the Sainte-Anne River contained non-overlapping lower concentrations of Cu, and overlapping but generally higher concentrations of Fe than those from the New Brunswick streams. Copper concentrations in lampreys from the Keswick River and Long Creek were an order of magnitude higher than those from the Sainte-Anne River, yet Cu is an essential nutrient that is generally well regulated by fish (Wiener and Giesy 1979). Holmes and Youson (1996) suggested that the high levels of Al, Cu and Fe found in lamprey ammocoetes from the six New Brunswick streams may be indicative of the maternal transfer of metals from females to embryos. The non-zero intercepts they observed for the body burden-total length relationships for these elements supported this concept. If concentrations of metals in juveniles are significantly influenced by concentrations in their far-ranging mothers, then the value of lamprey ammocoetes as biomonitoring organisms would be compromised.

Conclusions

The utility of freshwater mussels as biomonitors for metal contamination in aquatic systems is well known. In contrast, fish are not general-

Table 3. Metal concentrations (ng/g dry weight) in mussels (*Elliptio complanata*) and lamprey larvae (*Petromyzon marinus*) from other locations in eastern Canada, for comparison with the present study

			Concentration range (ng/g dry weight)									
Location	Collection date	Sample size	Species	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
St. Lawrence R. at Sorel, Quebec	June 1990	47	*Elliptio complanata*	130–1080	8100–45900	6670–22700	3640000–16220000	70–280	59300–3510000	2190–13100	5150–18800	136000–312000
Keswick R., N.B.	May 1986	15	*Petromyzon marinus*	—	—	6000–28000	407000–1280000	—	—	—	—	—
Long Creek, N.B.	May 1986	15	*Petromyzon marinus*	—	—	3000–16000	470000–1300000	—	—	—	—	—

ly considered to be suitable for this purpose because of their mobility and their capability to regulate certain metals. In this study, the hypothesis that freshwater mussels and lamprey ammocoetes would accumulate similar levels of metals in their tissues due to similarities in their ecology was rejected. Lamprey larvae from the Châteauguay River accumulated much lower concentrations of all metals except Hg than mussels, suggesting that lampreys may be capable of regulating some metals. According to Phillips and Rainbow (1993), "Regulators of metals should not be employed as biomonitors, as they do not respond to differences in the abundance of trace elements in the external medium." Mercury is supposedly not regulated by any organism, rather it tends to bioaccumulate continually over time. Lamprey ammocoetes appear to have an exceptionally high bioaccumulation capacity for Hg, hence they may be suitable biomonitors for Hg contamination in rivers.

Intra- and interspecific differences in metal concentrations among lamprey ammocoetes were relatively minor, thus allowing data from individuals of several species to be combined and used to determine the pollution status of a given site. Even though sample sizes were small and unequal, significant differences among rivers were observed for many metals based on the lamprey data. This suggests that lamprey ammocoetes may be used to indicate differences in metal contamination among rivers, notwithstanding their regulatory capabilities. As metals in the gut contents were found to constitute a substantial portion of the whole-body burden of metals in these animals, a gut content correction factor is recommended. Very small ammocoetes that cannot practicably be dissected may be precluded from analysis. The present study is one of only two studies to date that have considered lamprey ammocoetes as biomonitors for metals in freshwater systems. Additional data including trace metal levels in water and sediments at the lamprey sampling sites are required before the usefulness and limitations of these organisms can be properly assessed.

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