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Trace element and stable isotope analysis of fourteen species of marine invertebrates from the Bay of Fundy, Canada

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ABSTRACT

The Bay of Fundy, Canada, is a macrotidal bay with a highly productive intertidal zone, hosting a large abundance and diversity of marine invertebrates. We analysed trace element concentrations and stable isotopic values of $\delta^{15}N$ and $\delta^{13}C$ in 14 species of benthic marine invertebrates from the Bay of Fundy's intertidal zone to investigate bioaccumulation or biodilution of trace elements in the lower level of this marine food web. Barnacles (*Balanus balanus*) consistently had significantly greater concentrations of trace elements compared to the other species studied, but otherwise we found low concentrations of non-essential trace elements. In the range of trophic levels that we studied, we found limited evidence of bioaccumulation or biodilution of trace elements across species, likely due to the species examined occupying similar trophic levels in different food chains.

As an interface between terrestrial and marine environments, coastal habitats are particularly prone to accumulating various forms of pollution (Islam and Tanaka, 2004). Benthic macroinvertebrates inhabiting these environments are often suitable biomonitors of these pollutants because they are relatively sessile but they filter the water or feed in the sediments of these environments, thereby providing a strong index of local contaminant conditions (e.g., (Dallinger, 1994; Rainbow, 2006; Sizmur et al., 2013)). For example, in carrying out their life processes, these organisms accumulate essential (e.g., Mn, Zn, Cu and Fe) and non-essential (e.g., Hg, Pb, Cd, As) trace elements, in some cases at levels of toxicological concern (Rainbow, 2007). Various invertebrates can accumulate contaminants from sub-benthic, benthic, and pelagic sources, and often the accumulation of trace elements is a species-specific process governed by the species' physiology, functional anatomy, and feeding strategy, as well as the chemistry of the different trace elements (Dallinger, 1994; Rainbow, 2007). Feeding strategies vary distinctly among marine invertebrates, with sessile filter feeders likely accumulating trace elements from pelagic sources, and benthic scavengers and predators accumulating trace elements from benthic and sub-benthic sources. Barnacles accumulate trace elements in proportion to the ambient availabilities of these elements, which allow concentrations of trace elements to reach very high levels in these organisms (Rainbow and White, 1989; Morillo et al., 2005). The decapod *Palaemon elegans* and the polychaete *Hediste diversicolor* bioregulate their Zn concentrations by excreting a proportion of the Zn they accumulate, however, they accumulate Cd and Cu in a method similar to barnacles (Rainbow and White, 1989; Geffard et al., 2005). Consequently, monitoring a suite of benthic invertebrates may provide a more complete picture of trace element pollution in a particular site.

We examined trace elements in macroinvertebrates inhabiting the intertidal zone in the southern portion of the Bay of Fundy, Nova Scotia, Canada. This region has an immense intertidal zone which contains many highly productive mudflats and salt marshes that support a large diversity and abundance of invertebrates (Hargrave et al., 1983). Consequently, the region is a key site supporting migratory birds (Hicklin, 1987; Wilson, 1990), many of which may ingest and accumulate non-essential trace elements by foraging on abundant coastal prey (Elliott et al., 1992; Lucia et al., 2014). The Bay of Fundy region has naturally high background levels of As (Wong et al., 1999; Hung and Chmura, 2007; Walker et al., 2009) and Hg (Sunderland et al., 2012), but the concentrations of these and other trace elements in lower levels of coastal food webs have not been well-documented. This represents a substantial information gap, because the region is also targeted for industrial development of tidal energy installations (Karsten et al., 2008; Fundy Ocean Research Centre for Energy, 2014), and baseline data are required against which we can assess potential impacts of such development, including altered flow regimes and potentially adjustments to sediment transport and local benthic chemistry. Therefore, our goal was to fill baseline information needs by sampling benthic macroinvertebrates inhabiting coastal mudflats in the Bay of Fundy, and to determine trace element concentrations and their possible relationships to trophic position in these organisms.

Sampling occurred in May 2014 from three locations along the Bay of Fundy: Yarmouth Harbour (43.82°N, 66.11°W), Kingsport beach (45.16°N, 64.35°W), and Wolfville Harbour (45.09°N, 64.35°W; see

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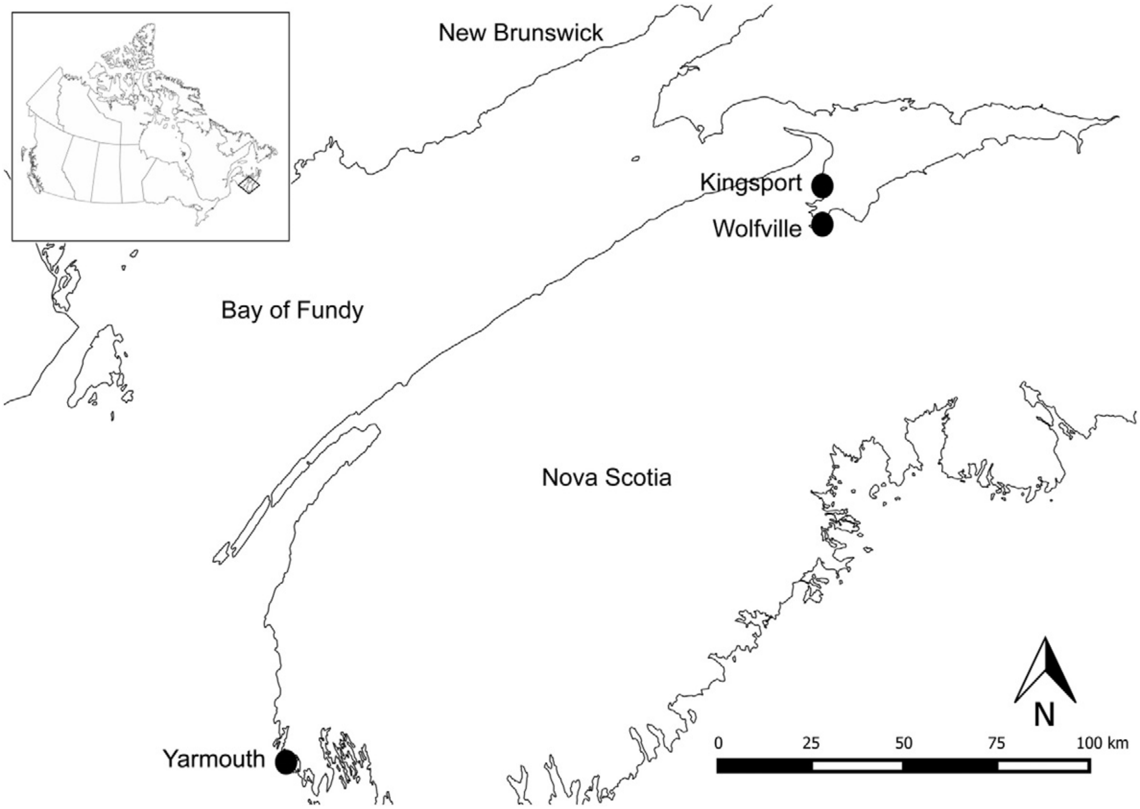

Fig. 1. Map of study sites in Nova Scotia, Canada.

Fig. 1). The three sites span a range of 6–15 m tides, experiencing major water and silt movement daily, and are not known to be contaminated sites. While our sampling was localized at these three locations and not systematic along the entire Bay of Fundy, we believe our sampling generally represents the sandy intertidal zone in the southern coast of the Bay of Fundy.

Fourteen species of benthic invertebrates were collected at low tide from the intertidal zone in each site (Table 1). Five samples of each species were prepared by homogenizing samples with a mechanical homogenizer, and the homogenates were stored frozen until they were sent away for analysis. All molluscs and *Balanus balanus* were removed from their shells prior to homogenization, and all other organisms were homogenized whole. Samples were either pooled samples containing multiple individuals of the same species, or individual samples containing only one specimen, and samples were sealed separately in sterilized vials. All instruments used to extract and process samples were cleaned in 95% ethanol, followed by distilled water between each sample. The organisms collected likely do not belong to the same food chain, but occupy similar trophic levels in different food chains in the Bay of Fundy.

Frozen homogenates were sent to the Stable Isotopes in Nature Laboratory (SINLAB, University of New Brunswick, Canada), for stable isotope analysis. Samples were combusted in an elemental analyser, and gases were sent to the isotope-ratio mass spectrometer using a continuous flow interface. Data are reported as differences in isotopic ratios, for which the units are parts per thousand (or per mil; ‰), compared to Pee Dee Belemnite (PDB), for carbon, and atmospheric nitrogen (AIR), for nitrogen, according to the following equation:

$$\delta X = \left(\frac{R_{sample}}{R_{std}} - 1\right) * 1000$$

where δX is the isotope of interest (either $\delta^{15}N$ or $\delta^{13}C$, in ‰), R is the ratio of the abundance of the heavy to the light isotope ($^{15}N/^{14}N$ or

Table 1
Species names, sample sizes, and species codes for the invertebrates collected in this study. Samples are either pooled containing multiple individuals of the same species (P), or samples containing a single individual (I).

Species	Class	Lifestyle	Sample type	n	Species code
Balanus balanus	Maxillopoda	Sessile filter feeder	P	5	BB
Cerebratulus lacteus	Anopla	Mobile predator/scavenger	I	1	CL
Clymenella torquata	Polychaeta	Mobile filter feeder	P	4	CT
Corophium volutator	Malacostraca	Mobile filter feeder	P	4	CV
Ensis directus	Bivalvia	Sessile filter feeder	I	5	ED
Glycera dibranchiate	Polychaeta	Mobile predator/scavenger	P	5	GD
Gammarus oceanicus	Malacostraca	Mobile filter feeder	P	5	GO
Hediste diversicolor	Polychaeta	Mobile predator/scavenger	P	5	HD
Ilyanassa obsolete	Gastropoda	Mobile detritus feeder	P	5	IO
Littorina littorea	Gastropoda	Mobile detritus feeder	P	5	LL
Mya arenaria	Bivalvia	Sessile filter feeder	I	5	MA
Macoma balthica	Bivalvia	Sessile filter feeder	P	5	MB
Mytilus edulis	Bivalvia	Sessile filter feeder	I	5	ME
Pagurus pubescens	Malacostraca	Mobile scavenger	P	5	PP