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Warm season chloride concentrations in stream habitats of freshwater mussel species at risk

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A B S T R A C T

Warm season (May–October) chloride concentrations were assessed in stream habitats of freshwater mussel species at risk in southern Ontario, Canada. Significant increases in concentrations were observed at 96% of 24 long-term (1975–2009) monitoring sites. Concentrations were described as a function of road density indicating an anthropogenic source of chloride. Linear regression showed that 36% of the variation of concentrations was explained by road salt use by the provincial transportation ministry. Results suggest that long-term road salt use and retention is contributing to a gradual increase in baseline chloride concentrations in at risk mussel habitats. Exposure of sensitive mussel larvae (glochidia) to increasing chloride concentrations may affect recruitment to at risk mussel populations.

1. Introduction

Increasing chloride concentrations attributable to road salt (sodium chloride) use have been observed in rivers and streams (herein referred to collectively as streams) in northeastern North America (Rosenberry et al., 1999; Godwin et al., 2003). Stream water chloride concentrations have been related to percent impervious surface, road density and other measures of urban development (Rhodes et al., 2001; Cunningham et al., 2009; Daley et al., 2009) prompting concern for the salinization of freshwater resources with increasing road coverage and road salt use (Kaushal et al., 2005).

Mass balance and modelling studies estimate that 40–77% of the chloride from road salt applied in a given year can be retained in a watershed (Novotny et al., 2009; Perera et al., 2010) and that chloride accumulated in soils and groundwater can be stored for months or years (Bastviken et al., 2006; Bester et al., 2006). Sub-surface accumulation of chloride can contribute to long-term increases in baseline salinity of surface waters (Kelly et al., 2008). Retention and delayed transport of chloride in the environment can also prolong the duration of exposure of aquatic species to elevated chloride, potentially overlapping with sensitive life stages (Findlay and Kelly, 2011).

Freshwater mussels, specifically their larval (glochidial) life stage, are especially sensitive to chloride compared to other freshwater organisms (Canadian Council of Ministers of the Environment (CCME), 2011). Freshwater mussels are among the most imperilled groups of animals in the United States and Canada (Williams et al., 1993). Stream habitats in the lower Great Lakes drainage basin of southern Ontario contain the richest assemblage of freshwater mussels in Canada (Metcalfe-Smith et al., 1998), including several species that are classified as endangered under federal species at risk legislation. The basin is also Canada's most road-dense region where over one million tonnes of chloride are applied annually as road salt (Morin and Perchanok, 2003). Most (>60%) of the chloride in the basin's streams is attributable to road salt application (Mayer et al., 1999). Gillis (2011) suggested that stream water chloride concentrations in the basin may pose a threat to successful mussel reproduction. Chloride was found to be a significant factor influencing mussel species richness (Metcalfe-Smith et al., 2003); however, a robust examination of stream water chloride conditions and trends in at risk mussel habitats has not been published.

Freshwater mussels have a complicated life cycle. Female mussels release glochidia from a brooding chamber into the water column to undergo a period of parasitism on a vertebrate host. Chloride and other aquatic contaminants can potentially limit survival of free glochidia or their ability to attach to a host, ultimately affecting recruitment to the mussel population (Cope et al., 2008). In Ontario, glochidia are released between May and October (warm season) depending on species-specific temperature cues (Gillis, 2011) and

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road salt is generally applied between November and April (cold season). The offset in the timing of glochidia release and road salt application would seem to favour mussel reproduction; however, it is possible that retention and delayed transport of chloride from road salt application in the cold season is exposing sensitive mussel glochidia to elevated chloride concentrations in the warm season.

This paper explores spatial, seasonal and long-term trends in chloride concentrations in stream habitats of mussel species at risk in southern Ontario, with particular emphasis on warm season results. Three questions are addressed.

1. Is there a relationship between land uses and chloride concentrations in mussel habitats?
2. When and how frequently do elevated chloride concentrations occur in mussel habitats?
3. Are concentrations in mussel habitats changing over time and at what rate?

It is hoped that the results will inform ongoing efforts to mitigate the environmental impacts of road salt use and to conserve at risk mussel populations.

2. Materials and methods

2.1. Monitoring sites

Locations of stream water quality monitoring sites (Ontario Ministry of the Environment (OMOE), 2011) were overlaid on the distribution of mussel species at risk in southern Ontario (Fisheries and Oceans Canada, 2011) using a geographic information system. Twenty-four long-term (25 or more years of monitoring) and independent stream water quality monitoring sites were identified within at risk mussel habitats (Fig. 1). The contributing drainage area of each site was delineated using digital elevation models and watershed attributes, including road density, population density and land cover, were quantified using available geospatial data layers (Table 1). Road density was calculated as the total length of road in the watershed, irrespective of the number of lanes, divided by the watershed area. Population density was estimated from the proportion of each census region (dissemination area) that overlapped with the study watershed. The nearest stream flow monitoring gauge to each site was identified and stream flow data were obtained from Environment Canada (2011).

2.2. Chloride data

Stream water chloride concentrations were measured approximately monthly at each site as part of the Provincial Water Quality Monitoring Network. Stream water samples were collected across a range of stream flow conditions, from base to storm flow, and delivered to the OMOE laboratory for analysis. Chloride concentrations were determined by reaction with mercuric thiocyanate, releasing thiocyanate through the sequestration of mercury by the chloride ion to form unionized mercuric chloride. The liberated thiocyanate then reacts with the ferric ion to form ferric thiocyanate, the absorbance of which is measured colourimetrically using a spectrophotometer. The detection limit of this method is 1 mg Cl L^{-1} (OMOE, 2010). Sampling at some sites began in 1964; however, this study is limited to the period 1975–2009 when the laboratory methods and detection limit for chloride analysis were relatively consistent. Corsi et al. (2010) note that continuous- and event-based monitoring strategies are needed to fully characterize the influence of road salt on stream water quality (e.g. Meriano et al., 2009; Perera et al., 2009). Results presented in this study may underestimate the full range of stream water chloride concentrations given that monitoring was not designed specifically to capture periods of road salt runoff.

2.3. Data analyses

Chloride data were divided into warm (May–October) and cold (November–April) seasons. Statistical analyses were completed using SYSTAT version 13 with

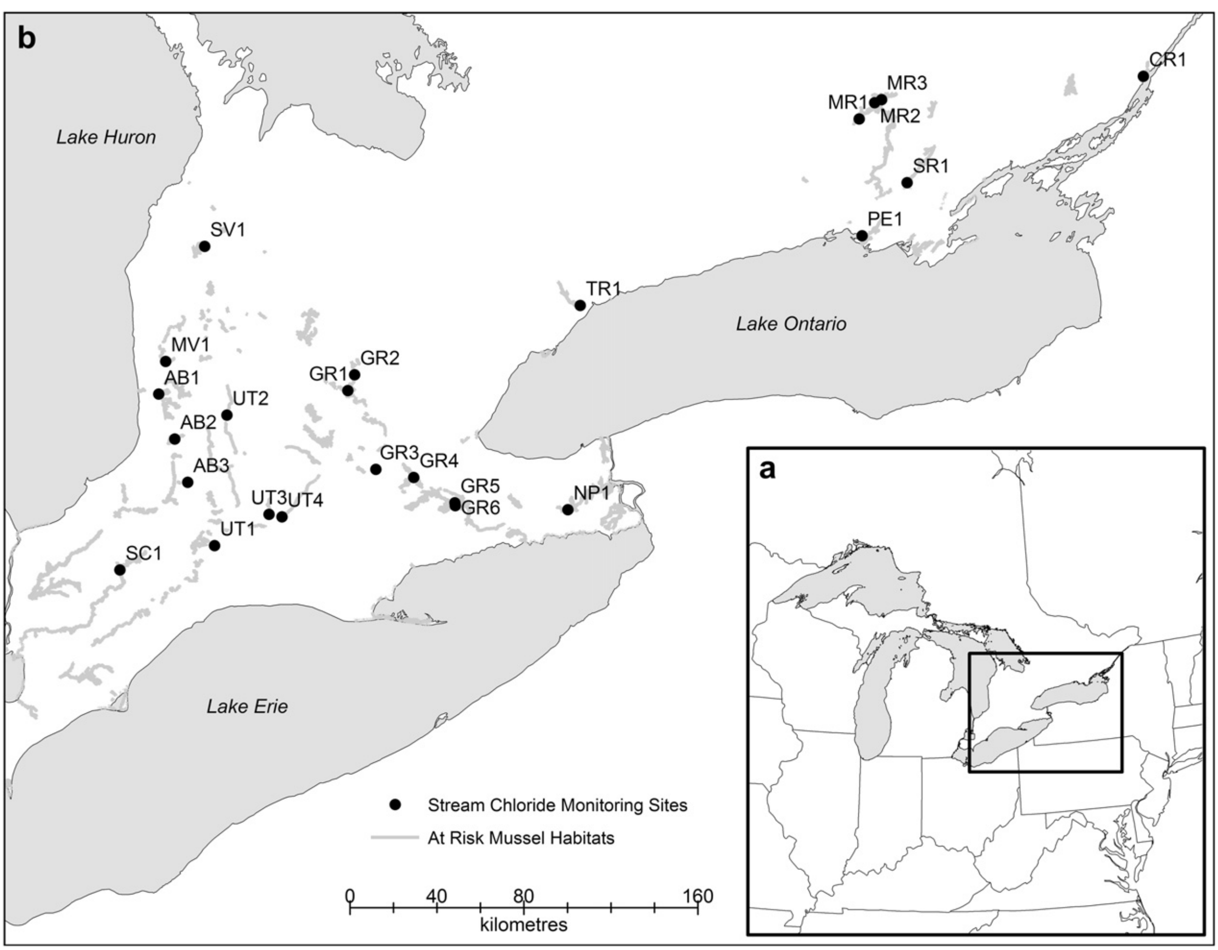

Fig. 1. (a) Inset map showing the study area in southern Ontario, Canada; and (b) Locations of the 24 stream water chloride monitoring sites in habitats of mussel species at risk.