EXHIBIT 17

Ecological benefit of the road salt code of practice

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ABSTRACT

Despite an overall increase in total road salt used over the past 14 years (the data record in this manuscript), there has been a 26% reduction in the rate (normalized as tonnes of salt per cm of snow per km of road) of road salt application by the City of Toronto since that city implemented mitigations from the Road Salt Code of Practice. The ecological benefit of the reduced use of road salt was approximated by comparing the estimated 26% salt reduction to the distribution of chloride tolerances that has been recently published by the Canadian Council of Ministers of the Environment (i.e., CCME). Species sensitivity distributions predict that between 1 and 14% of taxa would benefit from a 26% reduction in chloride concentrations in surface waters. Assuming that a typical 'healthy' Canadian watercourse might support between 100 and 200 species of fish, invertebrates and plants, the Code of Practice might provide benefit to between 14 and 28 species. However, the net ecological benefit of implementing the Code may be undermined in rapidly urbanizing watersheds where road networks continue to expand at a rate of 3–5% per year and chloride loads to urban streams are steadily increasing.

Key words | chlorides, ecological benefits, maximum field distribution, road salt, species sensitivity distribution

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INTRODUCTION

Snow and ice conditions on the road system have a significant impact on public safety, roadway capacity, travel time and economic costs (Keummel 1992). In Canada, control of snow and ice on road pavements and sidewalks is generally achieved by a combination of de-icing with road salts and mechanical plowing. Each year, approximately 5 million tonnes of road salts are used as de-icers on roadways in Canada (Environment Canada 2004). The City of Toronto, with about 5,500 km of dense road network (City of Toronto 2005) relies on about 135,000 tonnes per year salt application during the winter to provide safe transportation surfaces for all road and sidewalk users in an efficient and affordable manner.

Both aquatic and terrestrial ecosystems can be adversely affected by exposure to chloride concentrations associated with the typical use of road salts (USEPA (United States Environmental Protection Agency) 1988; Novotny *et al.* 1999; Environment Canada & Health Canada 2001; Rutherford & Kefford 2005). Elevated concentrations of chlorides in surface waters can cause changes in behavior (e.g., increased 'drift' of stream invertebrates; Crowther & Hynes 1970), and increase mortality rates of aquatic organisms (Evans & Frick 2001; Benbow & Merritt 2004). Cladocerans (e.g., *Ceriodaphnia*) are considered particularly sensitive to chlorides with concentrations as low as about 450 mg/L causing harm to individuals during short-term exposures (Dowden & Bennet 1965; Elphick *et al.* 2011). The larvae of some select rare and endangered Canadian freshwater mussels are also highly sensitive to chloride with concentrations as low as 113 mg/L causing harm to individuals in laboratory toxicity tests (Bringolf *et al.* 2007; Gillis *et al.* 2008; Gillis 2011).

Chloride concentrations vary spatially in Canada. Natural background freshwater chloride concentrations are generally in the 10–20 mg/L range, but stream chloride concentrations in highly urbanized areas can be as high as

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10,000 mg/L. Loadings are highest in urban centers including Toronto and Montreal (Mayer *et al.* 1999). Concentrations of chlorides are generally increasing in ground (Kincaid & Findlay 2009; Mullaney *et al.* 2009) and surface waters (Todd *et al.* 2009) in urbanized areas. There may be a relationship between percent imperviousness and chloride concentrations in streams, based on work in the USA (Kaushal *et al.* 2005), and implying that areas with an imperviousness of >30–40% are likely to have chloride concentrations in their surface waters of some 200–300 mg/L.

Environment Canada classified road salt a toxic substance on the basis of extensive review of fate and effects (Evans & Frick 2001). That classification required that Environment Canada consider regulatory instruments for mitigating the risks that were considered to be posed by the product. Environment Canada (EC) & Health Canada (HC) (2001) carried out additional research assessing various mitigation techniques (Marsalek 2003; Stone & Marsalek 2011), and then developed its Code of Practice (EC 2004). The Code of Practice is an assemblage of best practice guidelines for reducing the use of road salts in municipalities that use large amounts of the product. Environment Canada is encouraging municipalities that use more than 500 tonnes of road salt per year to implement the mitigations recommended in the Code. Municipalities that implement the best practices (including reduced application rates and more efficient timing of application) have been able to reduce chloride concentrations in groundwater by 50% over a 3–4 year period (Bester *et al.* 2005; Stone *et al.* 2010).

The ecological benefit of implementing the Code is questionable, considering that our road networks are continuing to expand and chloride loads to watersheds are increasing. Estimating the ecological benefit of the Code of Practice requires an understanding of the relationship between exposure concentration (as well as frequency and duration) and ecological effect. Chloride tolerances determined from laboratory toxicity tests provide one line of evidence of the potential effects that chloride concentrations can have in the environment. USEPA (1998) developed toxicity thresholds for chloride including a longer-term chronic criterion of 230 mg/L which is to be applied to exposure durations of 96 h or more, and a short-term acute criterion of 860 mg/L which is to be applied to exposure durations of 4 h or less. The Canadian Council of Ministers of the Environment (CCME) recently published a national guideline for chloride (CCME 2011). CCME recommended that concentrations of 640 mg/L would protect most species (95%) during short-term acute exposures, while 120 mg/L would protect most species under longer-term chronic exposures. CCME (2011) further recognized that some watersheds in southwestern Ontario contain species of Unionidae (freshwater mussels; northern riffleshell – *Epioblasma torulosa rangiana* and the wavy-rayed lamp mussel – *Lampsilis fasciola*) that are not only highly sensitive to chloride during their larval stages (concentration lethal to 10% of larvae is ~24 mg/L), but are rare and at risk of extirpation (COSEWIC (Committee on the Status of Endangered Wildlife in Canada) 2010a, b), and that these watercourses may require further protection greater than that afforded by the general guidelines.

The objective of this paper is to provide one estimate of the ecological benefit of Environment Canada's implementation of the Road Salt Code of Practice. The estimate here is specific to the City of Toronto's experiences. Reductions in chloride loads to streams, and associated concentrations in surface waters, were modeled using road salt application rates for the City of Toronto before and after implementation of the Code of Practice. The ecological benefit was estimated by comparing the observed salt reduction (pre to post implementation of the Code) to the distribution of chloride tolerances (Posthuma *et al.* 2002) that has been recently published by the Canadian Council of Ministers of the Environment (i.e., CCME).

METHODS

Normalized road salt loadings

Road salt application rates were computed for the Toronto area for the period 1996 to 2007. Salt application rates were provided by the City of Toronto – Transportation Services and by the Ontario Ministry of Transportation. Road salt application rates within watersheds and catchments depend in part on road density and primarily on the weather. Higher road densities generally result in more road salt being applied within a catchment. Greater amounts of snow also generally require a greater amount of road salt application in a given year. Changes in surface water concentrations pre-post the Road Salt Code of Practice (i.e., before versus after 2004) could, therefore, have varied because of changes in road density (i.e., increase) or changes in snowfall. Road salt application rates were thus standardized for road density and snowfall to better understand the impact of the Code of Practice on road salt application rates. Annual snowfall data for the Toronto area were obtained from the nearby Environment Canada weather station in North York. Digital road network data were obtained from the Ontario Ministry of Transportation. The relationship between road salt application rate (tonnes per year) and road density, as well as between road salt application rate and snowfall accumulation (cm per year) were quantified annually for the years 1996 through 2007. Salt application rates were scaled to road density and snowfall accumulation, and ultimately expressed as kg salt/km road/cm snow. Total length of salt-applied roads within the watershed was considered for the normalization as all roads drain to the stream network within a couple of hours due to lower roughness in storm sewer systems. The lag time in getting salty runoff to a stream is, therefore, much smaller than the time frame considered for short-term exposure for aquatic organisms (generally 24–48 h). A simple *t*-test was used to test for differences in normalized application rates between the period before (1996–2003) and the period after implementation of the Road Salt Code of Practice (2004–2007). The percent change in normalized road salt application rate was computed from before to after implementation of the Code.

Quantifying ecological benefit

CCME (2011) reviewed the existing chloride toxicity literature and developed a species-sensitivity distribution (SSD), which describes the expected distribution of species tolerances when exposed to chloride. CCME developed two curves: (1) the first SSD_a was for acute, or short-term (24–48 h) exposure to chloride; and (2) the second SSD_c was for chronic, or long-term (96 h or longer) exposure to chloride. Both SSDs were based on the set of taxa for which reliable toxicity data are available; data are not available for all of the tens of thousands of aquatic organisms that occur in surface water environments (creeks, streams, rivers, ponds, lakes) in Canada (Morton & Gale 1985). The SSDs, which are approximately normally distributed, however, can generally be used to predict the percentage of species that will be affected when exposed to chlorides for short- or long-term periods. Both short- and long-term SSDs were considered well fit using a log-Weibull model with the following form (as per CCME (2011)):

$$y = 1 - e^{-\left(\frac{x}{\lambda}\right)^{k}}$$

where, y is the percentage of species affected, x is the logarithm of the chloride concentration, and λ and k are constants that define the shape and form of the relationship. In the case of the short-term SSD, λ was 3.6268 and k was 10.9917; in the case of the long-term SSD, λ was 3.2119 and k was 7.0473. The SSDs are reproduced in Figure 4.

The SSD models were used with the normalized reduction in road salt application rates to quantify a potential ecological benefit to having implemented the Road Salt Code of Practice. Here, the reduction in normalized road salt application rates was taken as an estimate of the reduction in chlorides that could be anticipated, all other factors being considered, after implementation of best practices post the Road Salt Code of Practice. So for example, if the normalized road salt loadings were to have decreased by 10% post implementation of best practices, it was assumed that chloride levels in surface waters in Toronto area streams would be roughly 10% lower than if the Code of Practice had not been implemented. It is recognized that there are various lags when chlorides transport to streams, and that some of the lags are considerable (e.g., decades in some cases). For the purpose of this paper, it was assumed that chloride loadings to watercourses responded immediately to reductions in application of road salt to roadways. The ecological implication of that reduction was estimated considering the magnitude and form of the short-term and long-term SSDs. We computed the percentage of species that would be anticipated to benefit from reductions in chlorides (as per the estimated reduction in normalized road salt application rates), using both the short-term and long-term SSDs.

RESULTS

Reduction in normalized road salt application rates

Road salt application in the City of Toronto varied by an order of 3× from a low of ~57,000 tonnes in the winter of 2001/2002 to ~200,000 tonnes in the winter of 2007/2008 (Table 1). Over 50% of the variation in road salt application was related to cumulative snowfall (Figure 1). A little less than 5% of the variation in salt application rate was related to road density (Figure 2). Salt application rates normalized for both road density and snowfall are illustrated in Figure 3. There was a subtle but distinctive reduction in road salt application rates in the period defined as being after the Road Salt Code of Practice was implemented. The difference (26% reduction in mean normalized salt application rate)

Table 1 | Normalized road salt application rates

Winter period	Total amount of road salt applied (tonnes)	Cumulative snowfall (cm)	Length of roadway lanes (km)	Normalized road salt application (tonnes/cm/km)
1995/06	128,000	150	12,343	0.069
1996/97	157,600	167	12,415	0.076
1997/98	101,900	112	12,493	0.073
1998/99	140,400	124	12,493	0.091
1999/00	142,900	88	13,846	0.117
2000/01	176,600	181	13,800	0.071
2001/02	56,900	77	13,800	0.054
2002/03	208,200	145	13,800	0.104
2003/04	108,200	108	15,052	0.067
2004/05	147,400	166	15,052	0.059
2005/06	94,700	108	15,052	0.058
2006/07	89,100	83	15,052	0.071
2007/08	195,600	233	15,052	0.056
2008/09	147,100	195	15,052	0.050

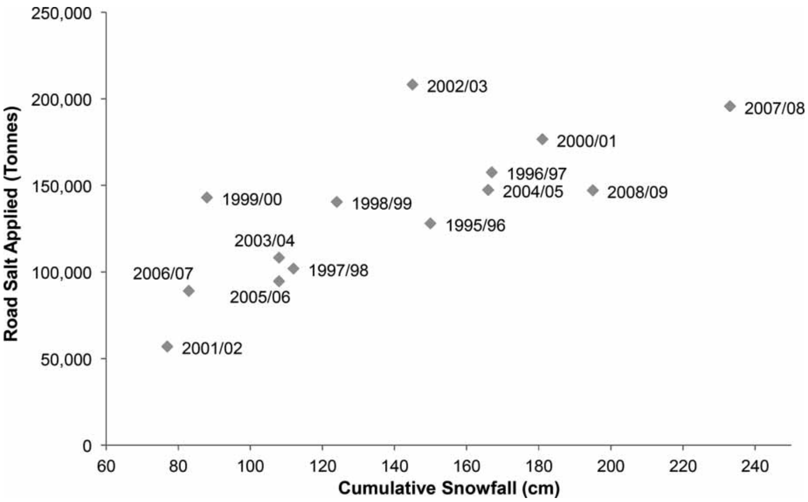

Figure 1 | Relationship between cumulative snowfall and tonnes of road salt applied in the Toronto area between the winters of 1995/1996 and 2008/2009.

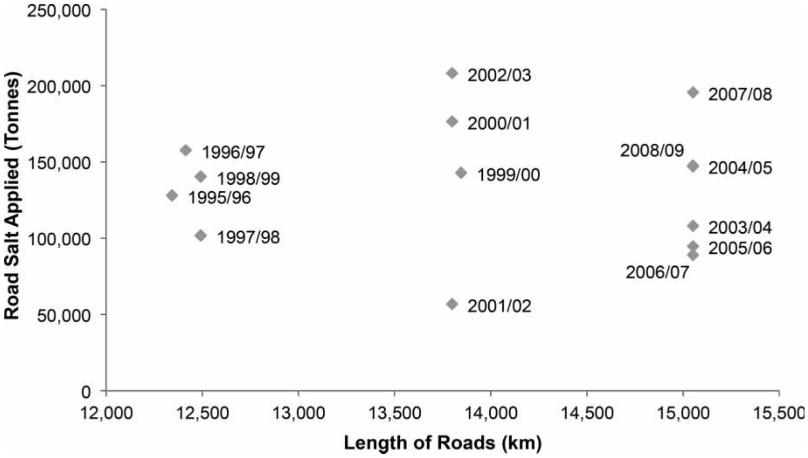

Figure 2 | Relationship between length of roads (km) and tonnes of road salt applied in the Toronto area between the winters of 1995/1996 and 2008/2009.

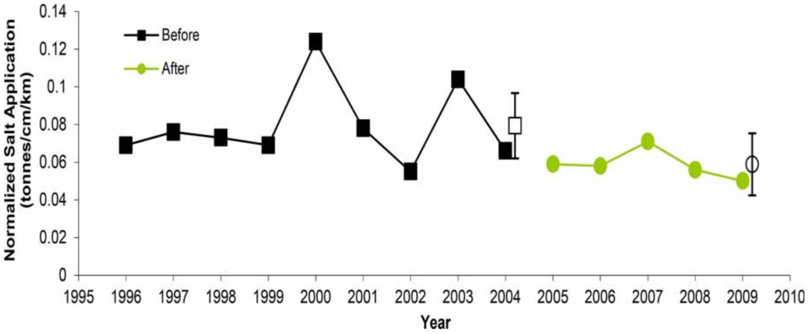

Figure 3 | Variations in normalized road salt applications rates, City of Toronto.

was statistically significant at a probability level of 0.03% (for a one-sided *t*-test).

Ecological benefit

The relationship between percent of taxa affected and chloride concentration was sigmoid in shape (Figure 4). The percentage of species benefiting from a 26% reduction in chloride concentrations, therefore, varies from a negligible fraction when the chloride concentrations are already low (say <200 mg/L), to ~14% when chloride concentrations decrease from ~6,000 to 4,400 mg/L in a short-term acute exposure (Table 2; Figure 4). The percentage of species benefiting also depends on whether the exposure is short- or long-term, with a greater benefit occurring under short-term acute exposure (Figure 4; Table 2). The ecological benefit was greatest within the zone of the SSD in which the slope of the relationship between species affected and concentration was the most extreme, for both the short-term and long-term relationships.

DISCUSSION

This analysis demonstrated a potential 26% reduction in chloride loads to watercourses in the Toronto area after implementation of the Code of Practice. That loading should, in the longer term, result in chloride concentrations being ~26% less than what they otherwise would have been, had the Code of Practice not been implemented. Those reductions in chloride concentrations, further, have the potential to benefit as much as 14% of potential freshwater

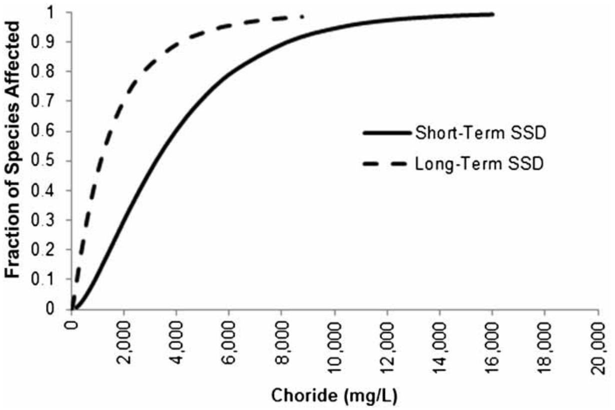

Figure 4 | Models of species sensitivity distributions for short-term and long-term exposures to chloride in surface waters. Models are from CCME (2011). Vertical lines indicate 2,000 and 1,400 mg chloride/L; horizontal lines indicate fraction of species affected by 2,000 and 1,400 mg/L in short-term and long-term exposures.

Table 2 | Percent of taxa benefiting from a 20% reduction in chloride concentrations in surface water

Initial chloride (mg/L)	Final chloride (mg/L) with 26% reduction	% benefiting under short-term exposures	% benefiting under long-term exposures
10,000	7,400	8	2
9,000	6,660	9	2
8,000	5,920	11	3
7,000	5,180	12	3
6,000	4,440	14	4
5,000	3,700	14	6
4,000	2,960	14	7
3,000	2,220	13	9
2,000	1,480	10	10
1,000	740	4	10
800	592	3	9
600	444	2	8
400	296	1	6
200	148	<1	3
100	74	<1	1

taxa. The estimated benefit: (1) assumes that the anticipated reduction in chloride loads is accurate; (2) recognizes that there are time lags between changes in application rates and concentrations in surface waters; (3) recognizes that chloride loads can be expected to generally increase in the future, regardless of implementation of the Code of Practice, and that aquatic species will more likely continue to be at an increasing risk; and (4) recognizes that other pollutants and stressors may override the influences of chlorides and further limit the distributions of aquatic organisms in heavily urbanized centers. Each of these points is discussed in greater detail below.

The estimated reduction in chloride concentrations in Toronto-area streams seems to be a reasonable observation based on other published works. In a review of the anticipated benefits of best practices for road salt applications, Gartner Lee Limited (GLL 2005) predicted about a 20% reduction in chloride loads and chloride concentrations. The City of Waterloo was further able to reduce total road salt application by 10% in the broader urban road network, and by 25% in the vicinity of well fields known to be susceptible to road salts (Stone *et al.* 2010). Municipal agencies, then, appear to be targeting a general reduction in the use of road salt by some 20–25%, and that level of reduction from historical loadings appears to be a reasonable expectation assuming that weather patterns also remain consistent into the future. As per Perera *et al.* (2010), road salt loadings are in part weather dependent, while changes in climate may result in a requirement to increase salt use per precipitation event, depending on air temperatures.

Despite the anticipated loading reductions, it is considered unlikely in the near term that chloride concentrations will significantly decrease in surface waters. Analysis of Ontario's long-term data set shows an increasing trend in chloride concentration in river waters in almost every region (Todd *et al.* 2009). Time trends in four watersheds, two rural and two urbanized, were examined, in particular by Todd *et al.* (2009). Chloride concentrations in the Skootamatta River near the village of Actinolite (surrounded by natural and agricultural lands) have increased from a 1980s baseline of ~2 mg/L to a present-day value of ~3 mg/L. Concentrations in the Sydenham River near Owen Sound (population ~15,000) have increased from a 1970s baseline of ~8–9 mg/L to a present-day value of ~12 mg/L. Chloride levels in Fletchers Creek in Brampton (outside Toronto) have increased from an average of ~100 mg/L in the 1970s to an average of almost 500 mg/L in 2008. Chloride concentrations in Sheridan Creek in Mississauga have increased from a 1970s baseline of almost 300 mg/L to a present day average of about 800 mg/L. Todd *et al.* (2009) further tested for statistical significance in trends over time across the province. They compared chloride concentrations in the period 1980–1985, to those in the period 2000–2004. For those stations for which there were adequate data to make the comparison, over 90% demonstrated a statistically significant increase in chloride concentration. The data, thus, overwhelmingly indicate that chloride concentrations in ground and surface waters are increasing, and those increases appear to be related to increasing densification of road networks.

The lack of reduction in chloride concentrations in surface waters is in part related to historical loadings that are now resident in groundwaters which provide a base flow to surface waters. Groundwater is a storage compartment for road salts (Kincaid & Findlay 2009; Mullaney *et al.* 2009), and has been identified as a particular challenge to short-term recovery of surface water concentrations by both Canadian and US researchers (Ramakrishna & Viraraghavan 2005; Wenck Associates Inc. 2006; Howard & Maier 2007; Cooper *et al.* 2008; Kincaid & Findlay 2009; Rubin *et al.* 2010). The University of Guelph, in association with the City of Toronto, has monitored chloride concentrations in rivers (Highland Creek, Rouge River, Don River, Humber River) in Toronto. Despite an estimated 26% reduction in normalized road salt application loadings (as estimated in this paper), concentrations of chlorides in the Toronto-area rivers has not measurably declined (Perera *et al.* 2010). Road densities increased over that period, while weather patterns varied, and total loading of chloride to streams has continued to increase. The long-term groundwater concentration of chloride was, further, estimated to be approximately 275 mg/L, or high enough to pose risks to aquatic organisms under long-term exposure scenarios.

There has been no calculation of the fraction of Canadian surface waters that will benefit from the implementation of the Code of Practice. Impacts are, currently, anticipated in heavily urbanized areas with high road densities, and in particular in surface waters that have low dilution (i.e., small watersheds or catchments) draining major roadways. The ecological benefits of implementation of the Code of Practice, therefore, are anticipated to primarily occur in the most densely populated urban areas where high chloride levels presently occur (Mayer *et al.* 1999; Morin & Perchanok 2000). The ecological benefits of the Code of Practice are, thus, most likely to occur in a relatively small fraction of the total land area in Canada.

The magnitude of the ecological benefit estimated here (14% of taxa) can be re-expressed in real numbers if we consider the number of species that might naturally occur in a watercourse. Of the some 10,000 aquatic species that occur in watercourses in North American (Morton & Gale 1985; Pennack 1989), inventories in Canadian waters typically produce about 100–200 individual taxa in a 'healthy' system if we consider fish, benthic invertebrates and macrophytes. If the calculations are correct, and implementation of the Code of Practice resulted in a reduction in chloride load of some 26%, and there was a benefit to some 14% of possible taxa, then the number of taxa in the watercourse may increase by as many as 14–28 taxa. Such an increase in diversity is clearly measurable assuming a statistically robust study design (EC 2002).

The ecological benefits of the Code of Practice may however be masked by other stressors. The ecological benefit from reducing chloride levels assumes that other 'urbanization-related' stressors are not also limiting the ecological diversity of a surface-water feature. Many urban centers, however, do release contaminants other than road salt into aquatic receiving environments. Metals and hydrocarbons, in addition to chlorides, contaminate runoff from roadways, at concentrations that are toxic to aquatic ecological receptors (Murakami *et al.* 2008). Nutrients, suspended particulate material, and pesticides from urban areas also enter surface waters (via stormwater runoff and treated sewage) at concentrations that pose additional risks to aquatic organisms (EC 2001). Storm flows from urban areas can also be erosive, leading to changes to physical stream habitats, and associated losses of the critical habitats of some species. The loss of riparian cover within watersheds leads to alterations in the hydrological cycle (greater storm flow volumes, increase in frequency of stream flashiness), which can lead to an increase in erosivity within watercourses (Booth & Jackson 1997). The lack of riparian zones further leads to increasing solar inputs to streams, resulting in warmer summer temperatures (Barton *et al.* 1985). There is thus the real potential that reductions in chloride levels will not result in real, measurable ecological benefit because of masking by other stressors. The masking effect is, however, hard to predict or quantify because we have a generally limited specific understanding of the tolerances of individual aquatic species to the numerous and various stressors that are present in urban system (see Stanfield & Kilgour (2006), for example).

We predict, herein, in the short term it is unlikely that we will observe any measurable and apparent ecological benefit of the Road Salt Code of Practice. Many watercourses, in the most salt-impacted regions (i.e., Toronto-area watershed, Mayer *et al.* (1999)), are already additionally impacted by other various urbanization related stressors. Increasing urban expansion and road densification is, further, leading to overall increases in chloride concentrations in surface waters. Further, although the Code of Practice is being implemented by many municipalities in Canada, it does not apply to commercial snow-plowing operations. Environment Canada considers it likely that commercial operators use larger amounts of salt to clear snow and ice from parking lots than typical municipal agencies would or do, in part because the commercial operators are compensated on the basis of use (Stone & Marsalek 2011). The lack of immediate ecological benefit should, however, not be used as an excuse to not implement the Code. The analyses here demonstrate that implementation of the Code of Practice will lessen the effects from what they might otherwise become as urban areas expand and road densities increase. Second, arguing that we should not address known risks associated with one substance because there are other known risks associated with another substance sets a dangerous precedence that could perpetuate risk legacies. The areas within which road salts pose significant ecological risks in Canada are relatively small and localized (i.e., to those areas that are heavily urbanized like the City of Toronto; Mayer *et al.* 1999). There are large areas in Canada where the risks associated with road salts can be considered negligible to the point that implementation of the Code of Practice would have a negligible benefit to ecological receptors. Kaushal *et al.* (2005) recently examined the association between chloride concentrations and percent imperviousness. They demonstrated, for watercourses in Baltimore that chloride concentrations in surface waters were generally <100 mg/L when percent imperviousness was <10–15%. That relationship could be used as one of several potential rules of thumb to identify areas where road salts are likely to pose a negligible risk to aquatic receptors.

CONCLUSIONS

The Code of Practice appears to have contributed to a reduction in the ‘normalized’ road salt application by about 26%. Despite increasing urbanization and densification of road networks, a 26% reduction in normalized application means in the long term that chloride levels will at least not be increasing by that amount. SSD in contrast predicted between 1 and 14% of taxa would benefit from a 26% reduction in chloride concentrations in surface waters. Thus, the Road Salt Code of Practice can be expected to benefit up to 14% of potential freshwater taxa over the long term. We predict that we will not in the near term observe ecological benefits of having implemented the Code of Practice because: (1) road salts pose ecological risks in limited areas (i.e., densely populated urban areas in southern parts of the country); (2) other urban stressors are expected to mask small ecological benefits associated with small reductions in chloride loads; (3) chloride loadings and concentrations are generally increasing in association with increasing urbanization. The lack of observed ecological benefit should not be used as an argument to not implement the Code of Practice in areas where road salts clearly pose risk to aquatic organisms.

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