The impacts of chloride concentrations on wetlands and amphibian distribution in the Toronto region

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Abstract: Declines in amphibian populations on global, national and local scales have been widely observed. Factors that influence amphibian decline include increased UV radiation, bacterial and fungal infections, and habitat loss. In Canada, habitat loss is the dominant factor in decline yet very few investigations have considered the effects of chloride concentrations on such habitats. In the past, it has been assumed that salts wash out of watersheds with spring runoff and have minimal impact on waterways. This paper reports on an intensive study of three wetlands in the Humber River watershed and a one-time sampling of 22 wetlands across the Don River watershed. Patterns of chloride concentration over the amphibian-calling season were assessed. Amphibian call monitoring was used to explore possible links between chloride concentrations in wetlands and the distribution of amphibians. Chloride concentrations in the Humber River wetlands increased throughout the spring and summer. Higher chloride concentrations were found with increased proximity to roads that received de-icing salts. When amphibian-monitoring results were correlated with chloride concentrations, amphibian abundance and diversity were consistently low in all wetlands where chloride levels exceeded 200 mg/l. Results indicate that chlorides may accumulate in wetlands from year to year and that the seasonal increase in chloride concentrations in wetlands may adversely affect the distribution of mid to late-breeding amphibian species.

Key words: amphibian decline, de-icing salts, metapopulations, call monitoring, wetland chloride concentrations

Introduction

Road de-icing salts are major contaminants in runoff from road surfaces. Of the pollutants found in roadway runoff, salts are the most cost-effective to monitor and, thanks to current de-icing technology, the most realistic to reduce. The diversion or collection of roadway runoff and the careful location of new highways has long been recommended (Pollock and Toler 1973), and models are available to predict the environmental effects of chemical pollution (Chandler and Luoto 1973). Although some of these recommendations have been incorporated into current de-icing practices, the cost of environmental effects are still not sufficiently considered. In the metropolitan area of Toronto alone, an annual average of 100,000 tonnes of de-icing salts are used to maintain bare pavement conditions during winter months (Howard and Haynes 1991). The majority of de-icing salts are transported by highway runoff into roadside soils and adjacent streams. This results in elevated concentrations of sodium and chloride in the Humber and Don River watersheds throughout the spring runoff season and summer months (Scott 1979). Initially, it was believed that most de-icing salts were washed out of watersheds during spring runoff. However studies by Howard and Haynes (1991) and Howard and Beck (1993) have revealed that approximately 55% of de-icing salts applied to roadways is retained within drainage basins. Moreover, salt concentrations in Toronto region waterways tend to increase with urban density (Scott 1976). Despite this knowledge, little is known about the extent of wetland contamination by road de-icing salts and the effects of salt levels on amphibian populations in the Toronto region.

Salts are released to groundwater in pulses after each rain event and fluctuations are seasonally cyclic, increasing in chloride until a balance between salt recharge and the continuous flushing and dilution by groundwater is reached (Weigle 1967). Sodium chloride de-icer is composed of 39.3% sodium and 60.7% chloride, while calcium chloride is made up of 36.1% calcium and 63.9% chloride (Schraufnagel 1967). Chloride is an essential micronutrient for plants but it is toxic in excessive amounts (Schraufnegel 1967; Prior and Berthouex 1967). Plants absorb de-icing salt elements and suffer from leaf burn, premature defoliation and terminal growth dieback (Hanes *et al.* 1970; Pedersen *et al.* 2000; Bryson and Barker 2002). In solution, the elements of de-icing salts become associated with the soil through adsorption or ion exchange (Prior and Berthouex 1967; Pollock and Toler 1973). Dissolved salt also acts as a weak electrolite and affects the conductivity of the aquatic system (Adams 1973). Excessive levels of sodium can result in reduced drainage of soils (Hutchinson and Olson 1967; Howard and Beck 1993; Lofgren 2001).

Amphibians are particularly sensitive to habitat destruction and fragmentation due to the reliance of most species on metapopulation structures. Networks of ponds and wetlands allow amphibians to migrate for breeding purposes, thus helping to maintain genetic diversity in amphibian populations, and also to survive during times of drought. Fragmented habitats, especially those near urban centres and surrounding rural areas, are often affected by contamination from rural and urban highway runoff that renders these habitats inhospitable for amphibians.

The effects of salt concentrations on the development of amphibians are reasonably understood. Anderson and Zotterman (1950) found that exposing some frog species to bathing solutions of as little as 0.05% NaCl initiated a change in osmoregulation. Exposure to high salt concentrations stresses the osmoregulatory systems of amphibians since their ability to maintain ion balance is limited. Skin resistance and concentration potential lower with the exchanges of sodium and chloride ions being independent of each other (Taylor and Barker 1965; West and Van Vlict 1992). Christy and Dickman (2002) reported significant increases in larval mortality and decreasing growth rates with increasing salt concentrations in one amphibian species. Unlike adult amphibians, larvae and embryos are incapable of active ion transport to maintain a positive ion balance. Other studies have investigated the effects of salt on embryonic development in water with low pH (Freda and Dunson 1985; Gascon and Planas 1986). There is also evidence that some amphibian species avoid breeding sites with high salt and chloride concentrations (Viertel 1999).

Despite these findings, few studies have examined the effects of de-icing salts on the distribution of amphibians (Brinkman 1999; Turtle 2000). It is possible that high salt concentrations from road salt runoff could be a factor in the absence of amphibians in some potential wetland habitats around the Toronto region. This study set two main objectives: 1) to assess patterns of chloride concentrations in Toronto region wetlands in relation to the use of road de-icing salts; and, 2) to examine the distribution of amphibians in Toronto region wetlands in relation to chloride concentrations.

Site description

The study was based primarily on intensive observation of three wetland sites (A, B and C) located north of Toronto near King City in the Humber River watershed at 43° 55' North and 79° 31' West (Figures 1 and 2). Criteria used to choose the wetlands included size, low urban density and proximity to main or secondary roads. The rationale behind the use of these criteria was as follows: larger wetlands would be more likely to support greater numbers and diversity of amphibians for study; low urban

Figure 1: *Location of the intensively studies wetlands in the Humber River watershed (Source: TRCA in press).*

density would reduce the occurrence of other sources of chlorides such as combined storm sewer outlets; and, proximity to main roads was needed to evaluate the impact of road de-icing salts as a source of chlorides in wetlands. Physiographically, the wetlands fall within the South Slope region of the Oak Ridges Moraine at elevations that range from 246 to 308 metres. The soils are largely composed of clay covered by a thin organic layer.

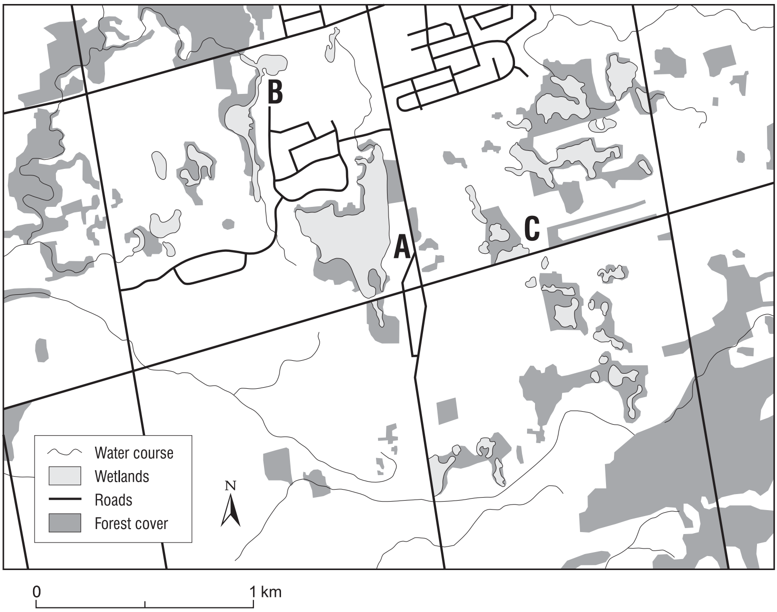


Figure 2: *Detail of the intensively studies wetlands in the Humber River watershed indicating wetlands A, B and C (Source: TRCA data base).*

Due to the high clay content in the soils, the area has a low susceptibility to groundwater contamination (Environment Canada 1979). The land-use history of the area is rural, with little residential development. A larger set of 22 wetlands located throughout the Don River watershed was also visited, but only once (Figure 3). The latter sites were consistent with those used for the Amphibian Monitoring Program of the Toronto and Region Conservation Authority (TRCA).

Methodology

The link between road salt contamination of wetlands and amphibian distribution was explored in two ways. First, thre wetlands located in the headwaters of the Humber River watershed (Figure 1), were investigated to establish seasonal patterns of salt contamination and amphibian occurrence. The second part of the study was based on a one-time sampling of wetlands in the Don River watershed. This included sites in rural areas of the greater Toronto region as well sites in the city core (Figure 3). This

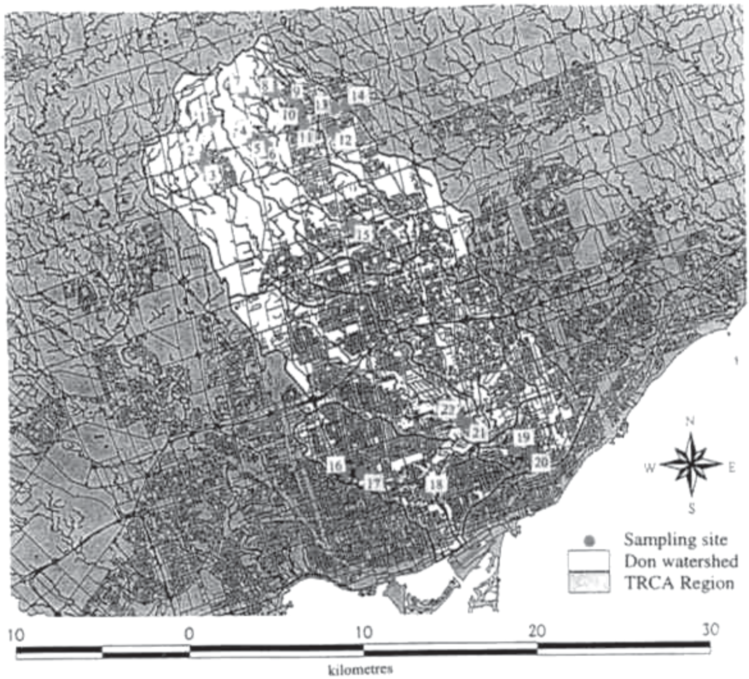
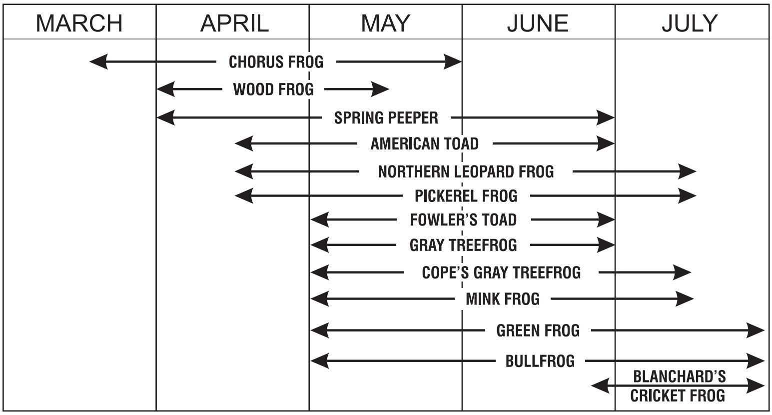


Figure 3: *Location of the 22 wetlands sampled in the Don River watershed (Source: TRCA in press).*

portion of the study examined salt contamination and amphibian distribution at the watershed level and incorporated data from TRCA's community-based Amphibian Monitoring Program.

Both components of the study used data on call monitoring of amphibians collected by TRCA from 1997 to 1999 as well as monitoring by the author during each site visit. These data were used to determine the species richness at each study site. Call monitoring by TRCA was conducted in the evenings when calling species tend to be most active. Call monitoring volunteers were encouraged by TRCA to visit their sites at least three times in a season. The first visit was made to record early breeding species and took place between mid-April and mid-May when the average daily temperature was greater than 5°C. The second visit was made between mid-May and mid-June when the temperature was above 10°C and when mid-season breeders could be monitored. The final visit



Source: Long Point Bird Observatory, 1996.

Figure 4: *Approximate breeding seasons for amphibian species of the Great Lakes Region (Source: Long Point Bird Observatory 1996).*

was made between mid-June and late-July when it was warmer than 17°C and when only late breeding species would be active. Figure 4 shows the approximate breeding periods for frogs and toads of the Great Lakes region. Weather and precipitation data for the three wetlands were purchased from Environment Canada.

The breeding calls of amphibians are very species specific. With some practise using tape-recorded calls, species can be easily identified. Following TRCA call monitoring methods, calls were assigned a rating of approximate abundance. Code 1 was used to indicate that only a few amphibians were present and that the number of calling individuals could be identified. Males will usually try not to call at the same time or call in close proximity to one another so that the females can hear them individually. Because of this, a few calling males of the same species can be located as well as accurately counted. Code 2 was used when several males were calling and their calls overlapped but the individuals could still be distinguished from each other. Usually calls can be distinguished and counted for up to 12 individuals depending on the species. Once the observer could no longer distinguish when one call began and another ended the calls were classified as a Code 3. Monitoring stations were established at each of the Humber River wetlands during each site visit. Call monitoring was conducted in the evenings at each site visit before water sampling. All non-calling frogs observed were also recorded as present to establish species presence and absence at the study sites.

During the first visits to the Humber River wetlands a water level mark was erected at each of the three sites so that changes in water level could be recorded throughout the spring and summer. At each visit, changes in water level from the previous visit were recorded and water samples were collected for chloride analysis. Samples were taken along transects so that the patterns of chloride movement over time could be established. Distances between transects were dependent on the size and shape of the wetlands. A piezometer nest was installed in each of the three wetlands to sample subsurface water. These piezometers consisted of 1.25 cm PVC pipes with a 20 cm slot zone covered with nitex mesh to prevent siltation at depths of 0.5 and 1.5 m. Shallow groundwater was sampled in August from the piezometer using a polypropylene syringe. Amphibian presence, as recorded through call monitoring and observation, was also recorded and mapped at each visit.

In mid-July 1999 a one-time sampling of the 22 wetlands in the Don River watershed was conducted from the headwaters north of the city, where urban density is very low, to the city core. Each sample site corresponded with a TRCA call monitoring station used between 1997 and 1999. Water samples were collected at one to three locations per wetland depending on the size and number of TRCA monitoring sites per wetland. The purpose of this was to determine if higher chloride levels were present in parts of the same wetland where amphibians were absent. Samples were transported to the laboratory and analyzed for chloride concentration using standard techniques on a Technicon Autoanalyser System (Environment Canada 1979). Distance from each of the 22 sampling stations to the nearest upstream road was measured on a topographical map.

Amphibian call counts, codes and the numbers of species were totalled for the monitoring period from 1997-1999 since not all wetland sites were monitored each year. The highest individual count and call code for each species during the three-year period was used to represent the amphibian abundance for each site. It was assumed that amphibian populations did not experience any severe fluctuations in population size over the time period. The highest call code is indicative of the highest potential abundance of amphibians. Where a call code was 3, the maximum number of identifiable individuals, a count of 12 was recorded. At no time was a chorus so loud as to imply that there were many more than 12 calling individuals.

The relationship between the amphibian data and chloride levels in the wetlands was analyzed using three variables, namely, amphibian abundance, the diversity of species and the sums of the call codes. For each site, the highest number of calls and sightings over the three-year period was used to represent the maximum-recorded number of individuals of each species. The highest recorded number for each species was then added in order to give the most optimistic representation of the quantity of amphibians present. The highest numbers of individuals were consistently recorded in the early breeding species *Pseudacris crucifer* and *Bufo americanus* (American toad). Four wetland sites (10, 12, 17 and 20) were found to have no amphibians.

Results and discussion

The 1999 spring and summer season was dryer and hotter than average. From March to July precipitation was 8% below average while temperatures were 1.5°C above average. Between April and July temperatures were 2.0°C above average. This resulted in the evaporation of water at many of the wetland sampling sites throughout the season and the intensified concentration of the chlorides that remained in the wetlands. Relatively dry conditions meant that rain events did little to influence the results.

Humber River watershed sites:

All three intensively studied wetlands showed spatial trends in chloride concentrations. The highest concentrations were consistently found closest to the nearest upstream road implying that road de-icing salt runoff was the main source of the chlorides. The variability of the chloride levels was high in early spring in the three wetlands with values ranging from 9.1 mg/l to 910 mg/l. Before seasonal snowmelt, the wetlands had average chloride values of 146 mg/l (wetland A), 44 mg/l (wetland B) and 32 mg/l (wetland C). By May, when surface waters were at a maximum and most of the strong seasonal runoff had occurred, the average chloride concentrations were 179 mg/l (wetland A), 108 mg/l (wetland B) and 301 mg/l (wetland C). By the end of the season the averages for wetlands A, B and C were 517 mg/l, 118 mg/l and 311 mg/l respectively. This indicated that chlorides did indeed remain in the wetlands from one season to the next and did not wash out with seasonal runoff (Figure 5).

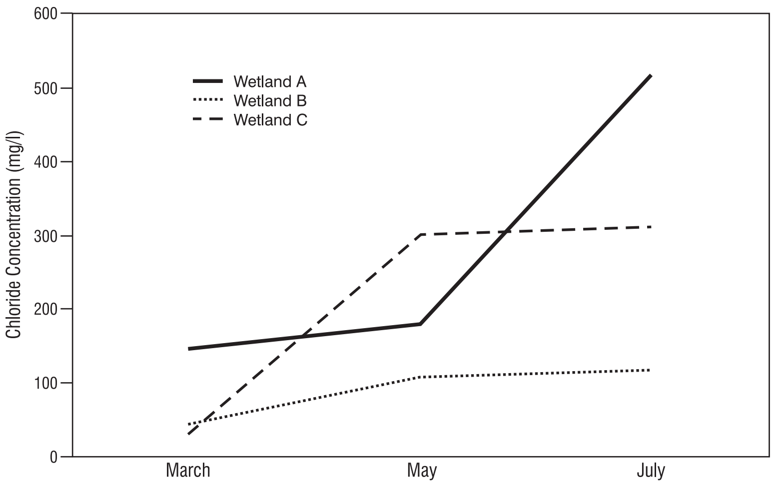


Figure 5: *Average chloride concentrations for wetlands A, B and C in the Humber River watershed for March, May and July.*

It is likely that a wetter season would result in lower chloride concentrations in the summer, however, the presence of chlorides in the wetlands in early spring and the high chloride levels after spring runoff indicate that even during a wet season, it is unlikely that the majority of the chlorides would be washed out of the wetlands. At the last sampling date in August, de-icing salt residue was still visible at the roadsides and likely continued to release chlorides into the wetlands with each rain event as elevated concentrations were observed after rain events.

Early breeding species such as *Rana sylvatica* (Wood frog) and *Pseudacris crucifer* (Spring peeper) would not be as susceptible to the increase in concentrations throughout the season since they tend to finish breeding and leave the wetlands by the end of the spring. The most abundant species heard and observed at all three wetlands were *Rana sylvatica* and *Pseudacris crucifer* with a few *Rana pipiens* (Northern leopard frog) seen across the wetlands.

Chlorides were found in high concentrations in subsurface water to a depth of 1.5 m in the Humber River wetlands in August 1999 (Table 1). The clay-rich soils underlying the wetlands inhibit the flushing of the system resulting in the prolonged retention of chlorides. The higher concentrations of chlorides at shallower depths suggest that the chlorides are entering the wetlands in surface runoff and are infiltrating downwards in the wetland

Table 1: *Chloride concentrations at groundwater sampling sites.*

	Depth = 0.5 m		Depth = 1.5 m	
	Cl concentration (mg/l)	Water level (cm)	Cl concentration (mg/l)	Water level (cm)
wetland A	194	40	132	90
wetland B	185	45	131	100
wetland C	132	45	110	90

soils. This is further supported by the fact that the water levels were consistently deeper in the 1.5 m piezometers as compared to 0.5 m piezometers. Evidence of elevated chloride levels to depths of at least 1.5 m suggests that even if the use of de-icing salts is reduced, water in these wetlands will continue to show high chloride level for many years.

TRCA call monitoring data from 1997 indicated that both *Rana sylvatica* and *Pseudacris crucifer* were present on the eastern edge of the wetland A. Monitoring results from 1999 show that both species were absent from that portion of the wetland and present only in very small numbers in the western part of the wetland. Adult *Rana sylvatica* at wetland A appeared to be tolerant to chloride concentrations as high as 171 mg/1 while the one *Pseudacris crucifer* heard was in an area where the chloride concentration was 118 mg/l.

At wetland B frog calling was very localized and only one species was heard. *Pseudacris crucifer* begins breeding early in the season and calling was most active before the occurrence of high chloride concentrations in the wetland. These chlorides may have originated from upstream. Breeding likely finished before concentrations exceeded 120 mg/l. The one leopard frog observed indicated the presence of the species at wetland B, however there was no calling evidence of breeding activity.

Rana sylvatica were heard and observed at wetland C over the spring breeding season. All calls recorded were at a Code 1 level with more adult frogs observed than heard. *Rana sylvatica* appeared to tolerate chloride concentration as high as 219 mg/l. As at wetland B, *Rana pipien*s were seen but not heard during the spring breeding season. When found, they were only on the south side of the road intersecting the wetland, where chloride concentrations were lower.

In early spring wetland areas that are still frozen inhibit water flow and contribute to variable chloride concentrations. Because of this it is possible that early breeding species are able to conduct breeding activity before higher concentrations of chlorides spread throughout the wetlands. The absence of calling evidence of breeding for mid and late-season breeding species indicates that these species possibly do not use these wetlands for breeding even though some individuals of mid and late-breeding species were observed.

Don River watershed sites:

In general, chloride concentrations were lower in the wetlands located in the northern upstream areas of the Don River watershed (Table 2). The wetland at sampling site 1 was an anomaly with a very high value of 700 mg/l. At this site only one sample was taken. The main source of chlorides at the site was likely a landfill located across the road from the wetland. Another anomaly was recorded at wetland site 16 where one sampling point indicated a chloride concentration of 505 mg/l while two other sampling points at the same wetland had chloride levels of 172 and 140

Table 2: *Don River watershed site data for riparian wetlands (RW) and ponds (P).*

Site	Wetland type	Chloride concentration	Distance upstream to nearest major road (metres)	Amphibian abundance	Species diversity	Sum of call codes
1*	P	700	5	0	0	0
2	RW	72	340	2	2	2
3	RW	72	400	1	1	1
4	RW	45	500	23	4	6
5	P	40	1,480	20	4	7
6	RW	37	2,300	26	6	9
7	RW	24	2,800	5	3	3
8	RW	25	3,600	4	3	3
9	P	51	750	3	1	1
10	RW	284	10	0	0	0
11	RW	74	810	4	1	2
12	RW	200	380	0	0	0
13	RW	262	500	1	1	1
14	RW	92	1,000	9	3	4
15	RW	91	1,150	9	5	5
16*	RW	272	1,330	4	1	2
17	RW	203	190	0	0	0
18	RW	146	350	18	3	5
19	RW	147	1,840	6	1	2
20	RW	148	840	0	0	0
21	P	134	900	24	2	5
22	RW	143	250	17	3	6

* not included in statistical analysis

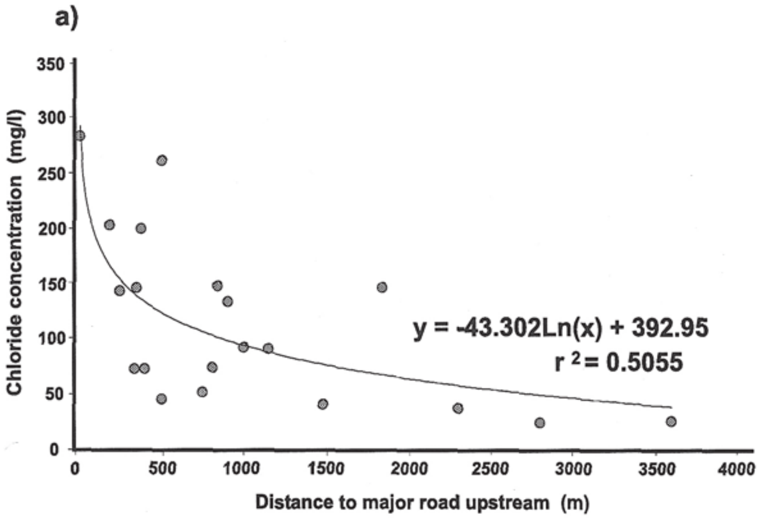
mg/l. The high value at this site was very localized and likely not the result of contamination from de-icing salt runoff.

Two wetlands sites (13 and 14) were joined by a stream that was crossed by a major roadway. One sample was taken upstream (site 14) and one downstream (site 13) of the road at equal distances from the road. The results were similar to those observed in the Humber River wetlands where the downstream side of the road had much higher chloride concentrations. One-time sampling at site 13 provided a concentration of 262 mg/l, while site 14 had a chloride concentration of 92 mg/l.

With regards to frog call monitoring, one disadvantage of the use of a community-based monitoring program is that the same sites are not monitored consistently from year to year. For this reason, species presence or absence was used to record abundance. Only long-term monitoring of urban wetland sites will determine accurate species richness of the amphibians present. Since many of the urban sites were visited only once and monitored through the TRCA Amphibian Monitoring Program for only one or two seasons, it is possible that more species were present at these sites but were not recorded.

Following log transformation of the data, a significant inverse relationship (r = -0.71, ± = 0.001) was established between chloride concentration and distance to the nearest upstream road. In related regression analysis 50.6% of the variation in chloride was accounted for by variation in distance (Figure 6a). This strong relationship may be explained by: 1) the accumulated salt residue on roadways (visible as late as August) being flushed into nearby wetlands with each rain event; or, 2) the relative lack of rain during the 1999 sampling season which would reduce the propensity of chlorides to be carried further into the wetland. Clearly distance is likely the single most important factor explaining variation in chloride concentrations. Nevertheless, since nearly 50% of the variation in chloride concentrations remains unexplained, factors other than distance should be considered in future research.

The relationship between the amphibian data and chloride levels in the wetlands was analyzed using three variables, namely, amphibian abundance, the diversity of species and the sums of the call codes. For each site, the highest number of calls and sightings over the three-year period was used to represent the maximum-recorded number of individuals of each species. The highest recorded number for each species was then added in order to give the most optimistic representation of the quantity of amphibians present. The highest numbers of individuals were consistently recorded in the early breeding species *Pseudacris crucifer*



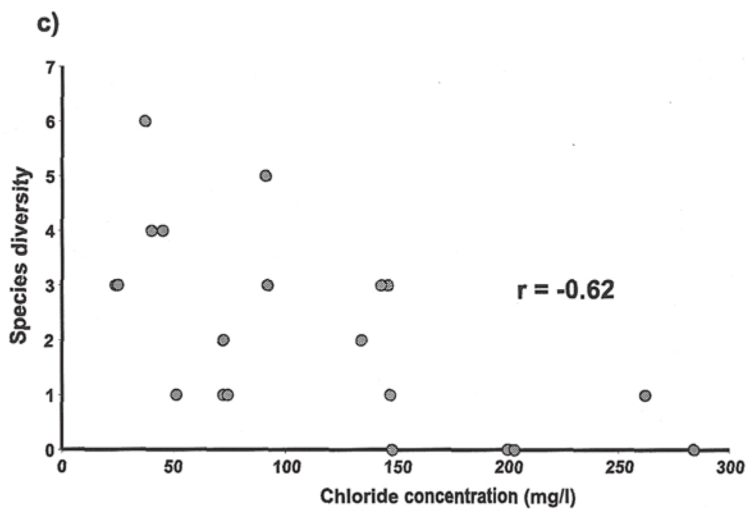


Figure 6 (a and b): *Scattergrams for relationships involving road distance, chloride concentration and amphibian distribution.*

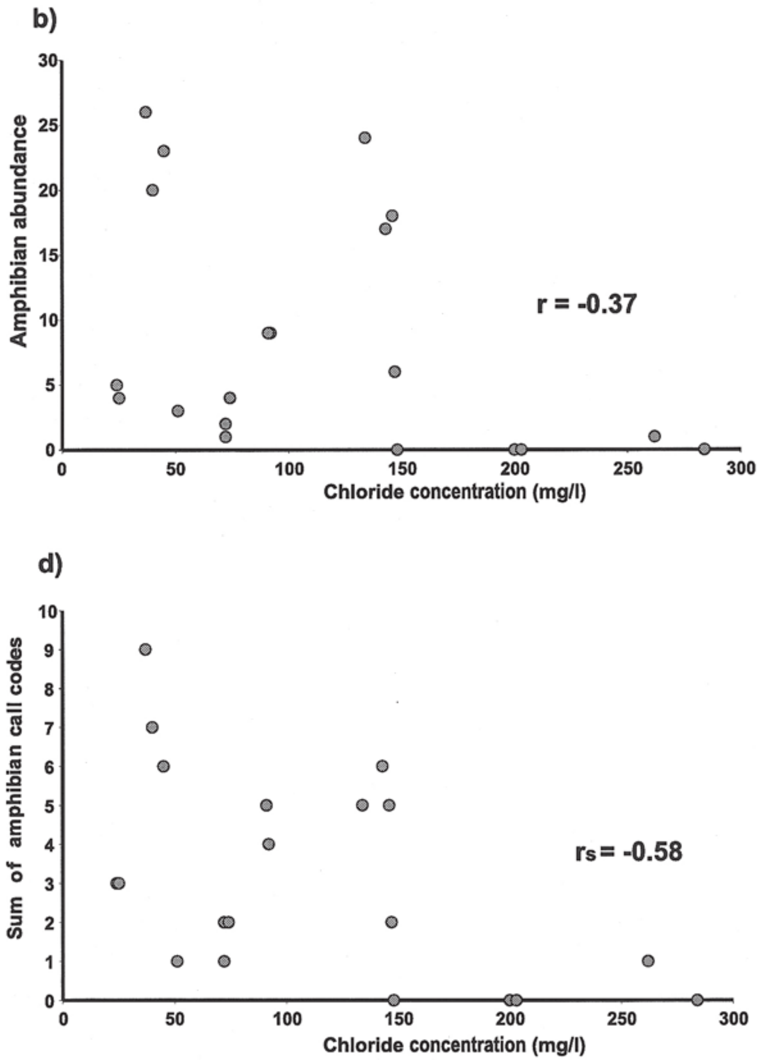


Figure 6 (c and d): *Scattergrams for relationships involving road distance, chloride concentration and amphibian distribution.*

and *Bufo americanus* (American toad). Four wetland sites were found to have no amphibians.

Regression analysis was not performed on the amphibian data as regression requires the independent variable (*x*) to be free from sampling error. As there was a possibility of sampling error when measuring chloride concentrations, correlation analysis alone was used. The relationships between chloride concentration and both amphibian abundance and diversity were analyzed using Pearson's product moment correlation. Due to the ordinal nature of the data on the sums of call codes, Spearman's rank correlation was used for that part of the analysis.

In general, amphibians were most abundant in wetlands located in the northern headwater areas of the Don River watershed where salt concentrations were lower. A significant negative relationship was established between amphibian abundance and chloride concentration (r = -0.38, ± = 0.05) (Figure 6b). There was no apparent link between the type of wetland and species diversity. However, a large wetland (site 5) and wetlands linked to greenway corridors (sites 6, 7, 8, 14 and 15) tended to have greatest species diversity. A strong negative relationship was established between amphibian diversity and chloride concentration (r = -0.63, ± = 0.01) (Figure 6c). In the analysis of call code sums both species abundance and diversity were incorporated into the call code classification. A significant negative relationship (r_s = -0.59, ± = 0.01) was established between call code sums and chloride concentration (Figure 6d).

Collectively the preceding results imply that road de-icing salt runoff has an impact on amphibian distribution. The linear correlation between amphibian abundance and chlorides was weaker than that between amphibian diversity and chlorides. This may be due to the highest numbers of amphibians being consistently found in early breeding species which tend to complete breeding activity before chloride levels rise. Although the numbers of amphibians heard or observed in 1999 were small, some results of individual species were consistent with trends observed at the Humber River sites. *Pseudacris crucifer* was only found in wetlands where chloride concentrations were less than 120 mg/l and *Rana sylvatica* was only found in wetlands with concentrations of less than 200 mg/l. The distribution and chloride tolerances of each species would have to be investigated in more detail before any conclusions could be made on individual species' tolerances to chlorides. All three measures of amphibians showed considerable scatter for chloride concentrations of less than 150 mg/l. However, these amphibian measures were consistently low in all wetlands where chloride levels exceeded 200 mg/l.

Many of the sites with high chloride levels were located in urbanized areas. In such settings there are numerous factors other than chloride pollution that can influence amphibian distribution via habitat fragmentation and loss. Consequently, whilst the relationships between wetland salt concentration and amphibian distribution are strong, it is possible that at least in urban areas other factors are equally important in explaining amphibian distribution.

Conclusions

Although the scope of this study was limited, some impacts of road de-icing salt runoff were apparent and were supported with statistical evidence. At the Humber River sites, water samples were found to contain higher chloride concentrations with increased proximity to roads. The patterns observed indicated that road de-icing salt runoff is a major source of chlorides in these wetlands. Groundwater chloride levels taken late in the summer indicated that chlorides do not wash out of the wetlands with spring runoff. The persistence of high chloride concentrations throughout the amphibian-breeding period appeared to affect the distribution of some amphibian species.

Results of correlation and regression analyses for the Don River sites pointed to significant relationships between road salting and chloride levels, and between chloride levels and amphibian distribution. The study indicated that some species of amphibians have higher tolerances to high chloride concentrations than other species. Specifically, *Rana sylvatica* and *Pseudacris crucifer* were found only in areas where chloride levels were below 250 mg/l. Both species are early breeding amphibians and finished using the wetlands for breeding before chloride concentrations exceeded this level. Intolerance of high chloride concentrations (over 250 mg/l) is undoubtedly one reason why other, later breeding species were rare or absent in wetlands large enough to support substantial amphibian populations.

The study represents one step in determining the full environmental impacts of road de-icing salts on the contamination of wetlands and the distribution of amphibians in the Toronto region. Results of the study suggest a need for comparative research in areas with different levels of urbanization and for assessment of salt contamination in the context of other roadway pollutants and environmental stress factors. The effect of environmental degradation on individual species and the relationship between specific environmental events (e.g., a severe rainstorm) and wetland contamination also need to be addressed. Finally, the study reveals that much still needs to be accomplished in protecting the Humber River and Don River watersheds from pollution by road de-icing salt.

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