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Winter Climate Variability, De-Icing Salt and Streetside Tree Vitality

Justin Miron[1], Andrew A. Millward[1], Maryamsadat Vaziriyeganeh[2], Janusz J. Zwiazek[2] and James Urban[3]*

[1] Urban Forest Research and Ecological Disturbance (UFRED) Group, Geography and Environmental Studies, Ryerson University, Toronto, ON, Canada, [2] Department of Renewable Resources, University of Alberta, Edmonton, AB, Canada, [3] Urban Trees + Soils, Annapolis, MD, United States

De-icing salts are applied to roads and walking surfaces to mitigate winter hazards resulting from ice, snow and freezing rain. The vitality of streetside trees, especially those growing in densely built urban areas, is compromised by repeated exposure to de-icing salts. Such trees already experience unfavorable establishment and growing conditions resulting from poor soil quality, inadequate moisture, physical abuse and air pollution—exposure to de-icing salt aggravates these challenges and can be an essential catalyst in tree mortality. Climate change is creating less predictable weather and, in some cases amplifying the intensity of winter storms. Cities that undertake snow and ice management may adopt modified approaches, and those less familiar with this practice may require its episodic adoption. We identify three pathways by which future climate warming may, counterintuitively, result in cities increasing their use of de-icing salt: (a) Warming winter temperatures in cities that were historically too cold to make effective use of sodium chloride (NaCl) for de-icing; (b) cities where daily high temperatures in winter may increase the frequency of freeze-thaw cycles; and, (c) cities in North America and Eurasia that may experience more severe winter weather resulting from greater variability in the circumpolar vortex (CPV). To offset potential damage to existing urban streetside trees and to ensure adequate soil and growing conditions for future trees, there is an immediate need for city foresters to collaborate with traffic safety and public works departments. We present a toolbox of approaches that can facilitate synchronized management efforts, including identifying the location of existing vulnerable trees and re-envisioning future infrastructure that would mitigate tree exposure to de-icing salts. At the same time, we call for the prioritization of research that investigates new potential pathways along which climate change may contribute to the novel adoption of de-icing salts.

Keywords: urban forest, city, climate change, pollution, winter storms, toolbox, management

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Dustin Herrmann,
University of California, Riverside, United States

****Correspondence:***
Andrew A. Millward
millward@ryerson.ca

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INTRODUCTION

In this perspective article, we present the case for potential increases in the application of winter de-icing salt in some areas of the Northern Hemisphere, despite clear trends in global atmospheric warming and generally milder winter temperatures. Our assertion is independent of the potential of other regions, ones that have historically relied on de-icing salts, to lessen application frequency in the future. Moreover, creating a ledger predicting global de-icing salt application is beyond the scope of this perspective. While de-icing salt is a known toxin to many plants (Equiza et al., 2017), our focus is on its impact on city trees (specifically effects of sodium chloride, NaCl). As integral components of urban ecological systems (Gaston et al., 2013; Duinker et al., 2015), city trees deliver numerous environmental benefits, including flood moderation, summer temperature attenuation, and improved air quality (Solecki et al., 2005; Roy et al., 2012). Moreover, they are essential to the mental wellbeing of urban residents (Donovan et al., 2013) and, in aggregate form, tree benefits have important monetary value, including energy conservation and flooding prevention (McPherson et al., 2011). At the same time, increases in demand for urban real estate have caused building densification and expansion of roads and pedestrian surfaces (Eigenbrod et al., 2011; Touati-Morel, 2015), thereby crowding out trees. Therefore, most dense urban areas integrate tree plantings adjacent to pedestrian and vehicular streets (Limoges et al., 2018); however, the growth of streetside trees is challenged by exposure to numerous stresses typically not associated with more naturalized urban areas (Gillner et al., 2016).

In cities that experience winter conditions, streetside trees and their soils are regularly exposed to and contaminated by de-icing salts used to improve vehicular and pedestrian safety. When considered in combination with the typically harsh growing conditions most city streets experience (Mullaney et al., 2015), exposure to de-icing salt can tip the balance in favor of tree mortality (Ordóñez-Barona et al., 2018). Therefore, it must be the responsibility of winter ice management operations, both public and private, to explore and embrace opportunities and approaches that prevent or ameliorate the harmful effects of salt contamination in urban soil. Moreover, collaborating with urban forestry managers, winter maintenance operations could triage resources by identifying priority salt-vulnerable treed streets coincident with assets and infrastructure that must be kept ice-free in winter. In these places, the targeted application of alternative de-icers, the selection of salt-tolerant tree species, and the integration of tree vegetation into a more expansive and protective network of green infrastructure (GI) would all serve to improve tree vitality and buffer against the mounting challenges of climate change in urban centers.

Snow and ice control are critical to maintaining safe road and sidewalk conditions. Hence, large quantities of solid and liquid chemicals (for de-icing or anti-icing, collectively known as de-icers) are now applied on paved surfaces in winter months to improve traffic and pedestrian safety. In many cities, urbanization has progressed around the requirements for personal automobiles (Pucher, 1988; Dargay et al., 2007). One such provision includes extensive paved surfaces both for driving and parking. In the mid-latitudes, winter weather (snow, freezing rain, sleet) is a common inconvenience for motorists and poses an essential threat to public safety. Perhaps the greatest danger to the motorist during winter conditions is when precipitation adheres to the pavement, forming ice (Andrey et al., 2013; Black and Mote, 2015).

Large-scale application of de-icers occurred in the United States northeast in the late 1930s (USEPA, 1999); following this, winter "bare pavement" policies soon became common across much of North America (USEPA, 1999; Rubin et al., 2010). Because de-icing salt was cheap and readily available, the approach of "if a little is good, more is better" became the *de facto* application standard. An early study by Kuemmel and Hanbali (1993) with North American data showed an average reduction in automobile accident rates based on de-icing salt application was 87% for two-lane undivided highways and 78% for freeways. With findings like these, the view that roads should be free of snow and ice has permeated the public psyche in North America—now a societal expectation that applies to most paved surfaces, including sidewalks and pedestrian paths, in global cities that experience winter weather (Fekete et al., 2021; Gerasimov et al., 2021).

Chloride-based salts are the most used de-icer by roadway agencies (Fay and Shi, 2012). Of these, sodium chloride (NaCl) has been the most widely used chemical to melt ice (and prevent its formation) due to its low cost and high abundance (Ramakrishna and Viraraghavan, 2005). However, calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) perform better as a de-icer at lower temperatures than NaCl (Shi et al., 2009). The effective minimum temperatures for $CaCl_2$, $MgCl_2$, and NaCl are –25°C, –15°C, and –10°C, respectively (Fay and Shi, 2012). $CaCl_2$ and $MgCl_2$ are used in road and sidewalk anti-icing practices by applying them before the onset of a snow event, where the first 1 or 2 cm of falling snow in contact with the road surface or sidewalk will melt. These anti-icing agents prevent black ice formation by weakening the bond between ice and road surface.

CLIMATE CHANGE MAY CREATE AN INCREASED NEED FOR DE-ICERS

A warming climate has produced less predictability in the location, intensity, and duration of winter weather events (O'Neill et al., 2017; Ummenhofer and Meehl, 2017). Urban areas are particularly vulnerable to weather irregularity as much of their infrastructure is designed around the probability of occurrence (e.g., 100-year events) (Henstra, 2012; Bulkeley and Tuts, 2013). In North America and Eurasia, average daily December, January, and February (DJF) temperatures have generally increased in the last century (Cohen et al., 2014). Additionally, winter freeze-thaw events show increased frequency in locations that once had daily high temperatures just below freezing (Sinha et al., 2010; Brown and DeGaetano, 2011; Vincent et al., 2018; Wang et al., 2020). Moreover, extreme winter storms, driven by instability in the circumpolar vortex (CPV), are predicted to occur more frequently in the United States central Midwest and northern Europe and Russia (Cohen et al., 2021). Each of these three pathways (**Figure 1**) may lead to the increased application of winter de-icing salt.

Figure 1—Pathway A identifies increases to daily DJF temperatures in Northern Hemisphere cities located at higher latitudes that motivate a shift toward increased use of NaCl because it is the least expensive and most easily administered of the de-icing options (Cunningham et al., 2008). Unfortunately,

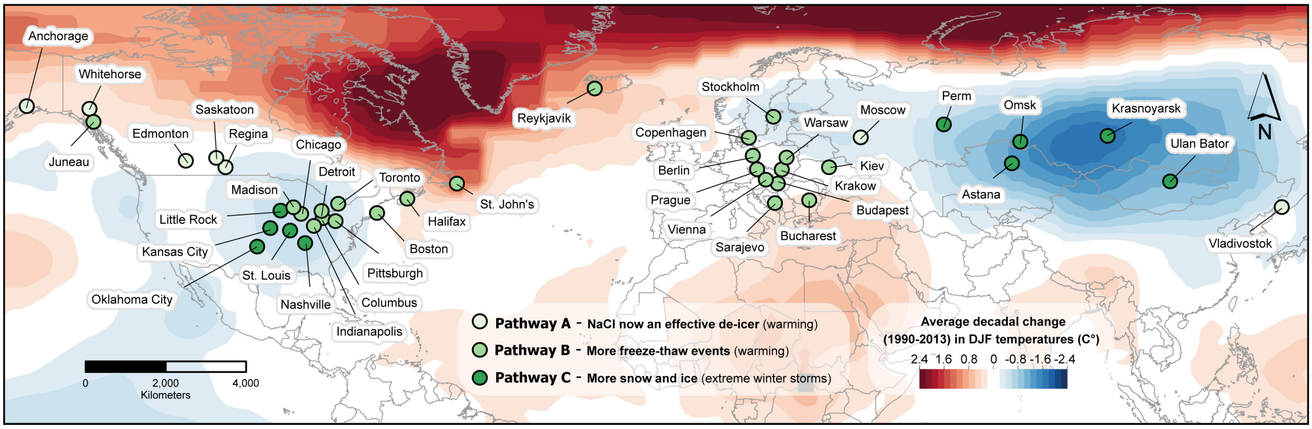

FIGURE 1 | Three pathways by which future climate warming may, counterintuitively, result in cities increasing their use of winter de-icing salt: **(A)** Warming winter temperatures in cities that were historically too cold to make effective use of sodium chloride for de-icing; **(B)** cities where winter daily high temperatures may increase the frequency of freeze-thaw cycles; and, **(C)** cities in North America and Eurasia that may experience more severe winter storms resulting from greater variability in the circumpolar vortex. Cities are selected to be representative locations for each scenario and do not constitute an exhaustive list. Locations experiencing Pathway B may also be subject to Pathway C. Temperature surface adapted from Cohen et al. (2014).

NaCl is also the most damaging of the de-icers to plants, and more broadly, ecosystem function (Czerniawska-Kusza et al., 2004; Kramberger and Žerovnik, 2008). NaCl is only effective as a de-icer (or anti-icer) at ground surface temperatures (working temperatures) between 0 and −15°C (Environment Canada., 2001), and most municipal operations define the low as −10 (Fay and Shi, 2012). In Edmonton, Alberta, Canada, annual January temperatures have risen 4.2°C in the last century (1920–2020), where average January high and low temperatures (2007–2017) were −6.3 and −14.8°C, respectively (Government of Canada., 2021). This brought diurnal temperatures into the range where NaCl can be effective; its use has recently been endorsed in de-icing policy by the Edmonton city council (Cook, 2020). Similarly, in Anchorage, Alaska, United States, winter warming has seen temperatures increase by 1.9°C (1954–2020), where average January high and low temperatures (2010–2019) were −3.7 and −10.1°C, respectively (NOAA, 2021), making NaCl an effective de-icer. For the last decade, Anchorage has been using NaCl as part of its winter de-icing operations (Alaska Department of Transportation and Public Facilities, 2014). On average, the sample of cities identified in Pathway A has had January average temperatures increase by 3.5°C [standard deviation (SD) = 0.84°C] between 1920 and 2020 and now are reaching average daily temperatures of −11.0°C (*SD* = 3.4°C) where NaCl can be an effective de-icer.

A sample of cities wherein winters were historically cold enough to prevent daily high temperatures from climbing above freezing in January, causing snow and ice melt, are identified in **Figure 1**—Pathway B. When temperature increases to the point where ice and snow melt and then refreeze during a 24-h period, a freeze-thaw event is said to have occurred (Baker and Ruschy, 1995; Ho and Gough, 2006). Such events are particularly hazardous to motorists and pedestrians because they manifest in rapid state changes of water. The freezing event can quickly create unpredictable traction between tires or footwear and a paved surface. Freeze-thaw cycles can also have critical damaging impacts on road infrastructure resulting from the repeated expansion and contraction of water volume (Hershfield, 1979; Kraatz et al., 2019). Early studies of freeze-thaw changes suggested that a warming climate would generally reduce their frequency (Intergovernmental Panel on Climate Change (IPCC), 1997). However, more recently, this outcome has been identified as less certain and, most importantly, geographically variable (Ho and Gough, 2006; Henry, 2008; Mekis et al., 2020; Tropea and Stewart, 2021). Furthermore, a study conducted in Finland found that warming temperatures in the mid-winter months of DJF resulted in a greater application of de-icing salt (Venäläinen, 2001). For the sample of cities identified in Pathway B, average January temperatures have increased between 1920 and 2020 by 2.1°C (*SD* = 1.6°C). From 2010 to 2020, average daily highs were 1.3°C (*SD* = 1.5°C), and average daily lows were −5.2°C (*SD* = 2.2°C), providing optimal conditions for regular ice formation and reformation (NOAA, 2021).

In recent years, climate change manifest in the rapidly warming Arctic has weakened the CPV. When the CPV in the stratosphere is disrupted (i.e., split, displaced, elongated), it shifts the jet stream southward, bringing Arctic air into the United States and Eurasian cities in the mid-latitudes (Kretschmer et al., 2018; Screen et al., 2018). This phenomenon has created severe winter storm events in cities that have not, historically, experienced substantial accumulations of snow and ice (Cohen et al., 2014, 2021). Examples of note include the Eurasia "Beast from the East" in March 2018 and winter storm Uri in February 2021 (Overland and Wang, 2019; Overland et al., 2020; Doss-Gollin et al., 2021). Increased knowledge of how climate change influences the CPV (Kim et al., 2014; Lillo et al., 2021) suggests that the unexpected should be the expected where Northern Hemisphere mid-latitude winter weather is concerned. **Figure 1**—Pathway C identifies a sample of cities in the United States' central Midwest and Eurasia that are likely to experience future novel winter storms driven by instability in the CPV. Temperature conditions arising from these storm events will likely favor the selection of de-icing salt, especially NaCl. Combined with reasonable availability and modest cost, it may increase its application, often in new urban settings or cities where the past application was limited.

While research has identified adverse effects of the use of NaCl for de-icing on vegetation and aquatic ecosystems as early as the 1970s (Hanes et al., 1970; Dirr, 1976; Roth and Wall, 1976), policies governing the use of de-icing salt have been slow to change, and private use remains unregulated in most urban areas. For example, in Toronto, Ontario, Canada, the use of de-icing salt by businesses and residents accounts for 40% of annual applications (Woodward, 2021). Working in Toronto and looking at a 10-year interval, Wallace and Biastoch (2016) determined that while urbanization had expanded by approximately 6% in land area, the amount of chloride (originating from de-icing salt) in proximate catchment streams increased by 48%. This significant increase in chloride in urban ecosystems suggests that the application of NaCl in new urban areas may be disproportionately greater than the expansion of paved surfaces. Several recent Canadian studies have measured streetside tree exposure to NaCl (Equiza et al., 2017; Ordóñez-Barona et al., 2018), and there is reason to believe that increased streetside tree exposure to salt is positively associated with elevated chloride concentrations in proximate bodies of water that receive direct runoff from these same paved surfaces.

THE IMPACT OF DE-ICING SALTS ON STREETSIDE SOIL AND VEGETATION

Sodium accumulation in soil has been demonstrated to reduce permeability, increase compaction, elevate soil pH, decrease aeration, and generally negatively influence soil fertility (Ramakrishna and Viraraghavan, 2005). On the other hand, calcium and magnesium cations present in some anti-icing agents have been shown to increase soil stability and improve permeability and aeration, likely through organic and inorganic particle flocculation (Defourny, 2000). However, calcium and magnesium de-icers also carry a potential risk of exchanging heavy metals in soils and releasing them into the environment (Fay and Shi, 2012). More generally, microorganism populations and soil community structure are negatively affected by de-icing salt (Ke et al., 2013), further affecting plant water and nutrient uptake. Soil electrical conductivity (EC) values increase with increasing soil salt concentration. They have been shown to reach levels characteristic of naturally occurring saline soils along roads and sidewalks where de-icers are regularly applied (Equiza et al., 2017). In these exact locations—where urban trees are often planted—soil pH is also elevated (Kayama et al., 2003; Gałuszka et al., 2011; Dmuchowski et al., 2014) and leads to further reductions in nutrient and water uptake (Green et al., 2008; Marschner and Rengel, 2012).

A tree's root system has a limited ability to sequester sodium. Once a threshold concentration is exceeded it is transported with a transpiration stream to the leaves, where it accumulates (Apostol and Zwiazek, 2003). The degree of salt injury experienced by a tree is closely correlated with sodium and chloride concentrations in the plant tissue (Olivier et al., 2020). While most of the damage to streetside trees can be attributed to sodium, chloride accumulation is also phytotoxic. Chloride can act synergistically with sodium by increasing its uptake and translocation to shoots, thus further aggravating plant injury (Franklin and Zwiazek, 2004). Munns and Tester (2008) show that chloride may even be more toxic for some trees than sodium because roots cannot readily sequester chloride, which is rapidly transported to the shoots where it accumulates.

Trees are exposed to de-icing salt through two primary routes: direct exposure to airborne particles (i.e., salt splash, spray and dust generated by vehicle traffic and wind) or through the effects of de-icers on the physical, chemical, and biological properties of the soil growing medium (Cunningham et al., 2008). Blomqvist and Johansson (1999) demonstrated that between 20 and 63% of the de-icing salt applied to streets moved through the air and was deposited in the soil as far as 40 m. While the concentration of airborne sodium decreases with increased distance from a road, Equiza et al. (2017) found that in the City of Edmonton, AB, Canada, sodium levels remained significantly elevated as far as 50 m away.

Tree species planted in urban areas vary widely in their tolerance to elevated soil salinity and airborne salt spray accumulation (Appleton et al., 2009; Dmuchowski et al., 2020). Consequently, species selection must be an essential factor in reducing tree mortality in salt-affected areas. Few evergreen tree species, for example, have been described as tolerant of saline soils or salt spray (Appleton et al., 2009), partly due to their persistent foliage that is both exposed to salt spray and prone to salt accumulation. The adverse effects of airborne de-icers can be easily observed in evergreen trees and manifest as extensive foliage necrosis on the side of the tree facing the roadway or walkway that has received de-icing salt applications. While this form of salt stress has been less extensively examined in trees than soil salinity, studies have shown that de-icers are easily absorbed by the needles of evergreen trees and through the buds, leaf scars, and young stems of dormant deciduous trees, thereby affecting tree growth and delaying bud flushing (Dobson, 1991; Zimmerman and Jull, 2006).

Under most environmental conditions, tree roots are naturally colonized by mycorrhizal fungi. Several recent studies have shown that this colonization in salt-affected soils can benefit streetside trees by improving nutrient and water uptake and lessening heavy metal and salt toxicity (Shi et al., 2019; Arora, 2021). Mycorrhizal associations can also reduce plant uptake, and associated tissue concentrations, of sodium and chloride, thus enhancing salinity tolerance in trees (Muhsin and Zwiazek, 2002; Bois et al., 2006; Calvo-Polanco et al., 2008). Studies on ectomycorrhizal associations with *Hebeloma crustuliniforme* and *Laccaria bicolor* showed that they could improve the growth of streetside trees (Garbaye and Churin, 1996) and ameliorate salinity and soil compaction stress in different species (Calvo-Polanco et al., 2008). However, different species of mycorrhizal fungi vary in their effectiveness in conferring salt tolerance to plants (Nguyen et al., 2006; Calvo-Polanco et al., 2009). Moreover, existing urban soil may not contain proper fungi species to colonize tree roots after planting or may have low mycorrhizal inoculation potential, creating sub-optimal protection against de-icing salt (Zwiazek et al., 2019).

A TOOLBOX TO SUPPORT THE CO-MANAGEMENT OF WINTER DE-ICING OPERATIONS AND URBAN FORESTRY IN SALT-VULNERABLE STREETSIDE LOCATIONS

Many city trees require significant, active, and potentially costly management efforts to survive to maturity (Nowak et al., 2013; Duinker et al., 2015; David et al., 2018; City of Toronto, 2020). To triage priorities and conserve resources, it is prudent to identify the geographic locations where streetside trees are most vulnerable to de-icers. These delineated "Salt-vulnerable Zones" (SVZs) provide a setting for novel and alternative approaches to caring for streetside trees (Government of Canada, 2013; Conservation Ontario, 2018; Durickovic, 2019). At present, most salt management efforts that delineate sensitive areas focus on watershed and aquifer protection (Durickovic, 2019). The establishment of SVZs to increase protective measures for vulnerable streetside trees could help to synchronize and integrate winter road and pedestrian safety with tree management goals.

Implementation of integrated salt and tree management strategies, including the delineation of SVZs, would require robust spatial analysis, design and planning, supported by data supplied by salt and tree monitoring technologies (Ordóñez-Barona and Duinker, 2013; Lake Simcoe Region Conservation Authority., 2015; Zhao et al., 2017; Li et al., 2019; Brokking et al., 2021). Moreover, an assessment of local opportunities and constraints for implementing a coordinated salt management effort is required. Once SVZs are established, a synchronous winter road/sidewalk maintenance and tree management effort would pursue a spectrum of different actions, from modifying de-icing products to creating robust GI that supports the bio-desalination of contaminated meltwater through enhanced species-specific urban greening. To this end, we propose a toolbox of actions prioritized by ease of implementation and increasing long-term effectiveness (**Figure 2**).

Actors responsible for minimizing the winter hazards of ice and snow must first avail themselves of opportunities for reduced use of NaCl de-icers, either by optimizing the timing and amount of their application through real-time precision applicator systems (McCormick, 2014; Ruiz-Llata et al., 2014) or by using alternative de-icing agents (Salminen et al., 2011). Where limited modification to the application of NaCl-based de-icers is possible, management efforts should instead focus on designing and implementing structures or strategies that intercept, detain, and divert salinized meltwater away from sensitive areas, including tree plantings (Reinosdotter, 2007; Xiao and McPherson, 2011; Herb et al., 2017; Payne et al., 2018). To minimize reliance on centralized facilities for snow management, especially during spring, meltwater management systems can be connected to locally implemented GI systems that support streetside trees, such as rain gardens and bio-retention cells, potentially located on the sides of streets (Jarden et al., 2015; Vadenais, 2015).

In the strategy envisioned here, GI performs rainwater and snowmelt management functions using vegetation and soil (Burgis et al., 2020). For example, bioretention cells detain and retain water through infiltrating soils and evapotranspiration, helping to manage the volume and quality of downstream water flows (Herb et al., 2017). Recent research suggests that these systems effectively manage salinized water from adjacent snowmelt and that their functions may be augmented with woody species and enhancements to tree-supportive soil media (Muerdter et al., 2018; Burgis et al., 2020). Streetside trees can be planted as a part of many design configurations that integrate into the street design (e.g., soil cell technologies) (Ow et al., 2018). Arguably, GI designs may include tree planting areas configured primarily to support tree growth and vitality with water runoff control as a secondary function. While the widespread adoption of GI as a reliable water management tool in cities is variable, and the crafting of supportive policies that promote their construction can be challenging (William et al., 2020), GI is gaining government support in many jurisdictions (Brokking et al., 2021). GI is a best practice for combatting many potential environmental challenges in cities aggravated by climate change (Johns, 2019). To ensure climate resilience, cities must advance infrastructure design methods that reflect functional, spatial and temporal flexibility, understanding that GI, and any integration of trees, should account for the range of design constraints found in high-trafficked, built-up urban areas (Brokking et al., 2021).

Perhaps the most effective approach to protecting streetside trees is to ensure a resilient and healthy soil environment for optimal growth and longevity (Pike et al., 2021). GI designs that provide ample soil volumes minimize compaction and encourage the formation of microbiological—especially mycorrhizal—communities beneficial to the health of trees (Calvo-Polanco et al., 2008, 2009) offer protection against the harmful effects of salt contamination. Ongoing monitoring of soil environments adjacent to the trees, both to appraise performance and help direct maintenance activities in the face of changing conditions, is an important investment in the long-term success of tree plantings and GI more generally (Pascual et al., 2019).

Planting streetside tree species that show evidence of salt tolerance is an essential step toward enabling successful urban greening (Dirr, 1976; Muerdter et al., 2018; Dmuchowski et al., 2020). However, when adopted in isolation, this strategy may limit urban forest biodiversity in favor of a homogenized ecosystem that performs well when exposed to de-icing salt but lacks resilience in the face of other climate-induced environmental changes such as drought or exposure to disease and insect pests (Groffman et al., 2014). Importantly, managing de-icing salt contamination should be coordinated with other urban greening efforts

FIGURE 2 | Actions can be conceived and executed as a progressive set of steps that build on one another, from the optimization of de-icing salt application (2) to the integrative solutions of (5) and (6). The action items are not exclusive of one another in that the completion of one does not suggest that no further action should be taken. The delineation of Salt-Vulnerable Zones (1) is arguably a necessary precursor to the other actions.

to maximize the benefits of trees to the communities in which they grow.

CONCLUSION

Our perspective is that climate change has the potential to increase, albeit counterintuitively, the demand for and application of NaCl-based de-icers in certain mid-latitude global regions, many with a dominant continental climate classification. Abundant research has demonstrated that exposure to these de-icers negatively impacts plant vitality and, in sufficient concentration, can cause mortality. Our concern is with the vulnerability of urban streetside trees to new or increased de-icing salt exposure. Novel or enhanced exposure can exert greater stress on the health and vitality of streetside trees, already subject to harsh urban growing conditions, further complicating and confounding existing efforts to revitalize and expand urban forest canopy. We identify the immediate need for cooperative and synergistic efforts between actors involved in ensuring public safety during snow and ice events and those focused on city forestry and tree protection. To this end, we have proposed a toolbox of actions that can triage proactive decisions beginning with establishing geographically circumscribed SVZs, paying particular attention to the health of vulnerable streetside tree populations and the soil environments that support them. This triage approach can serve as staging for: (a) space and time optimization of de-icing applications, (b) geographically targeted application of de-icing alternatives, (c) management of saline meltwater more generally, and (d) synergistic integration of GI initiatives and soil quality that address saline runoff and support tree growth, while at the same time achieving stormwater management objectives. Streets and sidewalks free of winter hazards do not need to conflict with the health and vitality of urban tree cover.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

JM: contributes overall direction and editing of manuscript. AM: contributes in-depth research, perspective, and writing, of effects of climate change on freeze-thaw events and deicing applications. MV: contributes in-depth research, perspective, and writing, on effects of salt deicers on tree vegetation. JZ: contributes in-depth research and perspective on effects of salt deicers on tree vegetation, with commentary on overall perspective. JU: provides in-depth research, writing, and perspective, of potential solutions to salt deicing pollution of downtown urban environments and streetside trees. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: JU is the owner of Urban Trees + Soil.

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