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Research article

Understanding reduced salt practices used by commercial snow removal businesses in the Lake Champlain Basin: A mixed methods analysis

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1. Introduction

Annual application of road salt (typically sodium chloride) for winter maintenance in the United States including governmental and commercial sources commonly exceeds 20 million metric tons (United States Geological Survey, 2017). Its use impacts water, soils, and vegetation. Numerous studies reported elevated levels of chloride in private wells in New York (Pieper et al., 2018; Kelly et al., 2018), New Hampshire (Daley et al., 2009), and Wisconsin (Rayne et al., 2019). Similarly, elevated chloride was observed in streams and rivers in the United States (Kaushal et al., 2005; Corsi et al., 2010), Canada (Laceby et al., 2019; Lawson and Jackson, 2021; Mazumder et al., 2021), and Europe (Niedrist et al., 2021). This was attributed in some cases to chloride-rich groundwater (Kelly et al., 2019). Increased levels of chloride have impacted natural lake processes and fish habitat (Wiltse et al., 2020) as well as aquatic communities (Szklarek et al., 2022). For instance, decreases in taxa richness (Grapentine et al., 2008) and sensitive benthic macroinvertebrates (Blasius and Merritt, 2002) were reported. In soils that received road salt, water retention capacity decreased (Garakani et al., 2018) and cations (Norrström and Bergstedt, 2001; Kim and Koretsky, 2013), including nitrate (Green et al., 2008) were mobilized. Native vegetation subject to road salt runoff decreased in richness and abundance (Richburg et al., 2001). Reduced chlorophyll content was observed in leaves (Equiza et al., 2017) of trees growing in soils exposed to road salt.

Road salt is a recognized contaminant in the Lake Champlain basin, which spans 21,401 square kilometers (8263 square miles) across portions of Vermont and New York in the United States and Quebec in Canada (Fig. 1; United States Environmental Protection Agency, 2015). Increasing chloride concentrations have been observed in the main lake, its tributaries, and smaller lakes within the basin over the past 50 years (Denner et al., 2009; Kelting et al., 2012; Medalie, 2014; Smeltzer et al., 2012). Seven tributaries to Lake Champlain are impaired by chloride (Vermont Department of Environmental Conservation, 2020), and 17 of 18 major tributaries to Lake Champlain demonstrated increased flow-normalized chloride concentrations between 1991 and 2017 (Vaughan, 2019). In the western portion of the basin, road salting affected spring mixing in Mirror Lake in Lake Placid, NY (Wiltse et al., 2020). At the southern end of the basin, chloride concentrations increased 30 times in Lake George between 1940 and 2009 (Sutherland et al., 2018). Road salt is predicted to increasingly impact surface waters in the basin over time (Denner et al., 2009; Dugan et al., 2017).

Municipal and state agencies in watersheds where waterbodies are listed as impaired due to road salt components (e.g., chloride) are compelled to implement best practices that reduce road salt pollution to fulfill their responsibilities established via the Clean Water Act (U.S. Federal Water Pollution Control Act § 1251, 1972). At the state level, only a few have policies aimed at reducing road salt use. In 2020, New York passed an Act (Randy Preston Road Salt Reduction Act, Assembly Bill A8767A, 2020) that established a task force in Adirondack Park to identify impacts of road salt, to make recommendations for trainings, and to establish a pilot program to promote reduced salt use. In 2023, Minnesota passed a statue limiting use of chemicals such as salt during snow removal (160.215 Snow Removal; Salt and Chemicals Restricted, 2023). New Hampshire established a limited liability law directed towards private winter maintenance contractors (Commercial Applicator

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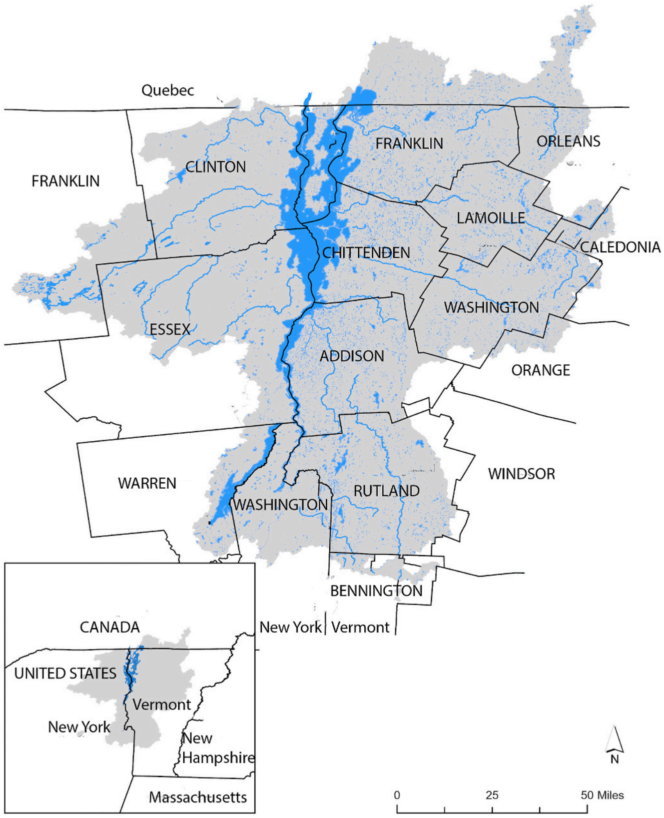

Fig. 1. Lake Champlain lies on the border between the New York and Vermont in the United States and on the international border with Quebec, Canada. Its basin encompasses all or portions of 11 Vermont counties and five New York counties.

Certification Option § 489: C:1, 2013; Liability Limited for Winter Maintenance § 508:22, 2021). Illinois (Snow Removal Service Liability Limitation Act 815 ILCS § 675, 2016) and Colorado (Snow Removal Service Liability Limitation SB18 § 062, 2018) also established limited liability laws. Such laws promote reduced road salt use and can save costs, reduce impacts to infrastructure, and improve consistency of services to improve safety for end-users (Meegoda et al., 2004; Nixon and DeVries, 2015; Shi et al., 2013).

However, a research gap exists on what practices non-state or municipal road salt applicators (e.g., commercial snow removal businesses) use and what barriers exist for adopting best practices (Sparacino et al., 2022). While commercial snow removal businesses were identified as a possible source of elevated chloride in Vermont (Denner et al., 2009) and New Hampshire streams (Trowbridge, 2007; Trowbridge et al., 2010), these businesses are not typically the focus of research, policies, laws, or management plans designed to mitigate road salt impacts (Denner et al., 2009). The characteristics and practices of professionals who maintain private properties and/or who are contracted by public entities to maintain public properties during winter have rarely been examined (e.g., Stone and Marsalek, 2011). This creates a knowledge gap of current practices, tools, and resources that – if implemented by private contractors – may reduce road salt use and impacts. Many reduced-salt best practices designed for municipalities may also be effective for private contractors. A review identified fourteen practices commonly found in municipal winter maintenance plans that may have low barriers to entry for private contractors and that may allow such companies to decrease liability and costs and maintain a similar level of service (Sparacino et al., 2022).

In the context of the Vermont and New York portions of the Lake Champlain basin, the goals of this research were to characterize commercial snow removal businesses and their use of reduced-salt best practices, and to assess their barriers and motivations to adopting such practices. Three hypotheses were developed to explore if the use of reduced-salt best practices varied based on organizational characteristics and/or the types of services provided (Nixon and DeVries, 2015; Shi et al., 2013; Transportation Association of Canada, 2013):

H1. Snow removal businesses with a greater number of clients adopt a greater number of reduced-salt best practices, on average, than those with fewer clients.

H2. Snow removal businesses that service larger surface areas adopt a greater number of reduced-salt best practices, on average, than those that service smaller surface areas.

H3. Snow removal businesses focused on commercial properties adopt a greater number of reduced-salt best practices, on average, than businesses focused on residential properties.

2. Methods

2.1. Overview

A mixed-methods, explanatory sequential design was used to characterize businesses and to assess hypotheses (Creswell and Plano Clark, 2007). Between November 2017 and May 2018, we implemented a 17-question census to identify business characteristics and practices (Supplementary Material). Companies described their motivations for and barriers to using a select set of 11 practices with potential to reduce salt usage while maintaining a similar level of service, hereafter called "reduced-salt best practices." We conducted ten follow up qualitative interviews between July and September 2018. These added depth, complexity, and validity to census results (Creswell and Plano Clark, 2007; Lindlof and Taylor, 2011; Miles and Huberman, 1994). The study was approved through the University of Vermont's Institutional Review Board (Study 18–0064).

Commercial snow removal businesses were identified via Internet searches and directories. These included government business directories in New York and Vermont, listings through the Better Business Bureau, online search engines (Google), and online community resources such as Yellow Pages and Front Porch Forum (a popular Vermont-based neighborhood online forum). A snow removal company was considered active if it had a functioning email or physical address at which to receive the questionnaire. This search process yielded 232 snow removal companies in the study area.

2.2. Quantitative census

A census was conducted instead of a survey due to the small population size (Dillman et al., 2014) and low expected survey response rate (personal communications with Connie Fortin, Patrick Santoso, Chris Navitsky, and Corrina King in July 2017). Plus, negligible additional resources were required to contact the population (Dillman et al., 2014).

The census included an initial testing phase, multiple contact methods, and reminder messages to maximize response rate (Dillman et al., 2014). Initially, businesses were contacted by email or letter and provided a copy of or link to the online questionnaire (Qualtrics, 2018). Between November and May, businesses were regularly contacted by email, phone, and USPS mail. Participants were eligible for a $10 gift card drawing to enhance participation. The census was closed in May 2018.

2.3. Statistical analyses

IBM (2018) SPSS Statistics 25 software was used to explore relationships in quantitative data and to summarize descriptive statistics. Prior to analysis, reported surface areas were converted to common units using standards in accordance with the U.S. Department of

Transportation Federal Highway Administration criteria. Lane miles were assumed to be 3.6 m wide (United States Department of Transportation Federal Highway Administration, 2018). Surface area responses with insufficient information or detail to standardize surface area(s) were omitted (e.g., *"10 parking lots"*).

An independent sample *t*-test was used to test H_1 to compare the mean number of reduced-salt best practices used between small businesses (≤40 clients) and large businesses (>40 clients). The relationship between the number of reduced-salt best practices businesses adopted and the size of the combined surfaces they maintained (H_2) was tested using a Pearson correlation. To test H_3, businesses were classified as commercial, residential, or mixed based on the type of surfaces serviced. Commercial businesses serviced parking lots but not driveways. Residential businesses serviced driveways but not parking lots. Mixed businesses serviced both. Businesses that did not report servicing parking lots or driveways were excluded due to the small number of cases ($n = 2$). Following classification, these groups were compared based on the number of reduced-salt best practices businesses adopted via a one-way analysis of variance (ANOVA).

2.4. Qualitative interviews

Four reduced-salt best practices were selected to serve as "targeted best practices" to explore in the qualitative interview phase of the study. These practices were selected based on existing literature (Sparacino et al., 2022) due to their reported lower frequency of use, effectiveness at reducing salt use, and potential ease of implementation. The targeted best practices were: (1) use of brine and/or pre-wet salt (to increase adhesion of salt to treated surfaces and help prevent bond between surface and snow/ice); (2) measuring pavement surface temperature (as sodium chloride is not effective at pavement temperatures below −9 C/15 F); (3) pretreating surfaces (also known as anti-icing, which is often, but not always carried out using brine to prevent the bond between pavement and ice/snow); and (4) calibrating trucks and equipment (to allow for measured salt distribution over time and space). Equipment calibration was excluded from descriptive analysis due to inconsistencies found between questionnaire and interview respondents' understanding of and interpretation of the practice, which was revealed during interviews (see Section 3.3.1).

To ensure interviews were conducted with companies with different characteristics, all companies that provided contact information (n = 52) were categorized by number of clients (i.e., small with ≤40 clients and large with >40 clients), number of targeted best practices used (i.e., 0 or 1 or 2 to 4), and by types of surfaces maintained (i.e., parking lots, driveways). The latter was used to identify the businesses as commercial, residential, or mixed. Businesses that represented all categories were then randomly selected to be interviewed (Sparacino, 2019). Interviews (Supplementary Material) followed a semi-standardized structure (Fielding and Thomas, 2008; Patton, 2002).

Following each interview, notes and transcripts were reviewed and best practices were categorized. These served as provisional codes to explore themes and organize responses (Miles and Huberman, 1994). Additional codes were added as additional interviews were conducted. After all interviews were completed, secondary coding was developed to further explore interview data and qualitative trends. This allowed for further exploration and verification of quantitative data (Creswell and Plano Clark, 2007; Fielding and Thomas, 2008; Miles and Huberman, 1994).

3. Results

3.1. Descriptive statistics

Seventy snow removal businesses responded to the questionnaire, for a response rate of 30%. Most operated in Vermont (84%), while fewer worked in New York (17%), New Hampshire (1%) or other states (1%). Customer bases ranged broadly in size. Thirty-four percent of companies reported 1–20 clients, 15% reported 21–40 clients, and 51% reported more than 40 clients ($n = 61$). Most respondents were company owners (82%, $n = 62$), and most indicated that company owners were the primary decision-maker for winter maintenance practices (91%, $n = 55$). Most identified as male (89%, $n = 45$). About a quarter of respondents were in each of three age range categories: 35–44 (28%), 45–54 (23%), and 55–64 (25%, $n = 60$). Many businesses reported using a sodium chloride and sand mix (76%), sand (74%), and/or pure sodium chloride (41%; $n = 58$, 57, and 51, respectively). Companies less frequently used packaged blends (19%) or alternative application materials (17%) such as calcium chloride, magnesium chloride, or calcium magnesium acetate ($n = 58$).

Businesses maintained a wide range of surface areas (Table 1). The smallest maintained approximately 100 m^2, while the largest maintained 1,267,700 m^2 (0.02 and 215 lane miles). On average, contractors serviced approximately 142,600 m^2 (24 lane miles) each across all surface types. The majority of businesses serviced driveways (85%), parking lots (75%) and sidewalks (67%; $n = 60$). Parking lots accounted for 67% of the reported surface area maintained, and no other surface type represented even 20% of the surface area maintained (roadways 19%; driveways 11%; sidewalks 2%; other 1%). A total of 6,133,200 m^2 (1042 lane miles) were serviced (n = 43).

The median number of reduced-salt best practices used by contractors was six ($n = 70$). Excluding equipment calibration, most contractors reported using none of the "targeted" best practices (64%), while 36% of contractors used between one and three targeted best practices ($n = 70$). Contractors most commonly used equipment that allowed for adjustable deicing/anti-icing product application rates (97%, n = 66) and avoided plowing snow into surface waters (97%; n = 64; Fig. 2). Contractors least commonly used pre-wetted salt and/or brine (8%, $n = 63$) and only one-quarter (n = 63) measured pavement surface temperature.

Contractors were most frequently motivated to use identified practices to address liability or safety concerns (66%, n = 70; Fig. 3) or customer requests or expectations (60%, n = 70), and to reduce costs (57%, $n = 70$). The most common barriers to implementing best practices were costs (60%, n = 70), time (46%, n = 70), and customer requests or expectations (29%, $n = 70$).

Most (69%) contractors always or often used a formal or written contract with customers ($n = 55$). Fewer (28%) rarely or never used one, with the remaining contractors answering not applicable or unsure. Contractors frequently included the level of service expected (66%), type of materials to use (58%), and area(s) to be serviced (55%) in contracts. Companies sometimes included expected response time (39%), a limited liability clause (31%), and the amount of materials to be applied (14%, $n = 64$). Most companies were classified as mixed (63%), servicing both residential and commercial surfaces ($n = 60$).

To initially learn winter maintenance techniques, most respondents (81%) learned through on-the-job experience (n = 64) while 42% had engaged in self-education or online learning. Another 16% learned from an acquaintance and 11% attended a workshop. Just 3% had college or technical school training. Respondents used multiple methods to continue to learn about winter maintenance practices. They did this most commonly through websites (42%), in-person trainings (27%), and

Table 1
Sizes (m^2) of areas maintained across different surface types by responding snow removal businesses in the Lake Champlain basin (n = 43). All values were rounded to the nearest 100 m^2. In addition, one respondent maintained 17,400 m^2 of docks and industrial areas.

Surface Type	Minimum	Maximum	Median	Mean
Parking lots	1900	1,214,100	37,400	137,800
Roads	3900	682,800	20,600	65,700
Driveways	100	94,200	5800	20,500
Sidewalks	0	18,600	1400	3900

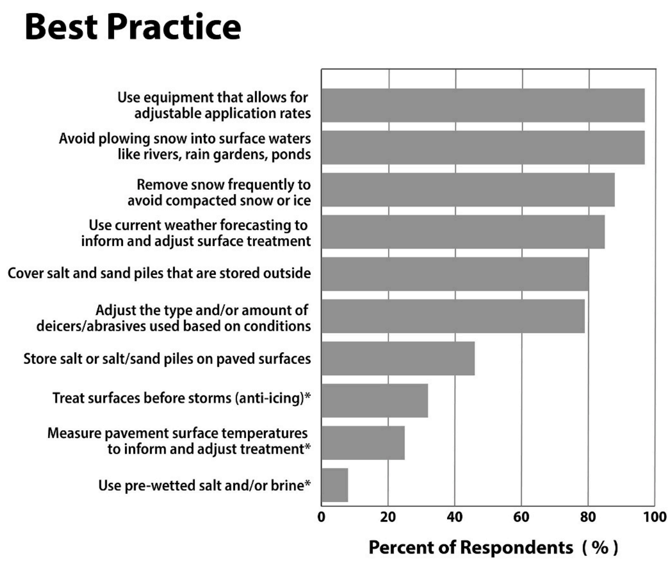

Fig. 2. Frequency of reduced salt best practices reported by snow removal companies in the Lake Champlain basin (n = 61 to 66). Targeted best practices are marked with asterisks. Equipment calibration was excluded from descriptive analysis due to inconsistencies found between questionnaire and interview respondents' understanding of and interpretation of the practice.

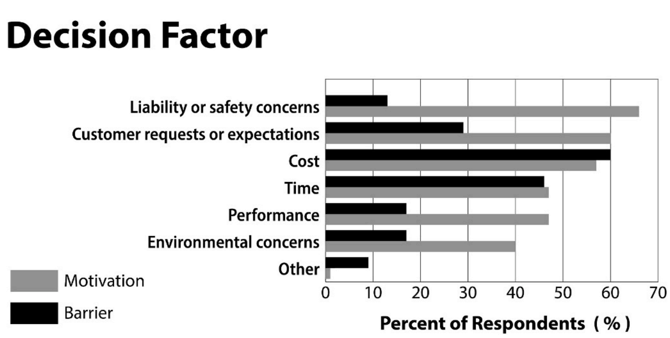

Fig. 3. Motivations and barriers of snow removal businesses in the Lake Champlain basin to using reduced salt best practices (n = 70).

email (17%). In open-ended responses, another 16% identified continued learning through experience and interactions with colleagues or peers/professionals in the industry (n = 64).

3.2. Inferential statistics

No significant difference existed between the mean number of reduced-salt best practices used by small and large companies (H_1, $p = 0.63$). A significant but weak positive correlation ($r^2 = 0.192$, $n = 43$, $p = 0.003$) existed between the number of best practices adopted and the combined surface area maintained (H_2). ANOVA suggested that business type (i.e., mixed, commercial, residential) was significantly related to the number of best practices adopted ($F\ (2, 55) = 6.12$, $p = 0.004$). Post hoc analyses using the Tukey criterion for significance indicated that the average number of best practices used by companies specializing in maintaining residential properties was significantly lower ($M = 4.7$, $SD = 1.4$) than those that maintained commercial ($M = 6.7$, $SD = 2.0$) or mixed ($M = 6.6$, $SD = 1.8$) properties.

3.3. Qualitative analysis

H_1 was further explored through follow-up interviews, which revealed that contractors did not adjust practices based on the number of clients, but rather on the types of surfaces maintained (e.g., parking lots). All businesses that serviced commercial (i.e., parking lots) and mixed properties (i.e., parking lots and driveways) reported increased amount of application materials requested by commercial customers versus residential customers. Surface type was therefore a likely confounding variable in the relationship between the number of clients and reduced-salt best practices used.

H_2 was supported in interviews. Larger companies with more staff serviced larger areas and had more capacity to employ reduced-salt best practices. One interviewee noted, *"usually in the morning we'll send out one guy and he'll go track properties, and that'll be our initial precheck, looking for refreeze, that kind of thing, and he'll check surface temperatures, and he'll make the call if we need to get people out and start salting or shoveling or whatnot."* This finding may relate to the need for larger companies to be more efficient. Best practices are generally more efficient (Nixon and DeVries, 2015), and staff of larger companies described engaging in more efficient actions more commonly than those from smaller companies. A contractor who owned a larger company observed, *"we're trying to mechanize because labor is such a huge issue. Instead of 20 guys with shovels you can get one guy with a tractor."* At the same time, smaller businesses recognized inefficiencies in use of certain practices. One person noted, *"he has to shovel a couple sidewalks … but shoveling takes quite a bit of time and slows you down when you really got to get around to driveways."* The association between the need for more efficient services to treat greater surface areas suggested an even stronger relationship between the size of surface area treated and the number of best practices used by contractors.

H_3 was strongly supported through interviews. In addition, businesses that serviced multiple surface types reported having more staff and an increased need for more advanced equipment and/or practices. Property type specialization (i.e., commercial, residential, mixed) was a better predictor of required staff time and types of practices used than number of clients. Interviewees reported quick and efficient service to residential customers, typically triggered by 2–4 inches of snow, which resulted in one or two treatments per day (*"we're … trying to bang out 30 drives[ways] an hour.*"). Commercial clients had more intensive needs, typically involving less snow to trigger a service call, a bare-ground/zero snow accumulation "no-tolerance" policy, or required continued applications per day (*"we have a lot of [commercial] facilities that are bare ground policies because of the liability. So they want you to make sure they have grip at all times and that it is salted every time you plow.*").

3.3.1. Decision factors associated with preferred materials and best practices

Follow-up interviews also explored the preferences contractors had for certain types of application materials and the decision-factors to using best practices. The negative environmental impacts of sand are well documented (Shi et al., 2013; Staples et al., 2004), and the use of sand as an application material was found in interviews to be a more polarizing application material than revealed through the questionnaire. While three quarters of contractors used sand, four out of six interviewees that provided year-round maintenance on properties were reluctant to use sand due to required cleanups in the spring (*"People don't prefer sand on their properties because it's just so much to clean up and it gets brought inside.*"). Further, three out of six cited potential environmental impacts in the warmer months (*"Sand gets into the drains and stays there and gets washed over time and time and time again and getting all that crap in there out in the rivers.*").

Interviews revealed multiple interpretations of the definition of "equipment calibration." This led to our decision, as noted earlier, to exclude equipment calibration from quantitative analysis. We defined calibration as the direct measurement of materials applied from equipment over some period of time for common equipment settings or configurations (Nixon and DeVries, 2015; Transportation Association of Canada, 2013). Contractor interpretations included checking that the gates on spreaders were open or using various application rates but not directly measuring material output in a set time period.

Using our study definition, interviews revealed myriad perspectives of the potential to put calibration into practice. In support of the practice, a few interviewees that already calibrated cited cost savings from lower amounts of application materials required for a similar level of service (*"you can do more parking lots per load, a smaller truck goes farther, so it's less investment, if you can go 25% farther, and you're going to four places, now you can do five before you fill. That's significant."*). The opportunity to save money by understanding how much salt was spread was also appealing to those who did not calibrate (*"I think we would* [implement calibration if a training were offered]. *It's a just a sensible thing to do if you save money after you're done adjusting.*"). Conversely, barriers to calibration included little or no familiarity with the practice, additional time and training needed (*"what you just described would take days and days of research and development really, and probably months' worth of testing. And you'd have to, literally have to have every single weather scenario on that spreadsheet. Every single one."*), a lack of perceived benefit (*"[calibration] doesn't even matter … it just doesn't, you put down whatever salt you need to put down."*), a lack of perceived consistency (*"Your thought of application, my thought of application covered area [sic], may be different. So, my theory is you cannot have two different individuals salting the same parking lot and putting down the same amount of volume."*); worries about complexities involved to adjust spread rates based on conditions and doubts that staff would continue to use the practice after training (*"I wouldn't know how much ground you could travel in a minute, and then how much to throttle it back one way or the other for temperatures; and, I also wouldn't know how to get the operators to use that information – if they could even retain it."*).

Interviewees reported mixed to negative feelings about anti-icing/pre-treatment. Four out of eight contractors that had used anti-icing felt it was potentially effective to help prevent snow and ice bonding to surfaces (*"The residue will take care of it pretty good, so when you go in to plow, it cleans it right up*"). However, all eight articulated barriers to its use. These often centered around difficulties in justifying the additional time *("Essentially we [would] have to service the properties twice")* or costs to customers and demonstrated the influence of customer expectations on contractor actions (*"To me, the benefits of pretreating don't warrant trying to talk the customer into why it works, because, in my opinion, it doesn't.")*. Contractors also noted challenges to implementing the practice (*"I've tried to justify [pretreating] in the past, and I've noticed there's been a little bit of squabble. You know because the weather apps aren't always accurate so that's a catch 22."*).

Similarly, interviewees tended to have negative feelings about brine (*"I don't care for it. I think it's worse than rock salt* [for the environment]."). No interviewees used brine at the time of interviews, and only three showed interest in using it in the future. Startup costs were almost always described as a barrier to implementation (*"You have to have your storage facility, your mixing units, power, stock, and now you have to outfit all your vehicles with a brine applicator.")*. Interviewees often cited perceived accelerated rusting and/or corrosion of cars and infrastructure from brine, stemming from its ability to stick to surfaces (*"it ruins equipment worse than what they just treat the roads with."*). Contractors from one company identified that others' experiences with brine usage had influenced their perceptions (*"We find [here] there's a lot of negativity towards brine. Mostly because I think [others] bungled it when they put it out … We're hoping to this year, we're hoping to get into the brine game. It's not that we don't want to be in the brine game, we do, it's just that the publicity of it is really bad right now …"*).

Like the other targeted best practices discussed during the interviews, measuring surface temperature was a relatively unused practice by interviewees. Though, unlike the other practices, interviewees did not identify any major barriers to using the practice, though some thought the technology could have high costs (for example, using a truck-mounted pavement temperature sensor with a display in the truck cab). Most companies were not familiar with the relatively inexpensive hand-held infrared thermometers but noted potential for the practice to improve their applications.

4. Discussion

4.1. Key findings

We characterized practices of commercial snow removal businesses in the Lake Champlain basin of Vermont and New York including use of, barriers to, and motivations for adopting reduced-salt best practices. We believe this study is the first of its kind. Thus, our results contribute new knowledge that can inform outreach and policies that promote adoption of reduced-salt best practices and subsequently more sustainable environmental management.

Our findings that more best practices were used when larger surfaces were maintained (H_2) and when commercial or mixed (i.e., residential and commercial) property types were serviced (H_3) may have been influenced business age, capacity, and level of expertise about winter maintenance. Companies that managed snow and ice across larger areas or across varied property types may have expanded their capacity to do so (e.g., through equipment purchases or infrastructure investments) while concurrently accumulating knowledge about practices over time, and as a result increased use of reduced-salt best practices. This aligns with research on knowledge generation in a business setting (Leonard, 1995). Companies used new methods and equipment over time to improve their operational capabilities (Leonard, 1995). This also aligns with learning theory, specifically concept learning (Knowles et al., 2014). When this theory is applied to commercial snow removal businesses, it would suggest that knowledge gained over time would improve the capability for a business to respond to certain situations more efficiently (Knowles et al., 2014). In turn, the business would have expanded capacity to enhance its services such as by maintaining larger areas or varied property types.

The lack of a statistically significant ($p < 0.05$) relationship between the number of best practices used between small and large companies (H_1) suggests that different sized companies may have similar barriers and motivations to using best practices. Top motivations and barriers to adopting best practices were also similar among different sized companies. This may be due to overlap between benefits and impacts of the practices as related to the environment, costs and liability (Sparacino et al., 2022). For instance, best practices can result in long-term cost savings via more efficient materials applications or decreased application time, but many have up-front capital, equipment and/or training requirements (Transportation Association of Canada, 2013). Further, these costs and requirements may scale with business size. This may create barriers to adoption of the practices by businesses regardless of the number of clients or overall capital capacity. Similar barriers to best practice adoption regardless of capital capacity were also documented in the agricultural sector (Prokopy et al., 2008). Insignificant relationships were consistently observed between adoption of best management practices by agricultural producers and capital capacity (150 out of 181 models assessed) as well as income (24 out of 34 models; Prokopy et al., 2008). In addition, more positive relationships existed between best management practice adoption and education capacity (21 out of 42) and information capacity (12 out of 20) in the models studied (Prokopy et al., 2008). The insignificant relationship we observed between reduced-salt best practice adoption and number of clients (H_1) as well as findings on best management practice adoption among agricultural producers suggest that training opportunities, reducing investment costs, and/or providing resources that introduce and promote best practice adoption may be similarly effective for both small and large businesses. In addition, our results demonstrated that both small and large companies were highly motivated to use their chosen practices due to customer requests and liability concerns. Social interactions are most influential on the decision to adopt best management practices at early stages of awareness of the challenges to be addressed through use of such practices (Coggan et al., 2021). Customer requests may serve to heighten focus on challenges of using salt (e.g., impacts to the environment) and help drive adoption of best practices. Developing trainings and providing resources for customers that aim to change attitudes and behaviors (e.g., to lessen customer requests for contractors to use excessive salt) may indirectly influence contractors' use of reduced-salt practices. The influence of liability concerns on motivations to use reduced-salt practices may also relate to social networks. In agriculture, adoption of best management practices was influenced through social networks (Young and Burke, 2001; Streletskaya et al., 2020). If contractors observe or become aware of liability cases among peers and build awareness that use of reduced-salt best practices may limit liability, that may promote greater adoption of such practices. The establishment of New Hampshire's Green SnowPro limited liability program that includes a required training for contractors as well as tracking and use of reduced-salt practices that provide consistent and safe results for communities, and the subsequent adoption of that education program in Connecticut (Dietz, 2020) may have influenced use of best practices by contractors in the nearby Lake Champlain basin. Similar policies developed in the Lake Champlain basin in the future may further promote adoption of reduced-salt practices.

To promote adoption of reduced-salt best practices among contractors, their awareness of environmental issues and influence by peers and external information sources should also be considered. An individual's proximity, awareness, and perceived importance of environmental problems have been shown to be predictors of pro-environmental behaviors (Gifford and Nilsson, 2014; Séguin et al., 1998). Contractors' understanding of environmental impacts of using sand, as noted in interviews, supports these findings. Therefore, helping contractors to understand environmental impacts of salt is important in helping promote adoption of best practices.

The majority of private contractors initially learned winter maintenance techniques through on-the-job experience and peer learning. As noted, social systems and networks are important for influencing behaviors (McKenzie-Mohr, 2011; Monroe, 2003). In the agricultural sector, a study on contracts, climate change mitigation information, and behavior changes suggested that informational sources and trust had an impact on behaviors (Schewe and Stuart, 2017). For these reasons, workforce development programs focused on winter snow and ice management should consider delivering information about environmental impacts of salt and how to implement reduced-salt best practices via trusted information sources, such as industry partners and peers, to be most effective. Further, as websites were a major source of information for the contractors, trainings could be supported with web-based information that contractors could access as their schedules allowed.

4.2. Environmental management implications and opportunities

Several environmental management implications and opportunities result from our findings. Our findings may benefit future policies, educational resources, and outreach initiatives targeted towards private contractors to reduce road salt use while maintaining a similar level of service and potentially lowering costs or liability concerns.

The targeted reduced-salt best practices we assessed through the questionnaire and interviews have all been used successfully to reduce salt by professional snow and ice managers (Sparacino et al., 2022). If reduced-salt practices are used more frequently by private contractors, salt contamination of the environment can be significantly reduced. For instance, use of brine was demonstrated to reduce salt use by 30% (Fitch et al., 2013) to 45% (Haake and Knouft, 2019). Anti-icing also reduced salt use by 30% (Hossain et al., 2015). Measuring surface temperature through road weather information systems is commonly used to inform decision making about salt use (Bättig, 2008; Boselly, 2001), allowing snow and ice management professionals to opt out of spreading salt when pavement temperatures are above freezing or below temperatures at which sodium chloride is no longer effective. Calibration also has aided snow professionals in minimizing over application (Hintz et al., 2022). To ensure these practices are used properly to allow reduced use of salt, professionals must be properly trained. For instance, they must understand the principles of eutectic temperature and ice melting ability of salt brine (Achkeeva et al., 2015), and they have to use the information calibration and pavement surface temperatures provide to alter salt delivery.

Reduced-salt best practices that were infrequently used and had low barriers to entry should be prioritized in future social marketing outreach and trainings to promote greater adoption (McKenzie-Mohr, 2000) and proper use of the practices. Interviews suggested general interest in measuring surface temperatures, some hesitancy, but also curiosity about calibration, and mixed to negative perceptions about anti-icing and brine. As such, trainings to share surface temperature measurement and calibration methods – especially hands-on and on-the-job trainings – should be prioritized. Focusing trainings and outreach on calibration would also address the disconnect we observed in contractors' understanding of calibration and complement the high rates of use of adjustable application rate equipment already in place. Being able to measure salt output would add meaning to actions to adjust application rates and have potential to result in environmental, economic and infrastructure benefits.

For anti-icing and brine, a slower and more nuanced approach may be necessary to encourage contractors to adopt these practices. First, to harness the power of learning via social networks, contractor led trainings and peer-to-peer sharing of techniques and successes in using these reduced-salt best practices is warranted. These may help contractors understand merits of and proper ways to engage in use of these practices. In addition, both questionnaire results and use (or lack of use) of targeted best practices and sand demonstrated that customer expectations had strong influence on contractor actions. Therefore, education that allows the customer base of commercial snow removal businesses to understand the benefits of anti-icing and brine may be useful.

In addition, opportunities exist for outreach focused on business practices that can reduce costs by limiting the amount of application materials used. Contractors rarely included the amount of materials to be applied in contracts. Yet, best practices frequently result in reduced product costs (Transportation Association of Canada, 2013). Thus, focusing training programs on reduced materials costs that result when best practice are adopted may be an effective way to engage snow removal companies to adopt best practices. Trainings have been targeted in this manner for municipalities (Nixon and DeVries, 2015).

Numerous educational and non-profit organizations in the Lake Champlain basin develop and share outreach materials and offer trainings related to reduced-salt best practices. In addition, a Governor-appointed Adirondack Road Salt Reduction Task Force recently released a report (New York State Department of Environmental Conservation, 2023) with recommendations for a comprehensive education program that targets a variety of audiences. Our findings may enable outreach initiatives of these organizations or other similar efforts in other locations to be made more effective. This includes developing training programs that focus on practices with lowest barriers to adoption, and on those that are peer-led, on-the-job, and supported by web-based learning options.

Further, our findings have potential to inform future policies related to reducing road salt use by commercial businesses. Policies that include training requirements might follow guidelines outlined above. Additionally, knowledge that the greatest barriers to implementing reduced-salt best practices were cost and time may drive states to develop funding programs that support businesses to make capital investments to initiate their use of reduced-salt best practices. Through such trainings and policies, all parties involved, the environment, and infrastructure have potential to benefit.

While our study was conducted in the Lake Champlain basin of Vermont and New York, our results and recommendations have potential to inform outreach and policies across North America and beyond. Principles and practices that reduce salt use are likely to be consistent across cold climate geographies. For instance, five public education campaigns focused on road salt reduction currently underway in the United States and Canada promote nearly identical best practices (Adirondack Road Salt Reduction Task Force, 2023).

4.3. Limitations of the research

The study had several limitations. First, the somewhat low response rate may limit transferability of results across the surveyed population. We compared web presence of respondents and non-respondents to assess if company size may have related to its capacity to respond. Respondents maintained websites at similar rates (65%) as non-respondents (63%). This suggested they represented similar populations. Another limitation is that data were collected only within the Lake Champlain basin. Incentives and policies that impact snow removal companies may differ areas among geographic areas, thus influencing the decision-making factors surrounding use of best practices. Results may have been influenced by defining small (≤40 clients) and large (>40 clients) companies rather than allowing the data to describe the relationships between companies and reduced-salt best practices used. Future studies might use analyses that are less prescriptive about company size.

5. Conclusion

This study advances knowledge of private winter maintenance contractors' motivations and barriers to adopting reduced-salt practices, current practices used, and preferred methods of learning. These findings can inform future outreach, funding mechanisms, and policies that promote adoption of reduced-salt best practices. Organizations that provide workforce development trainings for private contractors may foster reduced road salt use by providing hands-on, peer-led, on-the-job trainings and online learning tools. Further, they can focus education on practices identified through this study to have lower levels of resistance to adoption yet high potential for salt reduction if employed. Education that helps contractors understand environmental impacts of road salt runoff can also be incorporated into trainings. Simultaneously, due to the influence of customer expectations on contractor decisions, there is need for outreach that is designed to shift customer expectations. Further, policymakers and funding agencies can use our results to help lower barriers to adoption of reduced-salt practices. For example, decisionmakers might develop limited liability policies that also require contractor training in use of best practices. Agencies could develop funding mechanisms that reduce initial investment costs for new snow and ice management technologies like pavement temperature sensors, brine making systems, calibration tools, and salt tracking equipment.

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CRediT authorship contribution statement

Holden Sparacino: Writing - review & editing, Writing - original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kristine F. Stepenuck:** Writing - review & editing, Visualization, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Stephanie E. Hurley:** Writing - review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be publicly available through the FEMC at https://www.uvm.edu/femc/data

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Appendix A. Supplementary data

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