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Forester interest in, and limitations to, adapting to climate change across the rural-to-urban gradient

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ABSTRACT

Climate change-related challenges faced by forest managers are ecological, economic, and social in nature. While several past assessments have looked at the climate-related perceptions and needs of foresters working in rural contexts, urban foresters are not often included in these assessments. Examining foresters' risk perceptions, adaptation interests and intentions, and need for information/support in rural *and* urban contexts side-by-side reveals unique opportunities for learning across the rural-to-urban gradient. Through two surveys targeting both rural and urban foresters, we have identified key learning opportunities that support climate-adaptive forest management.

Our analysis shows that many foresters are seeking to maintain current forest conditions or restore forest conditions following a disruption or change, though some see value in transitioning forests to be more resistant and resilient to future climates. We also show a difference in confidence between urban and rural foresters when it comes to addressing climate change through specific adaptation strategies. Based on our findings, we propose facilitated learning opportunities across the rural-to-urban gradient. This would allow urban foresters to learn from rural foresters on topics such as establishment and maintenance of long-term, large, ecologically complex forested areas within cities. Rural foresters could gain insights from their urban counterparts on planting strategies and other approaches that are common in urban settings but novel in rural settings, including stock sourcing and species selection.

To better enable foresters to implement climate adaptation strategies, we suggest: (1) facilitating learning across the rural-to-urban gradient, (2) public engagement trainings and opportunities targeting foresters, (3) workforce development programing, and (4) programs that limit the financial risk that foresters, landowners, and municipalities face when applying forest adaptation strategies to rural or urban lands.

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1. Introduction

The Northeast and the Great Lakes regions are the most densely forested regions in the United States, with 174 million acres (~70 million hectares) of forest land cover, or roughly four out of every ten acres of land. Additionally, tree canopy and other greenspaces are estimated to cover 35 % of urban areas, though these areas are expected to shrink over the next several decades (Shifley and Moser, 2016). Urban forests, which for the purpose of this study include street trees and tree stands (Konijnendijk et al., 2006), provide a diversity of habitats and a range of important ecosystem services including enhancing water quality, temperature and wind regulation, erosion control, and recreational opportunities (Rustad et al., 2012). In addition to the benefits of rural forests, urban forests are recognized for their critical contribution of mitigating deleterious effects of climate change (Janowiak et al., 2021). With estimates that over 80 % of the North American population lives in urban areas (United Nations, 2014), urban forests provide valuable services to urban populations.

Additionally, forests support economic development and employment in rural and urban communities. This includes 509,301 jobs/ $47.0 billion U.S. dollars (USD) annually in direct industry output from forestry in the Northeast and Midwest (Pelkki and Sherman, 2020), and 258,550 jobs/$34.7 billion USD in direct industry output in urban and community forestry (Parajuli et al., 2022). Forested landscapes are foundational for subsistence and the cultural and spiritual traditions of many Tribal Nations (Lewis and Sheppard, 2005; Voggesser et al., 2014), from the Menominee and Anishinabek in the upper Midwest to the Wabanaki (Dawnland Confederacy) in Northern New England (including Passamaquoddy, Maliseet, Penobscot, Mi'kmaq, and Abanaki tribes).

The implications of climate change for forests in the Northeast and the Great Lakes regions are well-documented (Dale et al., 2001; Swanston et al., 2018). Primary changes are expected to result in shifts in precipitation and temperature dynamics, changes in forest hydrologic cycles, shifting populations of plants and animals, increasing frequency and severity of disturbances (e.g., fire, wind, pests and pathogens), and more (Rustad et al., 2012). An increasing frequency of extreme rainfall events, shortened winter harvest seasons, reduced snowfall, increased variability in weather patterns, and increasing pressure from invasive species are among the effects anticipated by forestry Extension and other outreach specialists in the Northeast and Midwest (vonHedemann and Schultz, 2021). Consequently, there are concerns that climate change will fundamentally alter ecosystem functioning and how humans interact with forests (Löf et al., 2019; Voggesser et al., 2014).

Rural and urban forests are likely to face sometimes overlapping and sometimes distinct challenges associated with a changing climate. Common challenges include the potential northward expansion of some invasive pest species. Other challenges are notably different depending on where a forest sits along the rural-to-urban gradient. For example, reduced snow pack in rural forest ecosystems in the Northeast and Great Lakes States will likely lead to deeper freezing, which may in turn lead to more pronounced root damage (Swanston et al., 2018). In many urban settings, reduced snow pack is less likely to represent a significant departure from the norm. However, increasing daytime and nighttime temperatures are expected to exacerbate heat island effects and increase the importance of street tree watering (Daniel et al., 2018).

Forester approaches for dealing with common challenges are necessarily shaped by their particular context. For example, treating trees with injectable or pourable, systemic insecticides for pests like emerald ash borer (EAB, *Agrilus planipennis*) may be feasible in an urban setting (Flower et al., 2015; Smitley et al., 2010). Indeed, most literature on the subject can be found in arboriculture and urban forestry literature. Tree injections are, however, rarely logistically or economically feasible in large-scale rural forests. Exceptions include use of emamectin benzoate (the insecticide of choice) in some ash seed orchards, on select state lands, and by some Indigenous foresters seeking to preserve important traditional seed sources (McCullough, 2020). In most cases, a rural forester is more likely to address EAB infestation by monitoring and harvesting to reduce abundance of host species in the canopy layer (D'Amato et al., 2023).

There is a growing imperative to adapt forest and urban management in light of climate change (Khan and Conway, 2020; Millar et al., 2007; Schuurman et al., 2022). Failure to do so could lead to negative ecological outcomes at local, regional, and global levels in rural and urban settings. Depending on the region, this could manifest as degraded water quality (Mikkelson et al., 2013), elevated greenhouse gasses emissions (Miles and Kapos, 2008), higher seasonal temperatures (Bonan, 2008), catastrophic wildfire (Mansoor et al., 2022), or biodiversity loss (Doroski et al., 2022; Mori, 2020). Failure to adapt to changing environmental conditions may also negatively affect rural communities that depend economically on wood products and recreation, translating into loss of jobs and income. In urban settings, climate change effects including heat, urban flooding, increased frequency and severity of wind can lead to reduced canopy cover and depressed provision of ecosystem services (Ordóñez and Duinker, 2013). This potentially translates into higher municipal expenditures on tree management, increased energy costs for local residents, and health and safety concerns. Though adaptation is imperative, successful adaptation varies by ecological, social, and economic context. Clarifying how these contexts and the constraints therein differ is important to advancing climate adaptation guidance.

1.1. Climate change adaptation in forestry

Fundamentally, forests are social-ecological systems where humans and ecosystems affect and are affected by one another over time in complex ways (Fischer, 2018). In the context of climate change, the effects of many forest and urban forest management approaches are uncertain, and managers must often make decisions without a clear understanding of probable outcomes (Yousefpour and Hanewinkel, 2015). Investigations in the upper Midwest of the United States suggest that rural and urban forest managers are taking proactive, as opposed to reactive, adaptive actions, and that adaptation strategies are often incremental as opposed to transformational (Brandt et al., 2021).

In the Northeast, rural forest managers adapt to climate change using strategies such as invasive plant management, silvicultural prescriptions, monitoring, changing their management timeline, and redesigning access to harvest and management areas, among others (McGann et al., 2022), though these strategies are not always accepted or condoned by the public at large (McGann et al., 2023). Studies of foresters' perceptions of climate change from around the globe suggest that these individuals understand that climate change will have significant effects on forest ecosystems (Sousa-Silva et al., 2016), and are interested in using long-term climate information to inform their management approaches (Carlton et al., 2014). Likewise, urban foresters are increasingly required to incorporate new or climate-exacerbated challenges into urban greenspace management. While urban trees are often presented as a solution to negative climate change effects (e.g., high temperatures deleterious to human health), it is also true that urban trees can be themselves negatively affected by these same stressors (Ordóñez and Duinker, 2013). Sensitivity of different tree species to changing environmental conditions, resistance to biotic and abiotic influences, ecosystem dynamics, interactions with human populations, and resource availability (e.g., water) all factor into the vulnerability of urban greenspaces.

The various adaptation strategies available to a forester may depend on many things, including forests' location along rural-to-urban gradients. Research that assesses rural forest vulnerability to environmental change and associated adaptive strategies are by far more common than similar studies addressing urban forests and green spaces (Piana et al., 2021). The few studies that have been conducted in urban spaces identify concerns about urban forest ecosystem resilience and a lack of strategic assessments of urban tree dieback and mortality due to climate change (Esperon-Rodriguez et al., 2022), which in turn stymies effective adaptive management. Concurrently, it is common in the research literature to focus on forestry professionals working in rural landscapes. These studies show that professionals who manage forested landscapes are diverse, working at a range of geographic levels, from local to regional (Laatsch and Ma, 2015).

Foresters working in rural and urban settings have different social and economic goals. Urban foresters may be responsible for maintain urban canopy cover, but make management choices based on ecosystem service potential, economic cost, and a need to address social equity (Nyelele and Kroll, 2020). For example, Wood and Dupras (2021) describe how planting trees capable of attaining significant canopy cover can decrease summertime energy use and increase carbon sequestration. However, some large-canopy species are especially vulnerable to the negative effects of climate change. Replanting species that succumb to climate-related stressors can be a costly endeavor, while planting structurally and functionally diverse urban trees can mitigate some risk of tree death and its associated costs. Rural forester goals, meanwhile, are influenced by the sector in which they work including industrial, state, federal, or private. In the United States, over a third of forest land is held by family forest owners (FFOs). A recent assessment of FFO land ownership motivations include (in descending order) but are not limited to: enjoying beauty, protecting wildlife, protecting water, protecting nature, land investment, and privacy (Sass et al., 2023). The decisions made by foresters working with these FFOs are heavily influenced by land owner priorities. These decisions differ from those typically made by industrial, state, or federal rural foresters, which are more commonly associated with managing for revenue generation and/or restoration.

To gain a better understanding of the diversity of forestry professionals in the Northeast and the Great Lakes regions, however, inclusion of both rural and urban foresters in studies of adaptive interest and capacity is essential.

1.2. Theoretical framework

A common framework used to guide research on adaptation in forest management in the United States is the *resistance-resilience-transition* (RRT) framework. In this framing, *resistance* practices are those that reinforce ecosystems against future environmental change and preserve forest ecosystem functioning; *resilience* practices are those that facilitate forest recovery from ecological disturbances, or "shocks" to the forest ecosystem; and *transition* practices are those that fundamentally change the forest ecosystem with the hope of improving the forest's resistance and resilience capacity under future environmental conditions (Millar et al., 2007). It should be noted that the RRT framework was developed for rural contexts, though application in urban forestry systems is also useful.

This framework is useful given that forests have varying composition and vulnerability to biotic and abiotic stressors, leading to similarly varied "tipping points" beyond which some sort of ecological transition is inevitable (Thom, 2023). Additionally, natural resource management in general is characterized by trade-offs. For example, optimal management strategies may be prohibitively expensive or may require unavailable resources, while suboptimal strategies may be more feasible. Interventions can be prioritized using this new combined framework, along with analyses of the acceptability and probability of forest transformations (Higuera et al., 2022).

Considering the need for greater understanding about how foresters are responding to climate change, and the opportunity to increase communication and learning between urban and rural foresters, we pose following research questions:

(1) Are there differences in rural and urban foresters' level of concern related to climate change impacts?
(2) Do climate change concerns affect foresters' interest in specific adaptation strategies?
(3) What forest-management goals influence foresters' decisions to apply specific strategies?
(4) What limitations do foresters face when seeking to implement adaptation strategies?
(5) To what degree do urban and rural foresters express confidence in adopting climate change adaptation practices?
(6) What are the similarities and differences between the perspectives and experiences of rural and urban foresters, and what opportunities exist for learning across the rural-to-urban gradient?

The answers to these questions may help inform targeted program recommendations and policy interventions in support of future adaptive forest management.

2. Methods

2.1. Survey design and administration

Two surveys were conducted in 2020/2021. The first was targeted towards rural foresters, and was executed between 11/4/2020 and 12/29/2020. The second was targeted towards urban foresters, executed between 9/4/2020 and 1/4/2021. Each survey was tested prior to deployment with three forestry professionals familiar with each topic area, and revised according to their feedback. Final surveys were administered through Qualtrics. Surveys were designed to be completed in less than 30 min. No compensation was offered to participants.

For the survey of rural forest managers, we used purposeful informant sampling (Patton, 2002) targeting individuals in the Northeast and Great Lakes regions of the United States. We solicited participation through membership lists for the New England, New York, Michigan, Minnesota, and Wisconsin chapters of Society of American Foresters (SAF). We also targeted members of the Northeast and Lake States Region Forest Stewards Guild Chapters. Combined membership of these organizations totals 11,000 individuals, accounting for estimated overlaps in membership. Members of SAF and the Forest Steward Guild are likely to belong to one of the following groups: foresters, conservation professionals, and researchers.

Professionals employed to manage urban greenspaces come from a diversity of educational backgrounds and are grouped into numerous occupational categories including but not limited to urban foresters, arborists, public administrators, horticulturalists, outdoor recreation specialists, landscape architects, municipal planners, and engineers (O'Herrin et al. 2020). The International Society of Arboriculture estimates that only 20 % of professionals who practice stewardship of urban greenspaces are members of their association. Because of the hard-to-reach and diverse target population, we conducted the urban survey as a snowball sample, recognizing that we would need to take extra steps to ensure non-response bias and that our results may be susceptible to community bias. Participants were asked to forward the survey to 2 others in their network who may be interested. We solicited participation through the International Society of Arboriculture, whose membership includes urban foresters, arborists, city planners, civil engineers, landscape architects, and public managers. Because we were unable to target only the Northeast and Great Lakes region, this survey was distributed nationally.

Following completion of the online survey, we identified 12 foresters who operated in a rural environment, and 12 who operated in a rural environment. These individuals were identified by members of our team who had prior working relationships within these communities. The individuals were contacted by phone and assisted by a research assistant to complete the questionnaire. Phone respondents were assumed to be representative of non-responders, enabling us to compare responses between these individuals and those who responded to the online survey.

2.2. Analysis

The final number of valid surveys were 131 (rural survey) and 207 (urban survey), including both online and phone responses. We discarded survey responses in which the participant completed less than 50 % of survey questions.

To assess the likelihood that our survey population reflected the opinions and experiences of a broader population, we conducted a series of Kruskal-Wallis tests comparing online survey responses (collected through the solicitation approaches described above) and 12 phone respondents to each survey (assumed to be representative of non-responders). Tests were executed on using participant demographics (i.e., age, number of years practicing forestry, gender identity) as well as job responsibilities. For urban respondents this also included the proportion of their job dedicated to managing parks or urban natural areas and population of the municipality they work with; for rural respondents this included the type of organization they work for and the number of acres managed.

These comparisons showed no significant differences between online and phone respondents among rural or urban survey takers based on age or number of years practicing forestry. We observed no gender identity differences between online and phone responses among rural respondents ($H(1) = 0.468$, $P = 0.494$); however, there was a significant difference in the urban survey, with more women represented on the phone survey ($H(1) = 7.237$, $P = 0.007$). Across both surveys, men represented 78.6 %, women represented 19.5 %, and non-binary individuals represented 1.9 % on online responses. Men represented 60 % and women represented 40 % of phone respondents. No non-binary respondents participated by phone. There were no significant differences noted between phone and online survey respondents related to job responsibilities (proportion of their job dedicated to managing parks or urban natural areas, population of the municipality they work for, the type of organization they worked for, or the number of trees or acres managed). Because of these small differences, we assume that the risk of non-response bias influencing our results is minimal.

In question sets where respondent answers resulted in high correlation, such as when assessing forester concerns for climate change impacts, we used factor analysis to reduce factors into meaningful groups (Osborne and Costello, 2005). Assessment tests included Kaiser-Meyer-Olkin (KMO) tests, Bartlett's test of sphericity, and determinant of correlation matrices. To identify characteristics associated with resulting factors, we conducted a series of PerMANOVAs. Analyses were performed using the R base packages (R Core Team, 2021), as well as packages in R including ggpubr (Kassambara, 2022), vegan (Oksanen et al., 2022), pairwiseAdonis (Martinez, 2017), psyche (Revelle, 2022), and coorplot (Wei and Viliam, 2021).

Table 1
Survey respondent demographic summary. SD = standard deviation. Note that respondents could report working for more than one type of organization.

	Rural forester respondents (n = 131)	Urban forester respondents (n = 207)
Age	Mean = 51; SD = 13	Mean = 50; SD = 13
Gender identity	M = 76.0 % F = 15.7 % Other responses = 0.8 % non binary, 7.4 % missing	M = 69.4 % F = 19.9 % Other responses = 1.6 % non binary, 9.1 % missing
Average number of years working in reported profession	Mean = 23.6; SD = 14.0	Mean = 22.6; SD = 13.6
Average number of square miles or acres managed	Less than 49 acres (<1% of respondents) 50–99 (<1%) 100–9,999 (7.8 %) 1000–9,999 (18.6 %) >10,000 (55 %) not applicable (17.1 %)	Mean square miles = 38.5; SD = 20.9
Employment*	State agencies (n = 41, 31.8 %) Private consulting (n = 33, 25.6 %) Private industry (n = 11, 8.5 %)	Municipalities (n = 176, 73.6 %) Private consulting (n = 16, 6.7 %) State agencies (n = 13, 5.4.%) Non-profit orgs. (n = 12, 5.0 %) Conservation orgs. (n = 6, 2.5 %)

* Responses constituting less than 5 % of the sample size omitted from Table 1.

Table 2
Factor loadings for **rural** forester concerns related to forest management.

	Mean (SD)	Eigenvalue	Factor loadings	Cronbach alpha
Rural forester concerns (n = 120; degrees of freedom = 52; RMSEA = 0.035; Tucker Lewis Index = 0.975)				
Biotic and abiotic stressors	1.7 (0.69)	3.901		0.88
Tree damage due to more frequent extreme wind/ice events			0.86	
Heat stress on trees			0.86	
More frequent or severe drought			0.89	
Higher incidence of wildfire			0.74	
More extreme rainfall			0.59	
Reduced snowpack or freezing during winter			0.49	
Increased pressure from insects and diseases			0.49	
Concern about the ability to implement best management practices (BMPs)			0.42	
Operational challenges	2 (0.75)	2.147		0.77
Seasonal conditions disrupting harvest schedules			0.948	
Season conditions disrupting harvest activities			0.935	
Change in site accessibility			0.365	
Regeneration challenges	2 (0.73)	1.269		0.66
Increased herbivory			0.802	
Increased competition from plant species			0.333	
Difficulty achieving adequate, desirable regeneration			0.619	

Table 3
Factor loadings for **urban** forester concerns related to forest management.

	Mean (SD)	Eigenvalue	Factor loadings	Cronbach alpha
Urban forester concerns (n = 179; degrees of freedom = 101; RMSEA = 0.040; Tucker Lewis Index = 0.919)				
Biotic and abiotic stressors	1.9 (0.65)	2.952		0.82
More frequent or extreme drought			0.922	
Heat stress on trees			0.832	
Tree damage due to more frequent extreme wind/ice events			0.646	
Reduced snowpack or freezing during winter			0.581	
Urban heat island effect			0.429	
Increased pressure from insects and diseases			0.376	
Availability of planting stock			0.349	
Extreme precipitation			0.292	
Regeneration challenges	1.5 (0.73)	2.035		0.68
Increased competition from plant species			0.846	
Increased herbivory			0.792	
Increased pressure from invasive plant species			0.587	
Political and economic challenges	1.6 (0.68)	2.572		0.67
Political support for forest and tree management activities			1.023	
Public support for forest and tree management activities			0.795	
Availability of funding for tree maintenance			0.732	
Difficulty achieving adequate, desirable regeneration			0.404	
Level of cooperation between neighboring municipalities			0.258	
Development pressure and human users	1.9 (0.71)	2.035		0.71
Increased pressure from development			0.981	
Increased pressure from users of public space			0.593	
Infrastructure impacts on tree health			0.567	

3. Results

3.1. Description of respondents

Foresters working in the Northeast and Great Lakes regions were targeted for the rural survey, with respondents most frequently reporting that they work in Vermont (n = 31), Minnesota (n = 25), New Hampshire (n = 15), and Maine (n = 15). The most common

Table 4
PerMANOVA results showing significant relationships between climate concerns and foresters' interest in adaptation strategies.

	Concerns (factors)	Practices	Coefficient (R2)	P-value
Rural survey				
	Biotic and abiotic stressors	Identify reserves such as sensitive sites	2.18 (0.02)	0.04
		Manipulate species composition	2.88 (0.03)	0.05
		Manipulate stand structure	3.13 (0.03)	0.03
		Protect advance regeneration	3.43 (0.03)	0.02
		Adjust practices to reduce impact	3.03 (0.03)	0.03
	Operational challenges	Identify reserves such as sensitive sites	4.01 (0.04)	0.03
		Protect advance regeneration	4.14 (0.04)	0.03
	Regeneration challenges	Manipulate species composition	2.75 (0.03)	0.04
		Manipulate stand structure	3.71 (0.04)	0.02
		Reduce fuels or fire risk	4.78 (0.05)	0.01
Urban surveys				
	Biotic and abiotic stressors	Design tree installations to maximize benefits	2.35 (0.01)	0.05
		Manipulate urban tree diversity	5.22 (0.03)	0.01
		Diversity age classes	4.79 (0.03)	0.01
		Reduce the impact of biological stressors	3.19 (0.02)	0.01
	Regeneration challenges	Reduce the impact of biological stressors	3.19 (0.02)	0.01
	Political and economic challenges	Reduce the impact of biological stressors	3.77 (0.02)	0.02
		Develop watering plans	2.79 (0.02)	0.05
	Development pressures and human users	Manipulate urban tree diversity	4.34 (0.03)	0.01

type of forest managed was northern hardwood (n = 111, 21.7 %), followed by spruce-fir (n = 80, 15.7 %), mixed pine (n = 68, 13.3 %) and central hardwood/pine (n = 58, 11.4 %). Respondents from across the United States responded to the urban survey, with the most frequently reported states being Minnesota (n = 23), Colorado (n = 15), and Wisconsin (n = 13). Table 1 includes demographic summaries of both urban and rural respondents.

3.2. A comparison of rural and urban foresters' level of concern related to climate change impacts

In each survey, respondents were asked to report their level of concern about a variety of abiotic and biotic changes associated with climate change. Concern was rated on a 0–3 scale, with 0 indicating that the respondent was *not concerned* and 3 indicating that the respondent was *very concerned*. Among rural foresters, the impacts of greatest concerns included *increased pressure from insects and diseases* (mean score = 2.4), *reduced snowpack or freezing during winter* (2.3), and *seasonal conditions disrupting harvest schedules* (2.2); urban foresters reported high average levels of concerns about *increased pressure from insects and diseases* (2.4), *availability of funding for tree maintenance* (2.3), and *heat stress on trees* (2.2). Assessment of the data indicated the appropriateness of three factors for rural forester concerns, and four factors for urban forester concerns (Tables 2 and 3). All concerns that were asked about in each survey were loaded onto a factor. These groupings broadly related to concerns about biotic stressors, abiotic stressors, challenges that may disrupt management activities, and the ability to achieve regeneration.

The results of PerMANOVAs using the factors described above indicated that, among rural foresters, the state in which a forester works is likely to influence their level of concern about operational challenges (pseudo F = 1.73, P = 0.04) and regeneration challenges (pseudo F = 1.90, P = 0.03). The number of acres a forester reported managing was also significant (pseudo F = 1.74, P = 0.005). Specifically, those who managed 10,000 acres or more were more likely to be concerned about operational challenges. There were no characteristics that influenced how likely a rural forester was to be concerned about biotic or abiotic stressors, indicating that challenges grouped under this factor are shared similarly across all rural foresters in the study.

Among urban foresters, we found that the state a forester worked in influenced their level of concern about biotic and abiotic factors (pseudo F = 1.71, P = 0.01). City size affected urban foresters' level of concern about biotic and abiotic stressors (pseudo F = 1.82, P = 0.01), regeneration challenges (pseudo F = 2.25, P = 0.02), and development pressure and human users (pseudo F = 2.25, P = 0.02). Foresters working in small- or mid-sized cities were more likely to indicate concern compared to those working in very small municipalities (fewer than 1,000 people) or larger ones (more than 300,000 people). There were no characteristics that influenced how likely an urban forester was to be concerned about political and economic challenges.

3.3. The relationship between interest in adaptation and climate concerns

Rural foresters who were interested in implementing or who had already implemented climate adaptation strategies were more likely to report concern about biotic and abiotic stressors, operational challenges, and regeneration challenges, when compared to rural foresters who were not interested in these practices (Table 4). Likewise, urban forester respondents were more likely to indicate that they were interested in implementing or had already implemented climate adaptation strategies if they also indicated concern about biotic and abiotic stressors, regeneration challenges, political and economic challenges, and development pressures.

3.4. Forester adaptation goals: Principal and constituent adaptation motivations

Survey respondents were asked to report which management strategies they had already implemented, planned to implement, or were interested in implementing, and what motivated their decision or intention to implement these specific practices. Motivations were grouped into (a) *principal motivations*, which represent respondents' axiological beliefs, and (b) their *constituent motivations*, which contribute to the manifestation of a desired state. We provided three principal motivation options: "to maintain existing forest conditions", "to restore to past forest conditions", and "to change forest conditions to align with future climate". Constituent motivations were assessed through respondents' reports on their interest in specific management practices.

The primary motivation for rural foresters to engage in practices that reduced impacts to soils, riparian, or aquatic systems (Fig. 1) was to maintain existing forest conditions (Fig. 1). This was likewise the primary motivation for rural foresters interested in identifying reserves such as sensitive sites, those interested in manipulating species composition, and those hoping to protect advance regeneration. Meanwhile, the most frequently cited motivation among foresters who were interested in manipulating stand structure was a desire to restore past forest conditions. Of note, rural forester survey respondents who had already implemented, or were interested in implementing, planting trees or reducing fuels or fire risk were motivated by a desire to change forest conditions to better align with a future climate.

Among urban foresters we found that practices most likely to be motivated by a desire to maintain existing forest conditions included: promoting park, greenspace, or tree cover connectivity (Fig. 2); and developing watering plans or budgets. Restoring past

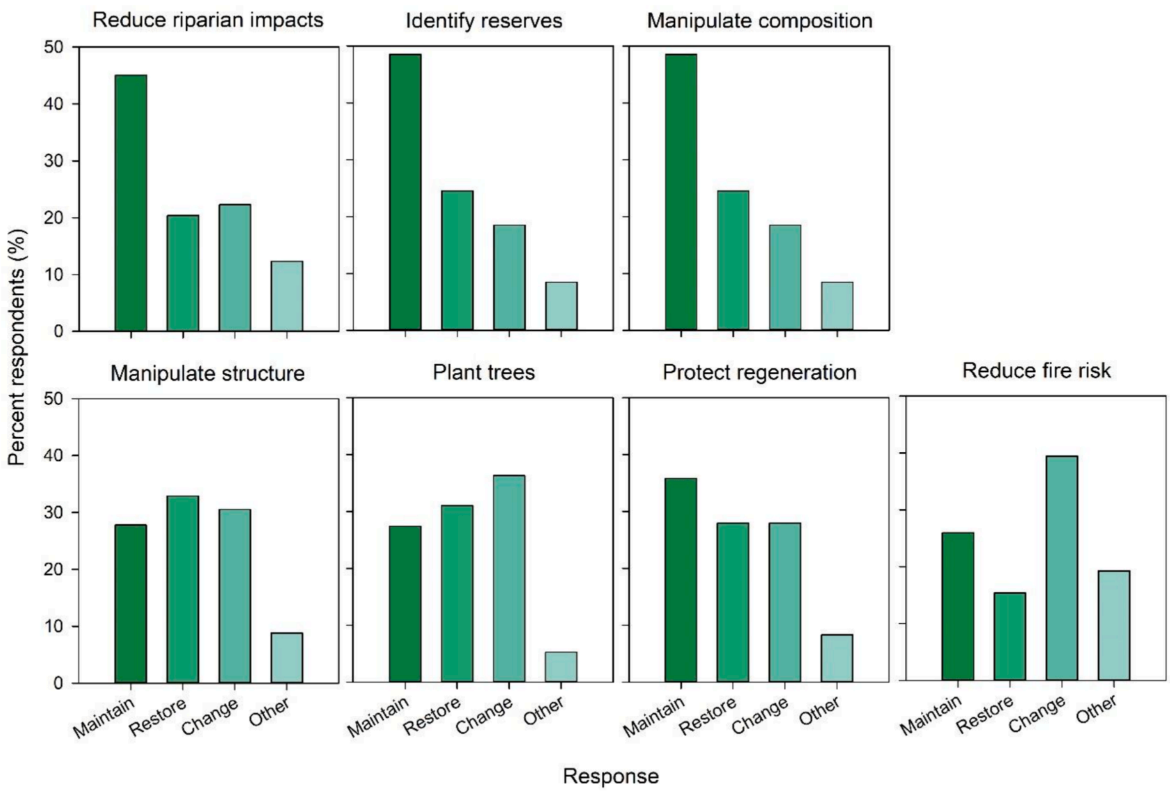

Fig. 1. Rural foresters' principle motivations for using specific adaptation practices. Panel headers: "Reduce riparian impacts" = Adjust practices to reduce impacts to soils, riparian, or aquatic systems; "Identify reserves" = Identify reserves, such as on sensitive sites; "Manipulate composition" = Manipulate species composition; "Manipulate structure" = Manipulate stand structure; "Plant trees" = Plant or seed trees, or implement other restoration practices; "Protect regeneration" = Protect advance regeneration, "Reduce fire risk" = Reduce fuels or fire risk. Response options: "Maintain" = To maintain existing forest conditions; "Restore" = To restore to past forest conditions; "Change" = To change forest conditions to align with future climate; and "Other" = Other reason.

forest conditions was not cited as a leading motivator for any practice. Eight practices were driven by urban foresters' desire to change forest conditions to align with future climate, including adjusting practices to reduce impacts to soils, riparian, or aquatic systems; manipulating urban forest tree diversity; diversifying age classes; manipulating stand structure; reducing tree or stand density; designing tree installations to maximize benefits; reducing the impact of biological stressors; and reducing the risk and long-term impacts of severe disturbances.

We found that rural foresters are highly influenced by their perception of whether specific practices are likely to be successful, whether other managers have had success with this practice in the past, and whether the respondents themselves have had success with the practice in the past (Table 5). The economic returns of a practice, the perceptions of other forest managers, and public perception of a practice were less likely to be influential among rural forest managers. Among urban forest managers, social factors that were cited as

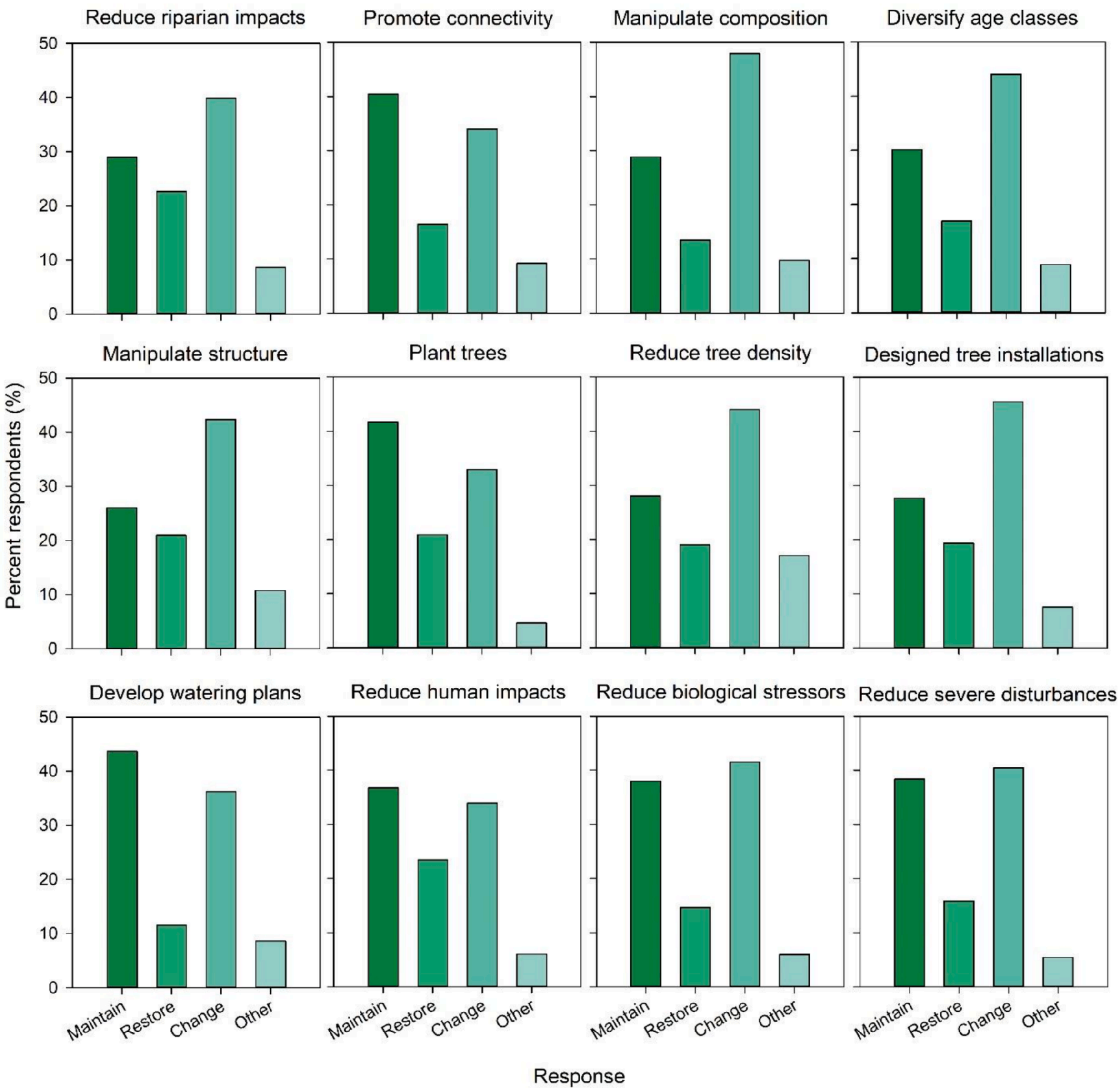

Fig. 2. Urban foresters' principle motivations for using specific adaptation practices. Panel headers: "Reduce riparian impacts" = Adjust practices to reduce impacts to soils, riparian, or aquatic systems; "Promote connectivity" = Promote park, greenspace, or tree cover connectivity; "Manipulate composition" = Manipulate urban forest tree diversity; "Diversify age classes" = Diversify age classes; "Manipulate structure" = Manipulate stand structure; "Plant trees" = Tree planting or restoration practices; "Reduce tree density" = Reduce tree and/or stand density; "Designed tree installations" = Designed tree installations to maximize benefits (stormwater, canopy, etc); "Develop watering plans" = Develop watering plans and/or budgets; "Reduce human impacts" = Reduce human impact in natural areas; "Reduce biological stressors" = Reduce the impact of biological stressors; "Reduce severe disturbances" = Reduce the risk and long-term impacts of severe-disturbances. Response options: "Maintain" = To maintain existing forest conditions; "Restore" = To restore to past forest conditions; "Change" = To change forest conditions to align with future climate; and "Other" = Other reason.

influential included: funding availability, how well the practice facilitates managers' ability to maintain greenspaces in the future, and the cost of the practice. The factors least likely to influence management decisions among urban respondents were other managers' perceptions of the practice, the potential for vandalism or misconduct; and coordination with neighboring municipalities. Urban foresters were likely to report that maintaining tree and stand diversity was a very important environmental factor that influenced their management decisions, as was supporting biodiversity, and stormwater mitigation. It should be noted that constituent motivation options differed between the surveys, based on suggestions from professionals working in each field during the survey development process.

3.5. Limitations faced by rural and urban foresters

The most frequently cited limitations faced by rural forester survey respondents across all practices were equipment availability, availability of financial resources, and workforce capacity (Figs. 3 and 4). Sixty-three percent of rural respondents who were actively reducing fuels or fire risk, 50 % of those interested in protecting advance regeneration, and 53 % of those interested in manipulating stand structure reported that workforce capacity was somewhat or very limiting. Rural foresters' ability to access information, regulations, and material availability were not widely perceived as limiting factors. The exception to this is that 74 % of those interested in planting or seeding trees noted that material availability was somewhat or very limiting. Rural foresters reported finances as being more limiting than any other factor, on average, across all practices. Workforce limitations were, on average, the second most limiting factor.

Among urban forester survey respondents, financial constraints and workforce capacity were frequently cited as limitations across all practices. Eighty-six percent of those interested in tree planting or restoration practices, 87 % of those interested in reducing tree

Table 5
Constituent motivations for use of adaptation practices reported by rural and urban foresters, including mean level of influence (0 = not at all influential, 4 = extremely influential) and standard deviation (SD).

	Motivation	Mean influence (SD)
Social factors		
Rural survey	The respondent thinks the practice is likely to succeed	3.10 (0.70)
	Other managers have successfully implemented the practice	2.87 (0.75)
	The practice has worked for the respondent in the past	2.87 (0.94)
	Landowner or supervisor requests	2.84 (1.15)
	Regulations	2.80 (1.22)
	Cost of practice	2.59 (0.99)
	Funding available for the practice	2.46 (1.25)
	The practice will serve as a demonstration	2.37 (1.11)
	Economic returns of the practice	2.02 (1.08)
	Public perception	1.76 (0.92)
	Perceptions of other managers	1.68 (0.88)
Urban survey	Funding available for the practice	3.15 (0.92)
	Ability to maintain urban greenspaces into the future	3.10 (0.87)
	Cost of practice (installation, maintenance cost, etc.)	2.92 (0.86)
	Potential to damage property (cars, buildings, etc.)	2.86 (1.03)
	Community support for the practice	2.75 (0.86)
	Respondents think the practice is likely to succeed	2.73 (0.82)
	Equitable access to green space	2.61 (1.05)
	Requests made by residents	2.54 (0.88)
	Competition between green space and development	2.50 (0.98)
	Other managers have successfully implement the practice	2.42 (0.95)
	Improvement of residents mental health	2.36 (1.12)
	Supervisor requests or directions	2.35 (1.20)
	Improvement of residents physical health	2.33 (1.07)
	The practice has worked for respondents in the past	2.33 (0.95)
	Permitting and regulations	2.28 (1.19)
	The practice will serve as a demonstration	2.14 (1.08)
	Other manager's perceptions of the practice	1.89 (0.99)
	Potential for vandalism or misconduct	1.63 (1.11)
	Coordination with neighboring municipalities	1.29 (1.09)
Environmental factors		
Urban survey	Tree diversity	3.19 (0.88)
	Biodiversity	2.78 (1.02)
	Stormwater mitigation	2.54 (1.01)
	Air quality	2.52 (1.07)
	Wildlife habitat	2.18 (1.08)
	Carbon sequestration	2.05 (1.15)
	Energy conservation	1.93 (1.09)
	Noise pollution	1.72 (1.14)

and/or stand density, and 80 % of those interested in reducing the impact of biological stressors were limited by workforce capacity.

Among urban forester respondents, workforce availability was cited as either the most limiting factor or one of the most limiting factors across most practices. Financial constraints were also noted consistently across practices. These two limitations dominated urban survey respondents' ability to implement adaptation practices, with other limitations being of much lower concern (Fig. 4). Notably, urban forest managers were also concerned about public opinion, specifically when it pertained to their desire to reduce human impact in natural areas and in tree planting or restoration activities.

3.6. Comparisons between rural and urban forester concerns, confidence, and motivations

We found no statistical difference in the level of concern reported by rural and urban foresters when it came to increasing insect and disease pressure, nor their concern about tree damage due to more frequent and extreme wind/ice events (Fig. 5). The level of concern about all other changes were statistically different between rural and urban foresters, with rural foresters being more concerned about reduced snowpack or freezing during winter periods, increased competition from plant species, more extreme rainfall, difficulty achieving adequate and desirable regeneration, and increased herbivory. Urban foresters indicated greater levels of concern about more frequent or extreme droughts and heat stress on trees.

Rural foresters are more likely to indicate confidence that manipulating stand structure and adjusting practices to reduce impacts to soils, riparian zones, or aquatic systems will be effective for climate change adaptation (Table 6). Meanwhile urban foresters are more

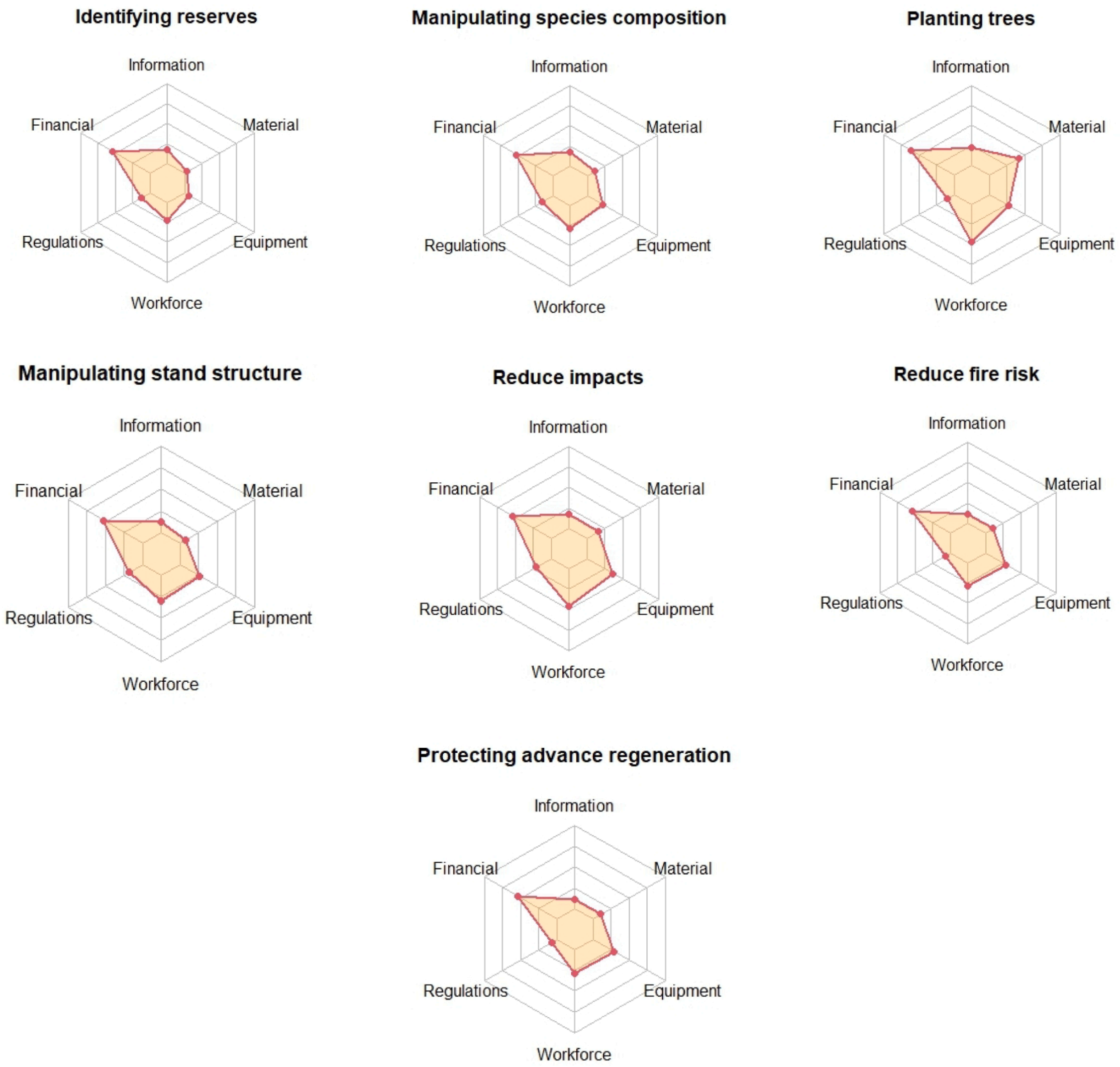

Fig. 3. Rural foresters who were interested in implementing specific adaptation practices reported limitations to achieving specified management practices. Respondents ranked limitations on a scale of 0 (not limiting) to 4 (extremely limiting). Points on each limitation axis represent mean scores.

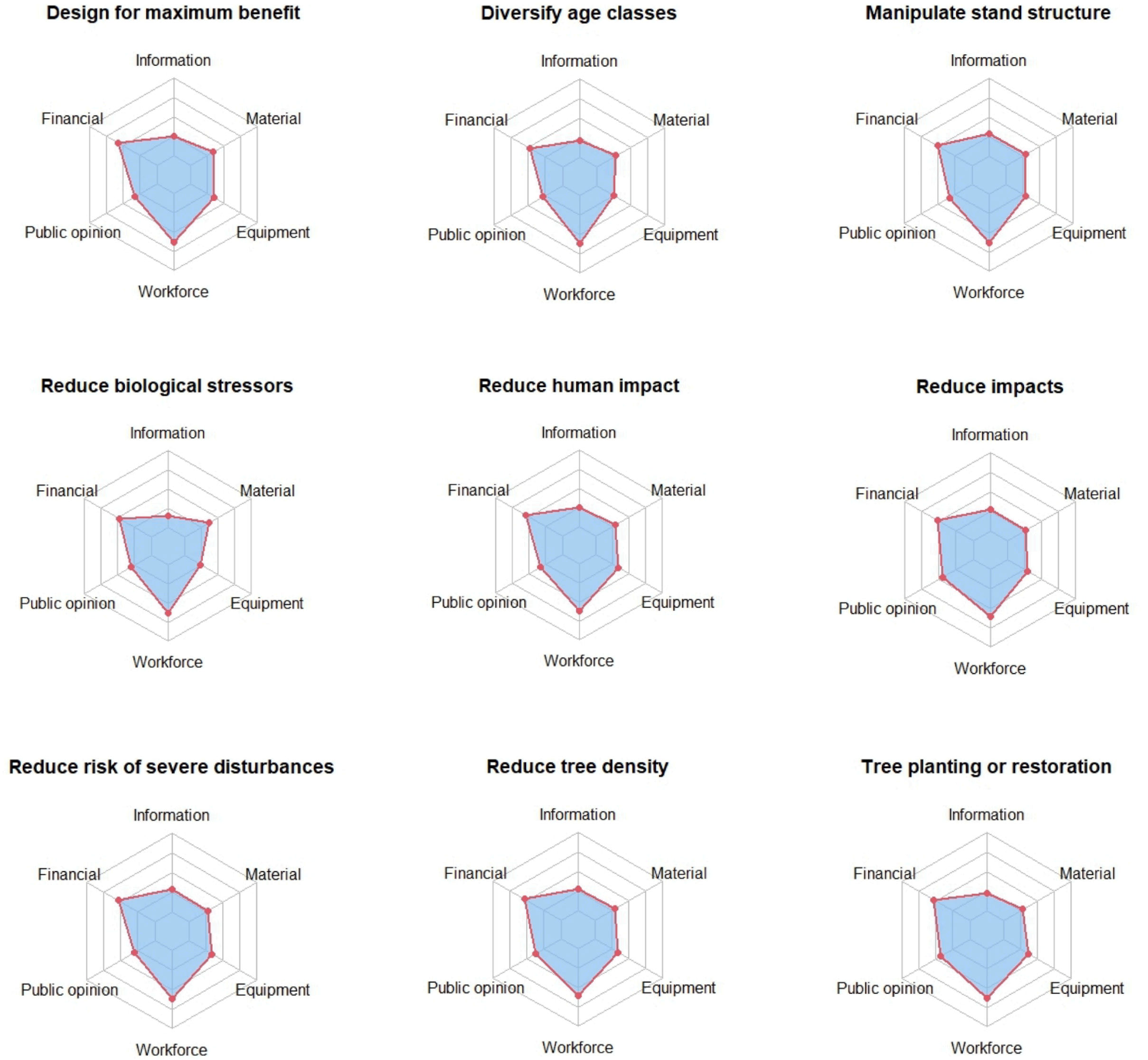

Fig. 4. Urban foresters who were interested in implementing specific adaptation practices reported limitations to achieving specified management practices. Respondents ranked limitations on a scale of 0 (not limiting) to 4 (extremely limiting). Points on each limitation axis represent mean scores.

likely to indicate confidence that planting or seeding trees or implementing other restoration practices will be effective for adapting to climate change, as will manipulating species composition and diversity of tree species. A similar pattern was evident when foresters were asked about their personal ability to implement or maintain a strategy, with the notable deviation that both urban and rural foresters were very likely to indicate confidence in species manipulation.

We then compared the motivations of urban and rural foresters in four categories aligned with the RRT framework. Specifically, we asked foresters if they were motivated to implement specific practices to maintain existing forest conditions (*resist*), restore past forest conditions (*resilience*), or change forest conditions to align with future climate (*transition*). T-tests with Bonferroni corrections showed significant differences between rural and urban foresters regarding four practices that were asked about in both surveys. Specifically, more urban foresters were interested in tree planting or restoration practices for maintenance purposes or to restore past forest conditions. More rural foresters were interested in manipulating species composition to restore past forest conditions and were likewise interested in manipulating stand structure for the same reason. Manipulating stand structure was also of greater interest to rural foresters who were motivated by maintaining current conductions. Rural foresters who wished to maintain current conditions were also interested in adjusting practices to reduce impacts to soils, riparian zones, or aquatic systems.

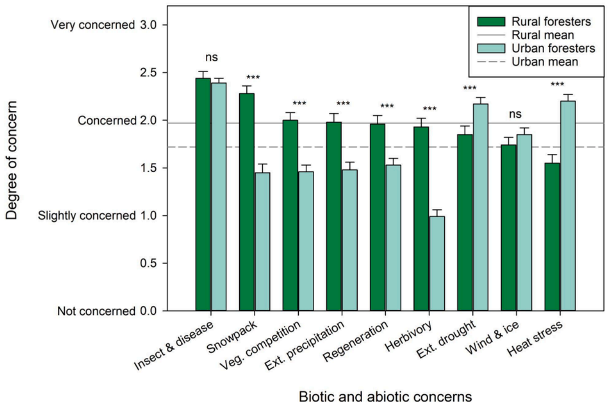

Fig. 5. Rural and urban forester concerns about climate-related changes. *** indicate significant differences between urban and rural responses at the ≤0.001 level, *ns* = no significant difference between concerns of rural and urban foresters. Column labels: "Insect & disease" = increasing insect and disease pressure; "Snowpack" = reduced snowpack or freezing during winter periods; "Veg. competition" = increased competition from plant species; "Ext. precipitation" = more extreme rainfall; "Regeneration" = difficulty achieving adequate and desirable regeneration; "Herbivory" = increased herbivory; "Ext. drought" = more frequent or extreme droughts; "Wind & ice" = more frequent and extreme wind/ice events; "Heat stress" = heat stress on trees.

4. Discussion

4.1. Challenges faced by foresters when adapting to climate change

Both rural and urban foresters are concerned with biotic and abiotic challenges associated with climate change and forestry, with notable differences between these two groups. Rural foresters reported being more concerned with harvest operational challenges while urban foresters were more concerned with policy and economic challenges.

In both settings, foresters expressed high degrees of concern with increased pressure from insects and diseases, which reflects the dramatic negative effects that these pressures have on both tree health and ecosystem services (Boyd et al., 2013). Both tree and pest species physiologies are anticipated to change due to climate change, and there is great concern that tree health will suffer from this shift (Brandt et al., 2021; Fahey et al., 2013; Tubby and Webber, 2010). Interventions often focus on biosecurity, with the focus being on transnational, national, state, and local policies. Such approaches include mandating pre-and post-entry inspections of wood and wood products, quarantines, and eradication programs (Lovett et al., 2016). Such tactics are, however, outside of the direct control of most foresters. Future research could clarify how foresters' perceptions of self-efficacy do or do not influence their forest management strategies and invasive species management outcomes. It is also important to include forester experiences and perspectives in setting policies related to biosecurity and invasive management, as inclusion of natural resource managers in the policy setting process has been shown to inform and legitimize these policies (O'Connor et al., 2019).

Rural foresters indicated that they were concerned about challenges such as reduced snowpack and freezing during winter and disrupted harvest schedules. In the Northeast and Great Lakes regions, a large proportion of timber harvests occur during winter months when soils are frozen to minimize risks of soil erosion and compaction from harvesting equipment (Aust et al., 2004). Additionally, seasonal weight limits on roads restrict transport of equipment and harvested timber (Conrad et al., 2018). Shortened freeze-periods reduce harvest periods, and by extension the consistency of timber supply, income generated from stumpage (Conrad

Table 6
Forester confidence of the efficacy of, and their own ability to implement or maintain, climate adaptation strategies. Only strategies included in both the rural and the urban forester surveys are included. Survey respondents ranked their confidence on a scale between 0 = not confident and 3 = very confident.

Practice		Confidence the practice will work as intended		Confidence in own ability to implement or maintain a strategy	
		Mean (se)	*P*	*Mean (se)*	*P*
Plant or seed trees or implement other restoration practices	*Rural*	1.86 (0.08)	<0.0001	2.23 (0.07)	<0.0001
	Urban	2.54 (0.06)		2.63 (0.06)	
Manipulate species composition (rural) or manipulate urban forest tree diversity (urban)	*Rural*	2.22 (0.07)	0.0005	2.52 (0.05)	0.4987
	Urban	2.50 (0.06)		2.50 (0.07)	
Manipulate stand structure	*Rural*	2.37 (0.07)	0.0007	2.58 (0.05)	0.0004
	Urban	2.00 (0.08)		2.17 (0.08)	
Adjust practices to reduce impacts to soils, riparian zones, or aquatic systems	*Rural*	2.37 (0.07)	0.0017	2.53 (0.07)	<0.0001
	Urban	2.09 (0.07)		2.03 (0.00)	

et al., 2017; Rittenhouse and Rissman, 2015), and employment opportunities.

Among urban foresters, availability of funding for tree maintenance was reported as a challenge. Many urban trees grow in challenging conditions that necessitate significant maintenance, and we found that urban foresters are often concerned specifically with the effects of heat stress on urban trees. Watering is the primary way to mitigate heat stress, requiring water availability, equipment, and labor (Daniel et al., 2018). Financial support for urban tree programs (including watering programs and planting activities) varies by municipality, with many cities struggling to secure sufficient and consistent funding. Some urban tree programs rely on private contributions of labor, supplies, and materials. We posit that private funding approaches are not ideal, and that municipalities may benefit from developing sustainable funding strategies for urban tree maintenance given the significant public benefit and cost savings that urban trees provide (Nowak and Greenfield, 2018).

4.2. Convergent and divergent motivations and limitations

Prior research shows that foresters often pursue a diversity of management options simultaneously (Ontl et al., 2018). Our analysis of foresters' principle and constituent motivations suggests that many are seeking to maintain current forest conditions or restore forest conditions following a disruption or change. A focus on resistance and resilience strategies has previously been documented among urban foresters (Khan and Conway, 2020) and rural foresters (McGann et al., 2022). This is particularly noteworthy considering the increasing calls for proactive adaptation in forestry and other land management sectors (D'Amato et al., 2017; Janowiak et al., 2021; Locatelli et al., 2015; Swanston et al., 2018). Even as this range of strategies may be conceived of as climate-adaptive in concept, foresters may not explicitly conceive of them as such. Accordingly, the divergence between forester motivations and the recommendations of scholars could lie in the overlap between climate adaptation practices and well-known "best management practices". In a nation-wide study of Extension and outreach specialists working with family forest owners, it was noted that some forest managers question the degree to which climate-adaptive forest management differs from traditional silvicultural approaches (vonHedemann and Schultz, 2021). By not addressing climate change explicitly in management decisions, however, management choices (including how intensively or broadly a practice is applied, or the timescale within which it is implemented) may not effectively address the particular challenges associated with a rapidly changing environment.

Among rural foresters, motivations may be rooted in the historical land management approaches common to the Northeast and Great Lakes regions, from European colonization onward. It is well documented that many of these practices led to reduced forest structural diversity and simplified species composition. Such simplification across the forested landscape is thought to reduce resistance and resilience to the negative effects of climate change (Messier et al., 2019). Conversely, structural complexity has been shown to improve forest ecosystem adaptability (Seidel and Ammer, 2023) and can mitigate the negative effects of post-colonial management approaches.

In this study, rural foresters reported interest in maintaining current forest conditions through manipulating species composition and stand structure, identifying reserves and sensitive sites, and adjusting practices to protect soils, riparian and aquatic ecosystems. These approaches suggest active interest among rural foresters in using ecosystem complexity (e.g., diversified age classes, species, and functions) to improve the health of forests. This reflects a broader shift in rural forest management towards integration of ecological models to guide stand and landscape-scale decision making over the past several decades (Himes et al., 2022; Palik et al., 2020).

Among urban foresters, planting trees was reported as an important maintenance strategy. Our results are reflective of both the common nature of this practice and the relatively high mortality rate of trees grown in challenging urban environments (Smith et al., 2019). Other important approaches included developing watering plans, reducing human impacts, reducing severe disturbances and biological stressors. Notably, the two primary challenges reported by urban foresters in this study were availability of funding and workforce capacity. This supports prior research which finds that unreliable or non-transparent funding streams can dilute the efficacy of urban forestry and greenspace programs (Pincetl et al., 2013).

Foresters who responded to our surveys also indicated that they were motivated to manage forests for transition. Literature suggests that common transition practices among rural foresters include partial harvests and uneven age management that supports regeneration of specific species (Lei et al., 2009). Such strategies can alter rural forests over decades or hundreds of years (Duveneck and Scheller, 2016; Gustafson et al., 2020; Nevins et al., 2021), and can promote complexity in forest structure. Meanwhile, in urban settings tree planting practices, human development, and high mortality among street trees contributes to a relatively rapid flux in the urban tree canopy (Bonney and He, 2019). Tree planting is common in urban settings due to the high rate of tree-death due to biological factors (e.g., taxa, tree size/age, and planting site characteristics) and human factors (e.g., stewardship, maintenance, and vandalism) (Hilbert et al., 2019). However, tree planting in rural forests is an emergent interest, the practicality of which is being evaluated as a transition approach (Clark et al., 2022; Palik et al., 2022).

For many of the practices asked about in our surveys, foresters reported that financial risk was a limitation in their ability to apply adaptation practices. Alleviating some of the financial risk may increase foresters' willingness to trial a particular adaptation strategy. Several funding mechanisms of this nature currently exist. For example, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) currently provides incentive funds for tree planting on private lands. To meet the goals of the recently released USDA Action Plan for Climate Adaptation and Resilience (2021), NRCS is expanding its efforts to support adaptation to and mitigation of climate change in the United States, including forest adaptation. Several practices included in this review are align with provisional practices in the NRCS Climate Smart Agriculture and Forestry (CSAF) Mitigations Activities List for FY2024, including *creating structural diversity with patch openings* (practice code E666K), *forest stand improvement to rehabilitate degraded hardwood stands* (E666L), and *facilitating longleaf pine regenerations and establishment* (E666S) (USDA-NRCS, 2023). Ensuring that forest managers in urban and rural areas are aware of, and supported to apply to, new and existing NRCS programs is of great importance. While investments in forest management activities have been declining over the past decades (D'Amato et al., 2017), recent signs of investment that could translate to ecological or adaptive practices have arisen (e.g., the Inflation Reduction Act, Subtitle D, section 23003 (USDA, 2023)). Additionally, payment for ecosystem service (PES) programs – which are common in the Global South (Jones et al., 2020) but are still emerging in the United States – may provide future income to forest land owners. We suggest further research that explores forester awareness of these programs, and their willingness to engage.

Both rural and urban respondents reported that workforce capacity limited their ability to implement management strategies. Employment in this industry has been declining over several decades, however, with the 2008 economic recession driving a severe decline (He et al., 2022). This was due to a decrease in demand for wood construction materials, pulp and paper, and furniture materials (Hodges et al., 2011). Even when market demand is high, however, rural foresters report challenges with finding loggers to work with (McGann et al., 2022). Our study suggests that this limitation also affects urban foresters, though further research would be helpful to identify which specific roles and professional training are needed to meet needs in urban forest management programs.

4.3. *Opportunities for learning across the rural-to-urban gradient*

Our study confirms prior research that shows that foresters perceive interconnected risks associated with changing environmental conditions, social attitudes towards forestry and timber harvesting, and market conditions (McGann et al., 2022, 2023). Because of the divergent, though related, natures of rural and urban forestry, we propose that future educational programs connect foresters along the rural-to-urban gradient to share how they have addressed some of these challenges. Our survey results show that rural and urban foresters are more confident in (a) practice efficacy and (b) their own ability to implement a practice when it is an approach that they are familiar with, or that is common in their industry. For example, rural foresters report confidence in applying natural regeneration strategies, while urban foresters are more confident in planting trees and engaging with the public.

Though the contexts of rural and urban forestry are in many cases very different, there are opportunities for learning across the rural-to-urban gradient. Urban forester might increase the structure and function of typically "unmanaged" natural areas by employing rural forest expertise related to establishment and long-term maintenance of large, ecologically complex forested areas. Rural foresters could incorporate the expertise of urban foresters in topics like tree planting and management of individual trees for amenity value, practices that are currently uncommon in the Northeast and Great Lakes regions. This is especially important to explore given the uncertainty of future climates, which necessitate creative thinking about adaptation in rural and urban forests.

To expand upon this important point, urban foresters may benefit from longer-range planning than is typically practiced. In urban settings, planning occurs on a relatively short time frame, though this varies depending on the type of urban greenspace. Prior guidance for urban forest management suggests that urban street trees have an expected lifespan of 10–25 years (Galvin, 1999), significantly shorter than most trees in rural forests (North et al., 2018). Street trees and smaller patches require frequent maintenance and replacement. However, recent research shows that larger urban forest patches behave similarly to secondary forests in adjacent rural areas in terms of succession and other natural processes (Doroski et al., 2022), and by extension may require less intensive management than small forested patches or individual street trees. Though planting is common in urban contexts, larger greenspaces present opportunities for natural recruitment of native trees, which can improve the green infrastructure of cities and generate associated ecosystem services (Doroski et al., 2018). Of course, monitoring for recruitment of non-native species is particularly important in these contexts given the relatively high potential for invasions in urban contexts (Cadenasso et al., 2007; Johnson and Handel, 2016). Urban forest managers could potentially benefit from learning from and with their rural counterparts, specifically on topics related to establishment and long-term maintenance of large, ecologically complex forested areas within cities (Ordóñez and Duinker, 2013).

Rural foresters can also learn directly from urban foresters on topics such as tree planting, a practice that is currently uncommon in the Northeast and Great Lakes regions. Despite a historic lack of tree planting in these areas, interest among forest landowners in the United States is increasing and reforestation efforts are common in other parts of the world. Sourcing planting stock, species selection, and other elements of planting programs remains a challenge (Fargione et al., 2021) and are areas in which urban forester experiences can help inform rural approaches. Notably, large scale rural tree planting programs have been critiqued for lack of attention to ecosystem-scale carbon capture, ecosystem disruption, missed potential for natural regeneration, and diminished biodiversity (Di Sacco et al., 2021; Fleischman et al., 2020). These critiques are leveled at monoculture tree plantings, which differ greatly from tree planting focused on improving stand age and species diversity and re-introducing complexity into forest ecosystems.

Additionally, urban foresters have long interacted with the public prior to installation or during maintenance of municipal green spaces. Gaining such approval has been called a *social license to operate* (Wang, 2019), or the ability to manage a natural resource with the public's approval for the public good. Public engagement in urban contexts includes community meetings, engaging the press, inviting public participation in management activities (when safe and possible), etc. Rural foresters have not traditionally needed to engage the public, though this may be changing. One catalyst for such engagement is the emerging "pro-forestation" movement, which some foresters believe threatens their social license to apply silvicultural interventions (McGann et al., 2023). To protect their social license to harvest timber and use other silvicultural interventions, rural foresters would benefit from an improved ability to communicate with a broader group of stakeholders. The relatively greater degree of public engagement experience held by urban foresters presents another opportunity for learning across the rural-to-urban gradient.

Confidence in personal and practice efficacy is an evidence-based, though often omitted, element of the climate adaptation process. Peer-to-peer learning has been shown to improve confidence among foresters (Kueper et al., 2014) and other land managers. For example, research about agricultural conservation practice adoption suggests that farmers are more likely to consider adopting a new practice if they see other farmers using it (Roesch-McNally et al., 2017). To bolster forester confidence in trying new (to them) climate adaptation strategies, we suggest further investment in demonstration sites and outreach programs with a peer-to-peer focus. Specifically, we suggest bringing rural and urban foresters together for this purpose. The importance of knowledge transfer, improved communication, and demonstration of different adaptation strategies can lead to important innovations (Sousa-Silva et al., 2016).

4.4. Limitations

This study represents one of few that compares rural and urban forester perspectives on climate change risks, adaptation, and limitations to those adaptations. Though incorporation of these two groups of foresters is valuable, we acknowledge the limitations in directly comparing them. Specifically, the diverse nature of professional urban forestry required our sampling strategy to be very broad (national) while our outreach to rural foresters was limited to the Northeast and Great Lakes regions of the United States. The concerns of urban foresters in regions outside of the Northeast and Great Lakes likely varied from those of foresters from within these two regions, where pressures like wildfire and restricted water resources are relatively small.

Though we sought to address non-response bias in both samples through telephone solicitation, we assume that a wide range of urban greenspace managers did not receive an invitation to our survey and that their perspectives are not captured here. Additionally, we acknowledge that the number of phone respondents and respondents overall was small considering the number of urban and rural foresters working in our study area. By using a key informant sampling approach for the phone respondents, we may have limited the diversity of perspectives represented in this sample. With this in mind, we suggest that the present study not be assumed to represent rural or urban farmers as a whole, and that future research be carried out to more thoroughly understand the perspectives and experiences of urban and rural forest managers. This work could build on the research of Dahle et al. (2020), which looks at the entry level skills of urban forestry professionals, and O'Herrin et al. (2020), who document the diversity of career trajectories held by those who practice urban forestry.

Additionally, when asking survey respondents to report their constituent motivations for climate change adaptation, we recognize that we did not offer identical survey response options. This was due to the high degree of input offered by collaborating professionals. Future studies along these lines could again compare these two populations of foresters, and include lists of motivations that are more closely aligned with one another.

5. Conclusion

As the planet continues to warm, both rural and urban foresters will need to employ adaptation strategies to contend with a multitude of biotic and abiotic stressors. This study contributes to our understanding of how foresters think about the risks associated with climate change, as well as their management goals, and any limitations they face when striving to meet those goals. We conducted two surveys, one targeting rural foresters in the Northeast and Great Lake regions, and one targeting urban foresters across the United States.

While there are common concerns reported by survey respondents across this study, many concerns are distinct based on whether that forester operates in a rural or urban context. Additionally, urban and rural foresters are confident applying different strategies and practices, though there are important opportunities for learning from each other, across the rural-to-urban gradient.

We find that many foresters are expressly interested in maintaining current forest conditions, with a focus on facilitating forest resistance and resilience. Foresters are also interested in transitioning forests to conditions conducive to a future climate, though foresters sometimes report low confidence in strategies that could prove to be essential in transition efforts. Foresters, like other natural resource managers, are highly influenced by whether a specific practice is likely to be successful, whether other managers have had success with this practice in the past, and whether the respondents themselves have had success with the practice in the past.

The results of these surveys suggest that foresters may not currently have all the tools they need to successfully adapt to climate change. In illustration, urban foresters struggle to secure adequate funding for maintaining municipal greenspaces, despite the public benefits derived from these greenspaces. Both urban and rural foresters are limited by labor availability. To enable foresters to successfully address climate change, and to protect the health and functioning of these important ecosystems, public policy and outreach would benefit from the following: (1) learning across the rural-to-urban gradient, (2) public engagement trainings and opportunities targeting foresters, (3) workforce development programing, and (4) programs that limit the financial risk that foresters face when applying adaptation strategies to the forested landscape.

In the future, rural and urban foresters would likely benefit from enhanced opportunities to learn from each other. Urban foresters may draw upon the expertise of their rural peers when seeking to complexify the structure and function of typically "unmanaged" natural areas. Rural foresters could incorporate the expertise of urban foresters when developing strategies such as tree planting and management of individual trees for amenity value, practices that are currently uncommon in rural forest management in Northeast and Great Lakes regions. Additionally, by working together both rural and urban foresters can more effectively learn from research that pertains to forestry along the rural-to-urban gradient. Sharing knowledge and skills between these aligned disciplines will be key to enhancing rural and urban forests for years to come.

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CRediT authorship contribution statement

Rachel E. Schattman: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Peter Clark:** Data curation, Formal analysis, Visualization, Writing – review & editing. **Anthony W. D'Amato:** Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing. **Todd Ontl:** Conceptualization, Methodology, Writing – review & editing. **Caitlin Littlefield:** Conceptualization, Investigation, Writing – review & editing. **Eric North:** Conceptualization, Investigation, Methodology, Writing – review & editing.

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

The data that has been used is confidential.

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Appendix A. Supplementary material

This survey instruments used for this project have been licensed under CC BY4.0. Users are required to attribute references of this survey instrument using the citation below. If you transform the survey and use it for your own purposes, any copyrighted derivatives must be distributed under the same license as the original survey. Suggested citations:

- Schattman, R.E., D'Amato, T.W., Littlefield, C., Ontl, T., North, E., McGann, T., 2021. Urban Forest Manager Survey. DOI: 10.6084/m9.figshare.16540134.
- Schattman, R.E., D'Amato, T.W., Littlefield, C., Ontl, T., McGann, T., 2021. Northern Forest Manager Survey. DOI: 10.6084/m9.figshare.16540065.

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