UNIVERSITÉ DU QUÉBEC À MONTRÉAL

IDENTIFICATION OF THE MOST DAMAGING ENVIRONMENTAL PRESSURES FOR THE URBAN TREES OF THE NORTHEAST OF NORTH AMERICA: A DELPHI APPROACH

MÉMOIRE
PRÉSENTÉ
COMME EXIGENCE PARTIELLE
À LA MAÎTRISE SUR MESURE : DÉVELOPPEMENT DURABLE ET CONSERVATION DES RESSOURCES NATURELLES RENOUVELABLES

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JUIN 2021

ACKNOWLEDGEMENTS

Thanks to my research directors, Jérôme Dupras and Christian Messier for their support and understanding. A big thank you to Rita Sousa, for her advice and guidance in this project. I also thank all the participants of the questionnaires, without them this research would not have been possible. Finally, thanks to everyone that have been by my side and supported me throughout the master's degree, from near and far.

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LIST OF ABBREVIATIONS AND ACRONYMS

CEF: Centre d'étude de la forêt

CSQB: Centre de la science de la biodiversité du Québec

2RLQ: Le Réseau Reboisement et Ligniculture Québec

ISFORT: Institut des Sciences de la Forêt tempérée

SD: Standard deviation

WAR.: Weighted average rank

ABSTRACT

The importance of urban forests and their benefits is being increasingly acknowledged and valued. However, the potential sensitivities of urban trees to urban disturbances are less well documented. For the future development of the green zones in cities, further research is needed as climate change is expected to increase the risk of disturbances to trees. The purpose of this project is to gather information about the tolerance of different urban tree species to several disturbances affecting trees in cities of northeastern North America using a closed survey and the Delphi method. This method consists of different rounds of questions aiming to achieve consensus on the opinions of different respondents (here, experts on urban forestry). This research has shown that urban environments are highly complex, as well as the tolerance of various urban tree species to the different disturbances that exist in cities. Among all tree species that have been most often mentionned in the questionnaires answered by the experts to be tolerant to the different stresses are *Gleditsia triacanthos*, *Quercus* sp., *Ginkgo biloba* and *Ulmus* sp., though none of them were rated as tolerant for all types of disturbance. Furthermore, in both questionnaires there was a lack of agreement regarding some disturbances. This has allowed us to see where there might be a possible gap in knowledge about the tolerance of key urban tree species. This can be used as an argument for conducting empirical experiments or more in-depth research on disturbances where there is a lack of agreement.

Keywords : Delphi method, urban forestry, urban stressors, tolerance, urban disturbances, resistance, resilience

CHAPTER I

IDENTIFICATION OF THE MOST DAMAGING ENVIRONMENTAL PRESSURES FOR THE URBAN TREES OF THE NORTHEAST OF NORTH AMERICA: A DELPHI APPROACH

INTRODUCTION

1.1 Urban forests

Urban forests encompass street trees, private trees, green spaces such as parks and woodlands, and related abiotic, biotic and cultural components in areas extending from the urban core to the urban-rural fringe (Tree Canada, 2019). They are defined by their proximity to the human population, and they are part of the urban development. Urban forests tend to be a mix of planted and naturally regenerated tree species and they are usually managed to be sustained and provide benefits to the human population (Bolund & Hunhammar, 1999; Dupras & Revéret, 2015; Nowak & Greenfield, 2020).

In the pursuit of sustainability and resilience to climate change and other stresses, cities are investing in projects intended to support a range of ecosystem services such as water cycling, sound and pollution mitigation among others (Nowak, 2006; Oldfield et al., 2015). Trees also directly affect human populations by altering the social, economic, and aesthetic aspects of urban environments. These effects exist in all landscapes composed of trees, but are more prominent in urban areas because of the higher concentration of people (Robertson et al., 2016). Furthermore, they can help in the process of climate change mitigation(Hotte et al., 2015; Paquette et al., 2021), as they influence the air quality by absorbing particulate pollution (Robertson et al., 2016) and contribute to cooling the air, reducing the effect of the urban heat island by shading surfaces and evapotranspiration (Kleerekoper et al., 2012; Wang & Akbari, 2016)

In light of the different benefits that urban trees can offer, it is clear how important they are. Although, as direct and indirect human activities have amplified different disturbances, including unfavorable climatic conditions, more information is needed about the possible stresses that urban trees can suffer and the interactions of these stresses, which are not well documented (Guz & Kulakowski, 2020; Johnston, 2004; Ordóñez & Duinker, 2015; Steenberg et al., 2017).

In addition to this, in the last years, there has been a trend to lose tree cover in urban areas in north-eastern North America as well as around the world (Nowak et al., 2020). Many cities are becoming increasingly dense, with more impervious surfaces and less vegetation-growing space, which combined with climate change and other urban stresses creates difficult conditions for the growth of trees (Czaja et al., 2020; Jim et al., 2018).

For the future development of urban forests and cities, further research is needed on the tolerance of urban forests, since global change is expected to increase the frequency of the different disturbances. Climate change will bring warmer and wetter winters, hotter and drier summers and more damaging exotic insects and diseases, like the emerald ash borer or the pine beetle (Climate atlas of Canada, 2021; Colombo, 2016). In addition, these effects will interact with existing urban stresses such as air pollution, soil compaction and heat island effects (Johnston, 2004; Ordóñez et al., 2015). Therefore, climate change may affect tree species suitability to urban environments (Khan et al., 2020; Ordóñez et al., 2015). Future investigations are needed to better understand (1) the future climatic conditions and stresses that urban trees will be subjected to, (2) the basic ecological requirements of alternative urban species that could be planted to continue to provide desired ecosystem services, and (3) the resources that will be needed to maintain, if desired, the current composition of species in cities (Khan et al., 2020).

1.2 Problematic

With climate change and a growing number of people living in urban areas, the importance of urban trees is becoming clear (Colombo, 2016; CSS, 2013; Dupras & Revéret, 2015; Nowak, 2006; Oldfield et al., 2015). Trees and other urban green spaces are increasingly critical resources in north-eastern North American urban areas that impact environmental quality, health, economy and climate change resilience, among other benefits (Hotte et al., 2015; Robertson et al., 2016; USDA, 2020b). Even so, more information is needed about these valuable spaces to ensure they continue to provide ecosystem services in view of climate change (Johnston, 2004; Khan et al., 2020; Ordóñez et al., 2015; USDA, 2020).

Urban forests not only suffer from events that climate change can exarcerbate, like strong winds, insects and diseases, extreme temperatures, drought, snow and ice storms but also fromeffects drive by urbanization like air pollution, soil compaction and. de-icing salts, among others (Colombo, 2016; Khan et al., 2020; Locosselli et al., 2019).

Strong winds can also cause damage to urban trees. Studies have demonstrated that winds and storm surges can severely injure individual trees and forest stands, causing trees to defoliate, partially break, drop branches, topple, or uproot (Escobedo et al., 2009). Other research has documented that multiple topographic, meteorological and biological factors interact to influence the patterns of damage, but it is yet unclear the extent to which these previous findings are broadly representative and can be used to predict future urban forest damage (Kushla, 2017; Snepsts et al., 2020).

In addition, urban trees under stress from future droughts and higher temperatures will be increasingly vulnerable to other disturbances such **insects and diseases** (Dale et al., 2017; Seidl et al., 2017). Emerald ash borer, hemlock woolly adelgid, Dutch elm disease or Gloomy scale are good examples of pests that affect urban trees. Due to climate change, insects and diseases are projected to expand to higher latitudes. This can have devastating effects on urban trees, especially when it concerns non-native insects, which can seriously affect native tree species, as has already happened in cities in northeast North America (Colombo, 2016; Limbu et al., 2018; Raupp et al., 2006; Schlarbaum et al., 1998).

As climate change will bring warmer wetter winters and warmer drier summers in the following years (2ºC more on average by 2035)(Reidmiller et al., 2018), the resistance to **drought** (Brunner et al., 2015; Nitschke et al., 2017; Stokes et al., 2010; Stovall et al., 2019), as well as the resistance to **extreme temperatures** (Khan et al., 2020; Rosenzweig et al., 2001; Sjöman et al., 2016; University of Illinois, 2019) are going to be important requirements for urban trees (Dale et al., 2017; Johnston, 2004). The majority of trees in street environments in northern Europe and north-eastern North America originate from rich and moist forest habitats and consequently have a limited capacity to tolerate water deficits that frequently occur in paved sites (Colombo, 2016; Raupp et al., 2006; Sjöman et al., 2015). The relationship between drought and the other disturbances affecting urban trees still needs to be clarified (Dale et al., 2017; Gaxiola et al., 2001; Itter et al., 2019; Leksungnoen, 2012).

Snow is another disturbance that can damage urban trees (Anderson, 2019; Bisbing et al.,2019; Nix, 2021; Sommerfeld et al., 2018; Tavankar et al., 2019). The most common form of damage is stem breakage but trees can also be bent or uprooted. Trees suffering snow damage are also more prone to consequential damage through insects or fungal attacks. Snow accumulation on trees is strongly dependent upon weather and meteorological conditions (Nykänen et al., 1997). Temperature influences the moisture content of snow and therefore the degree to which it can accumulate on branches. Certain characteristics, like slightly tapering stems, asymmetric crowns, and rigid horizontal branching are all associated with high risk (Nykänene et al., 1997). In addition to snow, in cold weather, **ice storms**, characterized by freezing rain, happen as well (Robb, 2016; Seidl et al., 2017). Also known as glaze events, they have a great impact on cities as well as on its fauna and flora (Groisman et al., 2016). When ice storms occur, branches or whole trees can break from the weight of ice (Anderson, 2019; Coder, 2015; Hewitt, 2004; J.Hauer et al., 2006; Warrillow et al., 1999). With climate change, freezing rain will happen more frequently (Groisman et al., 2016). Although some studies have sought to confirm which tree species are most affected in the forests of southeast North America (Hansen et al., 2016; Lu et al., 2020), there is not much information on which tree species are most damaged in the urban forests of north-eastern North America (Klopčič et al., 2020). In natural forests, a factor that can protect the different tree species is whether they are understory or overstory, as those who are part of the overstory are more affected by the freezing rain than those underneath. In urban forests these two positions are not frequent and information about the most vulnerable species in urban forests remains scarce (Lu et al., 2020).

Atmospheric pollution (Ordóñez et al., 2015)is a significant problem that exists all around the world (Nowak et al., 2018). The air pollutants that most afflict urban trees are ozone, nitrogen, sulfur and hydrogen compounds (Takagi et al., 2004), as well as the presence of micro particles (Gajbhiye et al, 2016). They can cause problems in the growth of some trees and affect their photosynthesis (Takagi et al.2004). Besides, pollutants can be found in the soil where trees are planted and cause similar effects to those linked to air particles (Dumont et al., 2014).

De-icing salts, used to help melting the snow, can also cause negative effects in urban trees. The most common de-icing salts are NaCL, CaCl2 and MgCl2; sometimes organic compounds can also be found. These salts may alter the soil structure, decreasing its permeability and increasing salinity levels, which makes the uptake of nutrients and water by the trees more difficult (Dmuchowski et al., 2019). Following these effects, there is also a risk of hydric stress or physical drought (Clatterbuck, 2010; Equiza et al., 2017; Ordóñez-Barona et al., 2018).

Another stress that trees suffer in urban areas is the **compaction of the soil**. There are different reasons leading to compacted soils, but one of the main reason is a small tree pit (Jim & Ng, 2018). Roots need oxygen and with soil compaction, it gets more difficult to obtain it. Furthermore, it increases soil density and decreases permeability, which stops water from percolating into the soil and roots suffocate because of this, (Correa et al., 2019; Jim et al., 2018; Jim et al., 2018b; Nawaz et al., 2013; Pineo et al., 2009).

Some studies show that with climate change, the meteorological disturbances listed above are going to happen more frequently (Khan et al., 2020). Widespread interactions between agents are likely to amplify stressors, while indirect climate effects such as vegetation changes can dampen long-term disturbance sensitivities to climatic changes (Dale et al., 2017; Leksungnoen, 2012; Moles et al., 2020; Sommerfeld et al., 2018). For example, disturbances by drought and wind strongly facilitate the activity of other stressors, such as insects and fire (Seidl et al., 2017). These disturbances, alone or when interacting, and in addition to urban trees mismanagement (Brancalion & Chazdon, 2017), will affect the resilience of urban forests and its tolerance to the different stressors.

In view of these disturbances, in this project we want to know which species of urban trees are the most tolerant to the different disturbances and which disturbances are the most damaging to them. Such understanding is increasingly demanded and important for the future development of urban forests and cities.

RESEARCH QUESTIONS AND OBJECTIVES

2.1 Research questions

The aim of this project is to understand the tolerance to different disturbances of certain urban tree species in north-eastern North America and determine which disturbances are the most harmful to urban trees. Note that this research is undertaken from a rather exploratory point of view and not from a perspective where hypotheses are going to be tested. The selected disturbances are those for which there is not much information in the literatureon how they can affect different urban tree species or which species are the most tolerant to them and those that most affect urban trees.

Through a questionnaire with the Delphi method (see Methods), we wanted to answer two questions:

(i.) What urban species are the most tolerant to different disturbances?

(ii.) What are the most damaging (canopy loss, broken branches, loss of function) disturbances to urban trees?

In relation to these two questions, we sought to obtain a consensus on the species that are most tolerant to the different disturbances. We also expected to obtain a consensus on the disturbances that cause the most damage to trees.

2.2 Objectives

This project aims to classify urban tree species in reference to their tolerance to different disturbances. In particular, we want to know their tolerance to soil compaction, atmospheric pollution, insects and diseases, ice storms, de-icing salts, strong winds, drought, snow and extreme temperatures. This project is focused on the largest cities of north-eastern North America: Montreal, Ottawa, Toronto, Quebec City, Halifax, Syracuse, Boston, and New York. These cities are among the most populated in north-eastern North America and have been selected because they present similar tree species composition (Cowett & Bassuk, 2017; Jenerette et al., 2016; Yang et al., 2015).

To achieve our objective, a survey with the Delphi method and another with closed questions was carried out. The Delphi method is used for obtaining, through a questionnaire, a collective view from individuals about issues where there is no or little definite evidence (Okoli & Pawlowski, 2004; Thangaratinam & Redman, 2005). This type of survey was aimed at experts in the field of urban forestry who work or have worked with urban trees. On the other hand, the closed-question survey was used to broaden the spectrum of respondents. All people who work or study or have worked and studied urban trees could participate.

Some research with a similar methodology has been done by the USDA. For instance, Iverson et al. (2011) and Mathews et al. (2011) classified tree species according to their resistance to several disturbances (flood, drought, invasive plants, insects and others) and according to biological characteristics (shade tolerance, dispersal, edaphic specificity and others). However, their focus is on natural forests whereas this project focuses on the urban trees of north-eastern North America.

The results of this project could help to predict tree species tolerance to the most important disturbances in urbanized areas and to the disturbances for which there is not much information in the literatureon how they can affect different urban tree species. Cities will need more resilient urban forests to face climate change and trees that are better adapted to reduce the costs of replantation and care (Vogt et al., 2017). The information generated by this project could improve metropolitan development, as cities could choose the most adapted trees based on such information.

METHODOLOGY

3.1 Study site

This project aims to get information on urban trees from different cities of the northeast of North America (Montreal, Québec, Toronto, Ottawa, Syracuse, Boston and New York city). For the majority of these cities, there is scarce information about the tolerance of the urban trees to many different disturbances (Khan et al., 2020). The targeted cities were the most populated cities in the northeast of North America. The cities are located in hardiness zones 5 to 7 and they have a strong annual temperature cycle, with cold winters and warm summers, which allows a greater number of tree species to thrive than in regions (USDA, 2020b).

For the Delphi method, as open questions were used and we did not want to influence the experts' answers, it was decided not to mention the most abundant species in the study area (Murphy et al., 1998), contrary to the closed survey.

3.2 Delphi technique

The Delphi method is used for obtaining a collective view from individuals about issues for which there is none or little definite evidence (Thangaratinam et al., 2005). This method was developed in the 1950s for a military project with the aim to solicit expert opinion (Linstone et al., 2002). It is a consensus building method that uses a series of questionnaires given to a small group of experts, usually from ten to eighteen participants, although a wide variability in the number of participants among researchers exists (Keeney et al., 2011; Linstone et al., 2002; Okoli & Pawlowski, 2004). This method is well suited for research when there is incomplete knowledge about a problem or phenomenon. In this case, as there are few studies about the tolerance of the urban trees species to the different disturbances, it is especially suitable. The Delphi method is also a good alternative to an experimental study (with fieldwork) with the same objective, since an experience of such magnitude would take many years to produce results. Furthermore, the complexity of this project requires expert participants in the subject. As Rowe et al. (2001) and Linstone et al. (2002) have explained, Delphi groups are substantially more accurate than individual experts and traditional groups, as well as more accurate than statistical groups (which are made up of non-interacting individuals whose judgments are aggregated). Also, the number of experts that we need is modest, which makes it achievable in a limited period of time. It is also important to note that statistical power does not depend on group size but rather on group dynamics for arriving at consensus among experts (Okoli & Pawlowski, 2004).

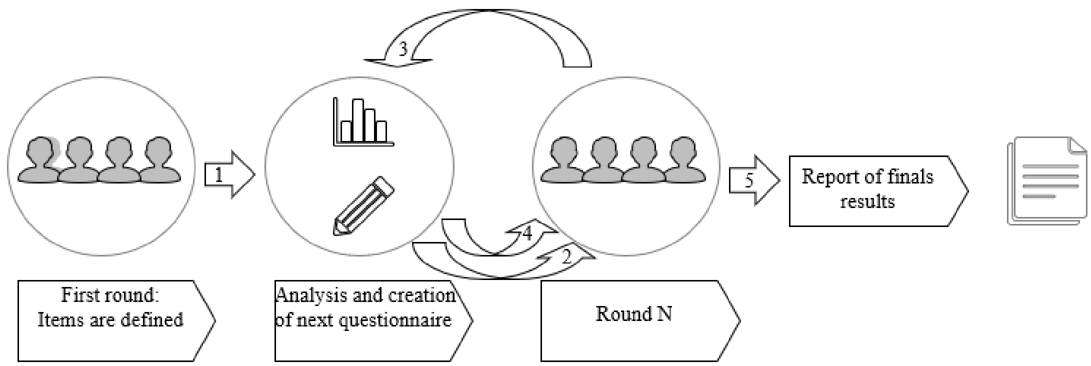

Figure 1 : Delphi technique used in this project.1.The experts fill the first questionnaire (open ended questions), where items are defined for the next rounds. 2. The 2nd round is sent to the experts. 3.Results from the 2nd round are obtained. 4. 3rd round is sent to the experts with the statements of the 2nd round that did not reach an agreement. 5. Finals results are obtained.

3.2.1 Advantages

The main advantages of the Delphi method are the compilation of anonymous information within a group of experts, the flexibility in data entry (time and space), and controlled feedback that allows for credible consensus (Linstone et al., 2002; Okoli & Pawlowski, 2004). This technique helps to avoid the costs and time involved in conducting a field experience (Steinert, 2009), for instance, such as measuring *in vivo* the effects of de-icing salt on trees. This method also offers an alternative to conventional meetings when the experts are geographically dispersed. In addition, as the questionnaire is anonymously filled, it can help to reduce the effects of dominant individuals in the answers (Donohoe et al., 2012).

Another positive aspect of the Delphi method is that the controlled feedback lets the experts think deeply about the questions and contribute for a better understanding of the different points of view. In the same way, it lets the experts consider all the different options in relation to the questions and it can lead to the development of new ideas and new knowledge (Murphy et al., 1998). This feedback process allows and encourages the selected Delphi participants to reassess their initial judgment about the information provided in previous iterations (Hsu, 2007).

Using the Delphi method enabled us to gain the added reliability of group decisions while avoiding typical problems encountered in face-to-face meetings, such as the bandwagon effect and deference to authority (Murry et al., 1995). Moreover, it is used when the problem does not lend itself to specify analytical techniques but can benefit from subjective judgments on a collective basis (Linstone et al., 2002).

Other methods used to obtain a consensus from experts are the nominal group technique (Ven et al., 1974) and the consensus development conference (Linstone et al., 2002). The problem with the nominal group technique is its lack of flexibility, since this approach can only address one problem at a time. As for the consensus development technique, its disadvantage is the fact it forces the participants to be physically present at the same place and time (Linstone et al., 2002). Therefore, given the objectives of this project and the quantity of information that we sought, the Delphi method was the one that was best suited to it.

3.2.2 Weaknesses

For a better understanding of the Delphi method and an improved procedure, it is important to know its limitations or the areas that have received more criticism. These are are the lack of universal guidelines, the size of the expert panel, implications of anonymity absence and the level of consensus (Linstone et al., 2002; Keeney et al., 2011).

In reference to universal guidelines, these are not well defined and it has led to numerous variations in format and implementation, which makes it difficult to create a single approach methodology. Even though, some general rules do exist, such as the need to conduct different rounds (Keeney et al., 2011; Linstone et al., 2002; Okoli & Pawlowski, 2004).

The number of participants in a panel can vary with the Delphi method. The majority of authors suggest 10 to 15 experts in order to simplify controlling feedback and analyzing results. However, others recommend as many as 50 participants (Keeney et al., 2011; Linstone et al., 2002; Okoli & Pawlowski, 2004). Despite these different suggestions, when the panel of participants is bigger than 15, controlling the feedback and analyzing the results becomes more complex. A small sample size may be more appropriate for homogeneous groups (Akins et al., 2005; Duncan et al., 2004; Hasson et al., 2000; Ogbeifun et al., 2016)while heterogeneous groups may require a larger number of participants to ensure the validity of results.

Anonymity can be one of the Delphi method advantages, but it also can be perceived as a weakness. It can lead to non-disclosure and to a lack of accountability for the answers on the part of the participants. Along with this, the definition of expert is really delicate. It needs to be as accurate as possible, since without it, to assess the suitability of an expert becomes complicated (Keeney et al., 2011).

The achievement of consensus is another concept to beware. It might seem mandatory within the Delphi method, but it is not. Occasionally, the consensus might not be reached and when it happens, it does not mean that the correct answer has been found (Hasson et al., 2000; Keeney et al., 2011; Powell, 2003). This technique does not substitute research on the topic of the questionnaire, although sometimes there is a risk that the researcher places greater reliance into the answers than it can be guaranteed. However, if this is kept in mind, the Delphi method can be a useful tool and an integral technique for consensus (Hasson et al., 2000; Keeney et al., 2011). Usually, the achievement of consensus is recommended to be equated with 75% agreement amongst respondents (Diamond et al., 2014).

One more limitation is that experts can be exposed to group pressure to attune their answers to the rest. Also, some studies have presented evidence that social-psychological factors can influence Delphi results, leading to experts that have divergent opinions to conform or abandon the process, as it requires time and commitment from the participants (Bardecki, 1984; Keeney et al., 2011).

3.2.3 Ethical issues

According to the guidelines of the Université du Quebec en Outaouais regarding the protection of human participants, a request was made to its ethics committee for approval to proceed with the surveys.The certificate number of the project is 2020-782.

For the anonimity of the experts, their comments and ratings were not shared with anyone except with the researchers. The respondents identities were replaced in the study by an individually assigned number. The same procedure was applied for the closed survey. They remained free to withdraw from the questionnaire at any time. This information was provided to them before each survey. To participate in this project, they had to sign a consent form with all the details and terms related to this research. After this, the questionnaires could be conducted.

3.2.4 Design

The questionnaire (Appendix B) was designed on Limesurvey website, a platform used for online surveys. This platform allowed the participants to sign up with an username and password in order to fill in the answers. In this way, they could pause and save their progress at their convenience and thus, they could continue at a later time. The survey was made available both in English and in French. After the first round, the remaining participants were Anglophones, so the subsequent questionnaires were only written in English.

For the design, it was taken into account that the wording used had to be appropriate. In the case that respondents were dubious about the questions, they had previously been told that they could contact the researcher to clarify any doubts.

When planning the second and subsequent rounds of the Delphi, a 5-point Likert scale was used to obtain the judgment of the experts. The Likert scale (frequently known as an "agree-disagree" scale) was first published by psychologists Rensis Likert in 1932 (Rinker, 2014). The technique presents respondents with a series of statements, for each of which they are asked whether, and how strongly, they agree or disagree, using a five-point scale (Brace, 2004).

The order of the Likert scale was also taken into consideration. The 5-point Likert scale used in this questionnaire was descending-ordered, as Campbel et al. (2018) have shown to be the best system to reduce response-order effects. It was chosen as it is the most frequently employed in questionnaires where a rating scale is needed (Giannarou et al., 2014). This method can reduce the frustration level of participants and increase response rate and quality (Kitchroen, 2004).

As seen in Appendix B, the questions included the "I don't know" answer option. It was decided to add it since participants might leave some blank answers. In that case, it would not be possible to be certain of the reason. It could be because they do not have the knowledge, because they do not recognise the species or because they are not sure at one hundred percent, so they decided to leave it blank. This is generally information worth having and should encourage the inclusion of "Don't know" codes in the questionnaire (Brace, 2004; Weijters et al., 2010).

3.2.5 Pilot test

When doing this type of questionnaire, it is highly recommended doing a pilot test (Brace, 2004; Hasson et al., 2000; Okoli & Pawlowski, 2004). Before sending the surveys, they were pre-tested with personnel from the CRF (Center of Forest Research, CEF in french) (CEF, 2021), to assess the clarity of the questions, the suitability to the participants and the time needed to complete it. Also, it helped to identify problems with the online survey or if any mistakes were made.

3.2.6 Experts

Regarding the definition of experts, we searched individuals with several years of experience (ten or more years) and knowledge in urban trees and who had worked in the different cities as managers, urban planners or arborists (Vogt et al., 2017). Hence, each answer had relatively the same context or level of certainty.

To find the experts, we contacted several networks related to urban trees by email, these being the Society of Municipal Arborists, Tree Canada and the parks and forestry departments of multiple cities. In the email (written in English and in French) (Appendix B), the purpose and the methodology of the project were explained. It was clarified that it consisted in reiterations in time and if they accepted, a specific period of two weeks would be allowed to fill out the questionnaires. Those who wanted to participate received a consent form, which contained all the ethic information and the survey terms. When the interested individuals signed it, they were given access to the questionnaire and they were reminded about the project and its objectives.

3.2.7 Contacting the experts

Twenty urban tree experts working in north-eastern Canada were contacted by email to account for experts that don’t accept to participate. In it, we introduced the research and its terms, in addition to the invitation to participate voluntarily. Before agreeing to join this study, they were asked about their years of experience in urban forests. They were also informed that at the end of the project they would be able to see the results (Keeney et al., 2011). These tactics help to increase the number of responses. At the same time, 20 experts from the north-eastern United States were also contacted. If people could not take part in the survey, they were asked to share the information in their network to help find other suitable respondents. Among those reached, there were several individuals who did not respond, as well as cases where those contacted could not answer the questions because they did not fit with the description of experts. We started by sending out three emails a week. As the response rate was very low for both groups of potential participants (Canadians and Americans), the list was enlarged so as to include more possible participants from other networks. Finally, after three months of search, eight people, from the Canadian and USA network, agreed to partake in the study and signed the ethical certificate (the minimum number to conduct the Delphi) (Duncan et al., 2004; Ogbeifun et al., 2016). When eight participants, the minimum to conduct the Delphi survey, was reached, the link to the questionnaire was sent. Participants were given two weeks to respond, although some participants took longer than this in all the rounds, so additional time was needed. After the first week and at the end of the second week, a reminder was sent to all participants. Participants who did not respond within the specified time continued to receive reminders.

3.2.8 First Round

The first round was an open-ended questionnaire designed to gather specific information about the different disturbances affecting the urban trees in the targeted area. It also aimed to list the most and least tolerant urban tree species to atmospheric pollution, soil compaction, insects and diseases, de-icing salts, strong winds, drought, extreme temperatures, ice storms and snow. The development of this first questionnaire is really important, as it has to truly represent the key issues of the topic (Franklin et al., 2007). This information given by the participants did not permit them to be recognized at all, since when they logged in to the web platform, they were assigned with a number instead of their name.

Participants were asked about the following disturbances: atmospheric pollution, soil compaction, insects and diseases, ice storms, de-icing salts, strong winds, drought, extreme temperatures and snow. Specifically, the experts were asked which were the effects of the disturbances on urban trees; what were the characteristics of the most tolerant and least tolerant species; to list the five most tolerant and the five least tolerant species for each disturbance; what were the effects of the combined disturbances; and if there were any stressors that they considered important but were not mentioned in the questionnaire.

3.2.8.1 Analysis

When the answers were obtained, data were reviewed and cleaned before the analysis (this was repeated for every round of the questionnaire). Then, a content analysis was done to identify the major themes that had been generated in the first round (Powell, 2003). The content analysis was done manually and consisted of reading and re-reading the responses, developing a process of coding, categorizing and conceptualizing the answers (Hsieh & Shannon, 2005). Once they were summarized, the statements were listed for the next round of questions (Hsu, 2007; Keeney et al., 2011). In the first round, the participants do not have the opportunity to elaborate their arguments, but usually, the opinions of the experts can already be glimpsed (Keeney et al., 2011) For each section, we identified different themes as we can see in the results section.

3.2.9 Second Round

The second round comprised the answers of the previous questionnaire summarized in categories through the content analysis. The experts were asked to rate the responses according to their agreement with them. For this purpose, a 5-point Likert scale was used (Clayton, 1997; Giannarou et al., 2014). The respondents were contacted by e-mail. A reminder with the objectives and methodology of the Delphi method was added to the message. Another two weeks were given to them to complete the survey.

3.2.9.1 Analysis

The data from this round (as well as for the subsequent rounds), being quantitative in nature, were analyzed using ranking techniques (Powell, 2003). For obtaining the results from the 5-point Likert scale, descriptive statistics (frequency, mean and the standard deviation) were used in order to present information concerning the collective judgments of respondents (Hsu, 2007; Nowak, 2006). Means and standard deviations were calculated for each round, as well as the Kendall's coefficient of convergence W, to measure the convergence of opinions (Ju & Jin, 2013; Okoli et al., 2004). The value of W ranges from 0 to 1, indicating no to perfect consensus of the whole questionnaire. Schmidt (1997) proposed that a weak consensus exists for $W<0.3$, moderate consensus for $W=0.5$, and strong consensus for $W>0.7$.

3.2.10 Third Round

In the classical Delphi technique this is the stage whereby expert panel members can begin to converge on a consensus. In this round, the questions from the previous one in which consensus (75% agreement amongst respondents) had already been reached were omitted. Statements that had not yet achieved consensus were presented again showing the group response (percentages) from the last round (Keeney et al., 2011). The experts were asked to rate the statements through a 5-point Likert scale and had the opportunity to revise and clarify their earlier answers if they chose to do so..Because of time constraints, and because we reached consensus in many ways, we decided to finalize the questionnaire after the third round. For ranking the species as the most (and least) tolerant, in addition to descriptive statistics, weighted average ranking was used.

This method, in which each quantity to be averaged is assigned a weight, determines the relative importance of each quantity on the average (Arunagiri & Gnanavelbabu, 2014), and helps to rank the chosen species from one to five based on the answers of the experts.

3.3 Closed survey

In addition to the questionnaire with the Delphi method, a closed survey (Annex 2) was written to complement and compare the information from the Delphi questionnaire. In the questionnaire where we used the Delphi method, we did not name the most abundant tree species in cities. Because the first round of the Delphi technique was done with open questions, mentioning the most frequent species could bias the answers (Scott & Steward, 2018). Not including them allowed the experts to select the tree species that they thought to be more appropriate without us intervening and creating bias (Desai & Reimers, 2019; Scott & Steward, 2018). For this reason, the closed questionnaire with the most commonly planted urban tree species could complement the Delphi method and gather information on the urban tree species that are the most abundant in the targeted cities as well as receiving input from researchers and scholars, in addition to the workers in urban trees.

3.3.1 Design

This questionnaire was also designed within the survey platform Limesurvey, the same that was used for the Delphi method. The questionnaire was also made available both in English and in French.

For the design of the questionnaire, to be sure that there was no doubt about the species listed, the common and the scientific names were given. In addition, at the beginning of the survey, a table with pictures of the chosen trees was shown so that they could be easily recognized. For the Likert scale, the order used was considered and it was argued that the “I don’t know” option was also necessary in this case (Brace, 2004).

For this survey, after a review of different inventories about the tree species of the cities in the targeted area, such as Québec (Ville de Québec, 2007), Toronto (City of Toronto, 2017), Montreal (Ville de Montreal, 2019), Ottawa (City of Ottawa, 2017), Syracuse (USDA ,2001), New York (NYC, 2015) and Boston (Welch, 1994), the five most abundant urban trees in each city were chosen and merged in one list (see table 1). Each species in this list represent up to 2% of the total tree species found in these cities. Species were chosen according to their representativeness, and then ordered from most to least frequent. In the case of Boston, the inventory of the street trees is ongoing. The association in charge (SFTT Boston) had published 15% of the work in their website (Azavea, 2019), so as the information was incomplete, the urban trees from this city were found in an article written by Welch (1994).

Table 1 : List of species used in the closed survey.

Acer platanoides	*Platanus x acerifolia*
Acer negundo	*Prunus serotina*
Acer rubrum	*Pyrus calleryana*
Acer saccharum	*Quercus rubra*
Acer saccharinum	*Rhamnus cathartica*
Amelanchier sp.	*Thuja occidentalis*
Fraxinus pennsylvanica	*Tilia cordata*
Gleditsia triacanthos	*Quercus palustris*
Malus sp	*Tsuga canadensis*
Picea pungens	*Ulmus americana*

In total, there were 20 different species which were listed in the questionnaire. We selected 20 tree species and not more because a long survey can cause response fatigue, misclassification problems and the last questions would have more probability to be answered wrongly (Brace, 2013; Egleston et al., 2011).

Respondents were asked to rank through a 5-point Likert scale the species according to their tolerance to the different disturbances, which are listed in Table 2. In each question, participants had to choose from number one to three, how confident they were of their answer: ‘1’ was really confident and ‘3’ not confident. As in this survey we were not targeting experts in urban forestry, this variable could indicate how reliable the responses were. The participants were contacted by e-mail. A reminder with the objectives was added to the message.

Table 2: Disturbances used in the closed-ended questionnaire to know how tolerant urban trees are to them. The same disturbances are used in the Delphi questionnaire.

Atmospheric pollution	Soil compaction	Drought tolerance
Insects and diseases	De-icing salts	Ice storms
Strong winds	Snow	Extreme temperatures

3.3.2 Participants

For the closed-ended survey, we contacted networks that were related to urban forests rather than communication with experts and scholars directly. At the beginning of the survey, there is a section with demographic questions to screen the participants (Brace, 2013; Rea & Parker, 2005). The respondants were asked what their highest degree in education was and to specify the title of it. They were also asked to give information about their current or previous job (in the case they were retired). After this section, they were asked about their work experience in urban forestry, that is, they had to write for how many years they had been working or studying urban trees and in which cities they had done so, as in this survey we wanted to have participants who had studied or worked with trees so that the answers would have more relevance.

The survey was sent through organizations such as the Centre d'Étude de la Forêt, Tree Canada, the Society of Municipal Arborists in United States, the Department of parks in Montreal, Trees New York, the CSBQ, Eco2Urb, 2RLQ and ISFORT, which were asked to share the link of the questionnaire within their network.

3.3.3 Analyses

Before the analyses, data were reviewed, cleaned and checked. The data from this survey, being quantitative in nature, were analyzed using ranking techniques (Powell et al. 2003). With the results from the 5-point Likert scale descriptive statistics (frequency, mean and the standard deviation) and graphics were done in order to present information concerning the collective judgments of respondents (Hsu, 2007; Nowak, 2006).

RESULTS

4.1 Delphi results

4.1.1 Demographic questions

After sending out the survey through the different networks via email, we obtained the confirmation of eight experts to participate. They consisted of arborists, a superintendent of urban forestry, urban forestry coordinators of Natural, Environmental Protection and Park Departments, as well as a forestry engineer working as an urban forestry consultant.

Of these eight respondants, three had more than 25 years of experience in the field of urban forestry, two had between 16 and 20 years and the other three had between 11 and 15 years.

The locations where the experts have worked are Boston, MA; Cleveland, OH; Connecticut (several cities); Michigan (several cities); Minneapolis, MN; New York City, NY; Charlottetown, PEI; Mississauga, ONT; Montreal, QC; and Toronto, ONT.

4.1.2 First round

After a content analysis, 20 major themes were identified and their statements organized (Tables 3 and 4). The responses related to all disturbances were quite diverse. They were sorted together for round two of the questionnaire. As for the most tolerant and intolerant species, the ones ranked with higher numbers were displayed for the subsequent round.

Table 3: Lists of themes resulting from the question on the effects of the disturbances on urban trees.

Atmospheric pollution
Leaves
Increased vulnerability to other disturbances
Precise particles/ Localised effect
Effects not recognizable
Whole tree

Soil compaction
Leaves
Root
Increases their vulnerability to other disturbances
Growth
Inability to obtain nutrients and water properly

Insects and diseases
Leaves
Whole tree
Increased vulnerability to other disturbances

De-icing salts
Leaves
Whole tree

Strong winds
Leaves
Whole tree
Roots

Drought
Leaves
Whole tree
Increased vulnerability to other disturbances

Extreme temperatures
Leaves
Whole tree

Ice storms
Leaves
Structure
Increased vulnerability to other disturbances

Snow
Whole tree
Browsing
Environment
Increased vulnerability to other disturbances

Table 4: Themes resulting from the question of the urban tree species characteristics in relations to the disturbances.

Tree characteristics related to low tolerance	**Tree characteristics related to high tolerance**
General tree characteristics	General tree characteristics
Environment	Environment
Depends on factors (climate, locations)	Depends on factors (climate, locations)
Origin	Origin
Location	Location
Structure	Structure
Growth	Growth

Leaves	Leaves
	Roots

4.1.3 Second round

After the responses from experts were compiled and categorized, 247 statements made by the experts were written for the second questionnaire (Appendix B). During these two months, seven of eight participants returned the questionnaire. Due to the lack of time, it was decided to go ahead with the analysis of this survey with the seven respondents. The Kendall's coefficient of concordance was 0.291, which shows a low level of agreement.

4.1.3.1 Atmospheric Pollution

This section received the lowest level of agreement of the entire questionnaire. In the question related to the effects of air pollution on urban trees, the experts agreed that they depended on the pollutant, the cultivation and the concentration of pollution. They also agreed that the characteristics of the most tolerant species to this disturbance were good health and thick leaves.

The species that were chosen as the most tolerant and intolerant to atmospheric pollution can be found in Table 5. These species were listed in the round 3 to be ranked from 1 to 5, that is, from least tolerant to most tolerant to atmospheric pollution. This applies to all the species lists from this round.

Table 5: Species selected by the participants as the most tolerant and intolerant to atmospheric pollution

Most tolerant species	**Most intolerant species**
Fraxinus spp.	*Acer saccharum*
Ginkgo biloba	*Betula* spp.

Celtis spp.	*Salix* spp
Gleditsia triacanthos	*Cornus* spp.
Ulmus spp.	*Pinus strobus*

4.1.3.2 Soil Compaction

In this section, the experts agreed that the effects caused by soil compaction were improper root development, increased vulnerability to other disturbances, weak growth, death, delay injury recover and inability to obtain nutrients and water correctly. The participants also stated that drought intolerance was a characteristic of the most intolerant tree species to soil compaction and that species adapted to seasonal flooding were the most tolerant.

Table 6 : Species selected by the participants as the most tolerant and intolerant to soil compaction.

Most tolerant species	**Most intolerant species**
Gleditsia triacanthos	*Acer saccharum*
Ulmus spp.	*Tilia* spp.
Acer rubrum	*Fagus grandifolia*
Quercus macrocarpa	*Fagus sylvatica*
Acer platanoides	*Nyssa sylvatica*

4.1.3.3 Insects and Diseases

In this section, the experts agreed that the effects of insects and diseases could be found notably on the leaves. In addition, they affirmed that the insects and diseases caused mortality, aesthetic impacts and disrupted the tree vascular system. As characteristics of the most tolerant species, a good health was selected as important as well as being adapted to different environmental conditions.

Table 7: Species selected by the participants as the most tolerant and intolerant to insects and diseases.

Most tolerant species	**Most intolerant species**
Ginkgo biloba	*Fraxinus* spp
Amelanchier spp.	*Ulmus americana*
Acer rubrum	*Prunus persica*
Gymnocladus dioicus	*Fraxinus pennsylvanica*
Pyrus calleryana	*Betula* spp.

4.1.3.4 De-icing Salts

For this disturbance, the participants agreed that the leaves, the growth of the whole tree and the uptake of nutrients and water were affected. Also, they recognized de-icing salts as the cause of death and increased vulnerability to other stressors. According to the experts, trees that have waxy leaves and are adapted to salts are the ones that are the most tolerant to this disturbance. In the table below, the chosen species can be found.

Table 8: Species selected by the participants as the most tolerant and intolerant to de-icing salts.

Most tolerant species	**Most intolerant species**
Celtis occidentalis	*Pinus strobus*
Gymnocladus dioicus	*Acer rubrum*
Gleditsia triacanthos	*Cornus* spp.
Fraxinus americana	*Betula* spp.
Acer rubrum	*Abies balsamea*

Fraxinus pennsylvanica	*Acer saccharum*
Zelkova serrata	

4.1.3.5 Strong Winds

In this round, the respondents stated that an effect of this disturbance was uprooting. The characteristics of the most intolerant trees on which the experts agreed were poor structure, shallow root system and a dense crown. On the other side, the traits of the most tolerant species were good structure, deep roots, stable rooting and slow growth.

Table 9: Species selected by the participants as the most tolerant and intolerant to strong winds.

Most tolerant species	**Most intolerant species**
Quercus rubra	*Salix* spp.
Juglans nigra	*Pinus strobus*
Quercus spp.	*Fraxinus* spp.
Taxodium distichum	*Picea abies*
Quercus alba	*Populus* spp.
Gleditsia triacanthos	*Pyrus calleryana*

4.1.3.6 Drought

In this section, the effects of drought on trees on which the respondents agreed were leaf damage, death, slow growth rate and increased vulnerability to other disturbances. The experts indicated that the most tolerant tree species to drought were also tolerant to soil compaction, had deep rooting, waxy cuticles, good health and were native from drought stressed places.

Table 10: Species selected by the participants as the most tolerant and intolerant to drought.

Most tolerant species	**Most intolerant species**
Quercus macrocarpa	*Acer saccharum*
Ginkgo biloba	*Acer saccharinum*
Ulmus spp.	*Betula* spp.
Gymnocladus dioicus	*Salix spp.*
Celtis spp.	*Fagus* spp.
Acer negundo	*Betula lenta*
Gleditsia triacanthos	
Quercus rubra	

4.1.3.7 Extreme Temperatures

For this disturbance, the experts agreed that it affected the leaves, it caused mortality and desiccation; and that the most tolerant trees are adapted to hot and dry conditions and have deep roots.

Table 11: Species selected by the participants as the most tolerant and intolerant to extreme temperatures.

Most tolerant species	**Most intolerant species**
Quercus spp.	*Pinus strobus*
Ginkgo biloba	*Acer saccharum*
Celtis occidentalis	*Cercis canadensis*
Ulmus spp.	*Abies balsamea*
Gleditsia triacanthos	*Betula alleghaniensis*

Fraxinus spp.

4.1.3.8 Ice Storms

In this round, the participants affirmed that ice storms could cause branch breakage, tree failure and structural damage. Also, according to them, the most intolerant species to this disturbanve have a poor structure and narrow branch unions, are evergreen, have included bark (ingrown" bark tissues often develop where two or more stems grow closely together causing weak, under-supported branch angles), weak wood and grow fast. On the contrary, the trees that are the most tolerant to ice storms have dense wood, a good structure, strong attachments, are decay free and have flexible branches.

Table 12: Species selected by the experts as the most tolerant and intolerant to ice storms.

Most tolerant species	**Most intolerant species**
Quercus spp.	*Salix* spp.
Quercus bicolor	*Pyrus* spp.
Quercus macrocarpa	*Pinus strobus*
Juglans spp.	*Fraxinus* spp.
Gleditsia triacanthos	*Betula papyrifera*
	Pyrus calleryana

4.1.3.9 Snow

The experts did not achieve a consensus in any statement related to the effects of snow. However, they agreed upon the characteristics of the most intolerant species to this disturbance. According to them, the trees have a poor structure, weak attachments, weak wood and a late defoliation. The most tolerant trees are supposed to be deciduous, to have dense wood, in good health, to be decay free, to have an early defoliation and flexibility in the limbs.

Table 13: Species selected as the most tolerant and intolerant to snow.

Most tolerant species	**Most intolerant species**
Quercus rubra	*Pinus strobus*
Pinus spp.	*Populus* spp.
Abies spp.	*Pyrus calleryana*
Quercus alba	*Thuja* spp.
Picea spp.	*Cercis canadensis*

4.1.3.10 Interaction of Disturbances

In this second round, the experts agreed that when wind, ice and snow interact, the effects are worse. They also agreed that the effects on urban tree species are aggravated when soil compaction and de-icing salts interact. Other interactions that participants chose were wet snow and ice, extreme temperatures with drought and climate change, drought with soil compaction, and drought with diseases.

In the question 11, where we asked which were the effects of the disturbances when they interacted, most of the statements achieved an agreement. Among them, we found that branch breakage happened from wind, ice and snow; branch breakage caused by wet snow and ice; stress from drought and disease; stress from extreme temperatures and drought; reduced water and nutrient uptake caused by soil compaction and de-icing salts; root slow growth because of soil compaction and de-icing salts; and reduced water and nutrient uptake induced by drought and soil compaction.

Finally, the experts agreed that they would add to the list of disturbances human impact (infrastructure construction, excavation), mechanical damage and absence of basic conditions for tree growth and establishment.

4.1.4 Round Three

In round three, Kendall's coefficient of concordance was 0.329. It still shows a low level of agreement, but greater than in round two (0.291). All the seven respondents that had finished the survey in round two completed it in round three. Because an increase in consensus and lack of time, it was decided to stop the Delphi method with round three.

4.1.4.1 Atmospheric Pollution

On the questions about atmospheric pollution, the participants agreed that this disturbance caused slow growth in urban trees. They also indicated that the most intolerant trees had thin leaves, as well as affirming that being non-native was not a characteristic of the most intolerant species. In the case of shadow tolerant trees, the experts chose the neutral response. In reference to the most tolerant trees to this disturbance, having large leaves was agreed as neutral. So according to the experts, having larges leaves did not interfere in the tolerance of the tree species to this disturbance.

In figure 3, the species chosen as most tolerant and intolerant are listed. As the most tolerants, *Ginkgo biloba* is in the first position with 42.86% and a weighted average rank (WAR) of 4.17. The higher the number, the higher it is in the ranking. In second place, *Gleditsia triacanthos* and *Celtis* spp. follow, have the same WAR. Even so, the SD is larger in *Celtis* spp, meaning that the data is more dispersed in relation to the mean than in *Gleditsia triacanthos*. In fourth and fifth place are *Ulmus* spp. and *Fraxinus* spp., which have a large dispersion of data relative to their mean.

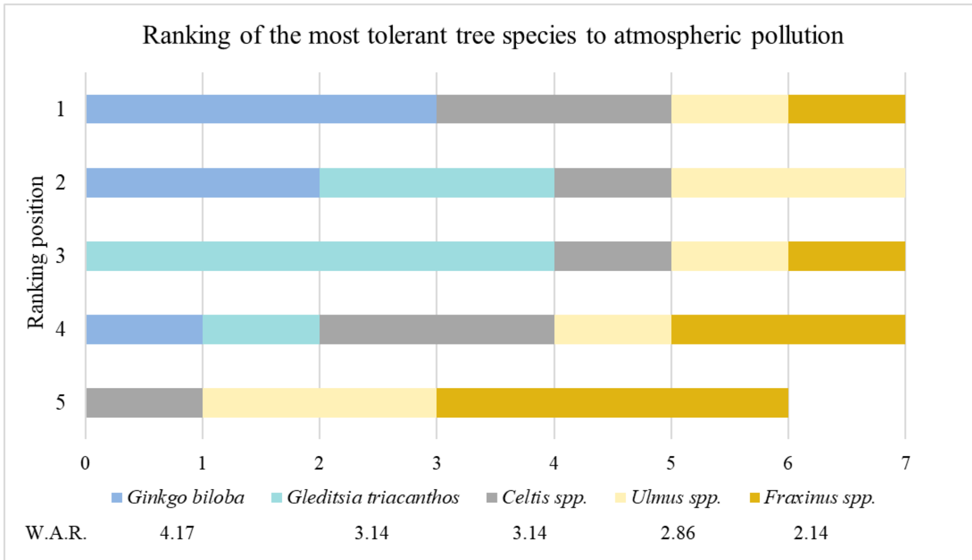

Figure 2: Ranking of the most tolerant tree species to atmospheric pollution obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

In the ranking of the most intolerant species, *Pinus strobus* is clearly in the first place. Most of the experts chose it for the position one or two. In the second and third positions, *Betula* spp. and *Acer saccharum* follow. Although the WAR was bigger for *Betula* spp. than in the other species, it has to be taken into account that *Acer* has been placed third because an expert chose it in last position. The last two taxa are in a similar situation. *Cornus* spp. precedes *Salix* spp. Even so, the SD of *Cornus* is larger and 57.14% have selected *Cornus* in 5th position and *Salix* in 4th.

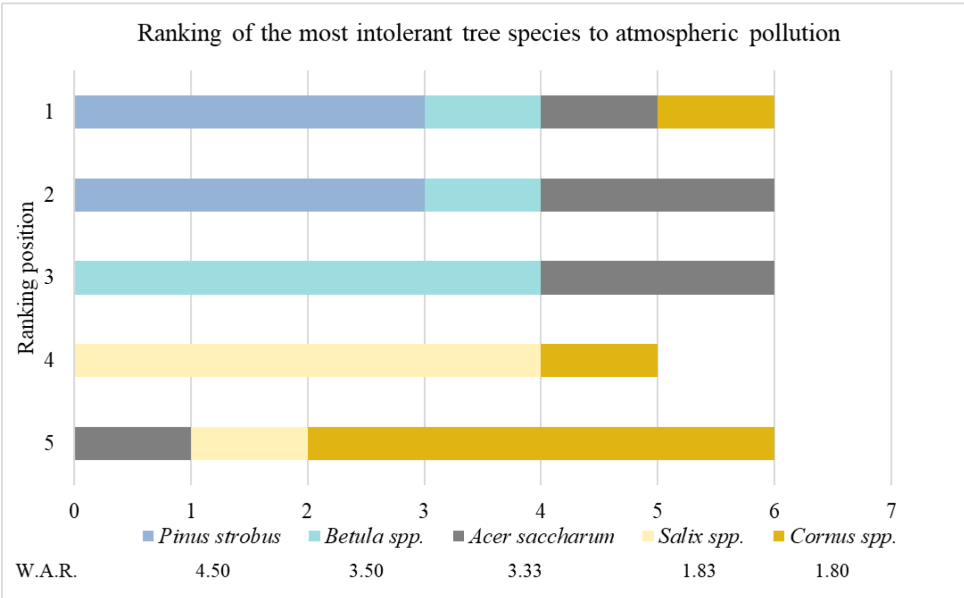

Figure 3: Ranking of the most intolerant tree species to atmospheric pollution obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.2 Soil Compaction

In the third round, it was agreed that soil compaction caused defoliation and a high number of surface roots. The experts stated that the most intolerant trees to this disturbance had a reduced growth rate and that species were intolerant to compacted soils depending on the climate area. The characteristics chosen for the most tolerant trees were drought tolerance, hard wood and species native from wetland sites. Participants selected the neutral response, meaning that they did not agree nor disagree with the following characteristics: deciduous, leaf pubescence and hard wood species. Between rounds two and three, the consensus was higher than for atmospheric pollution. Out of 26 statements that were originally written, 18 of them reached an agreement by the end of round three.

In the figure 5 we have the ranked species. According to the WAR, *Ulmus s*pp. and *Acer platanoides* are in the same position in the ranking. If we look at the SD, it is larger in the second species, meaning that there is more dispersion of the data in this one. The rest of the trees that follow also have a SD.

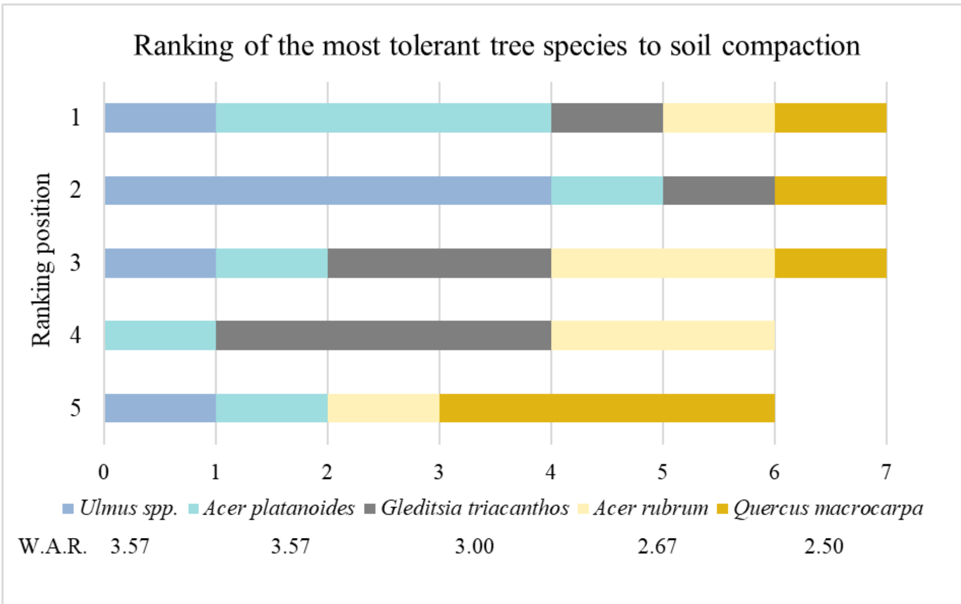

Figure 4: Ranking of the most tolerant tree species to soil compaction obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

In the list of the most intolerant species, *Fagus grandifolia* stands out with a higher WAR than the rest and small data dispersion. For the rest of the species, the dispersion is lower in *Tilia* spp., which has been chosen last and has an SD of 0.45.

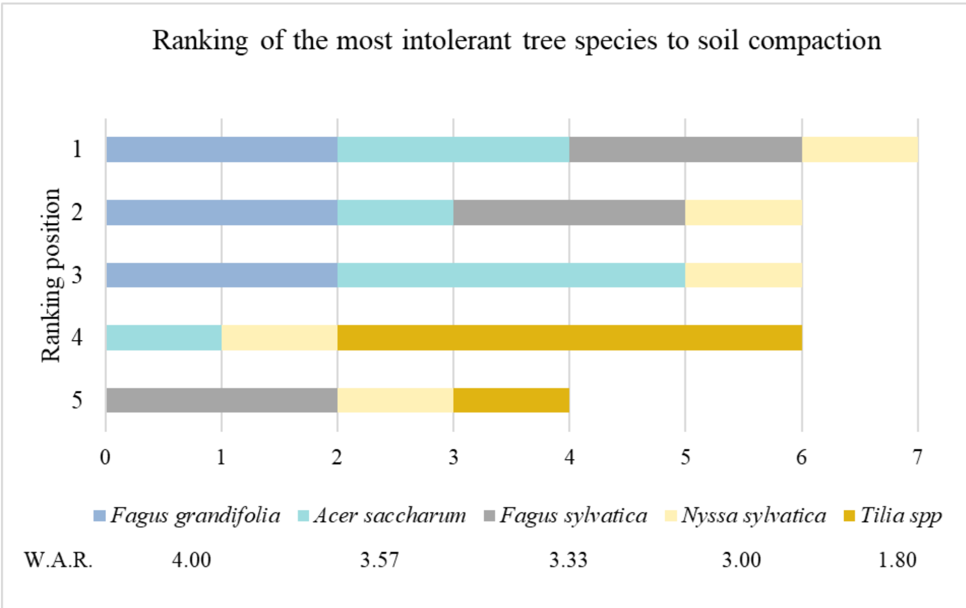

Figure 5: Ranking of the most intolerant tree species to soil compaction obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.3 Insects and Diseases

In this section, participants only agreed that one of the effects is trunk damage. Out of 20 statements that were originally written, 9 of them reached a consensus by the end of round three. *Ginkgo biloba* was selected as the most tolerant by all the participants (Figure 7), followed by *Gymnocladus dioicus* and *Pyrus calleryana.* According to WAR, *Pyrus calleryana* has been chosen in second place, but it should be noted that the overall percentage of *Gymnocladus dioicus* is bigger, which means that more experts selected this species as tolerant. Finally, for *Acer rubrum* and *Amelanchier* spp., the SD shows that there is not a clear opinion about these species.

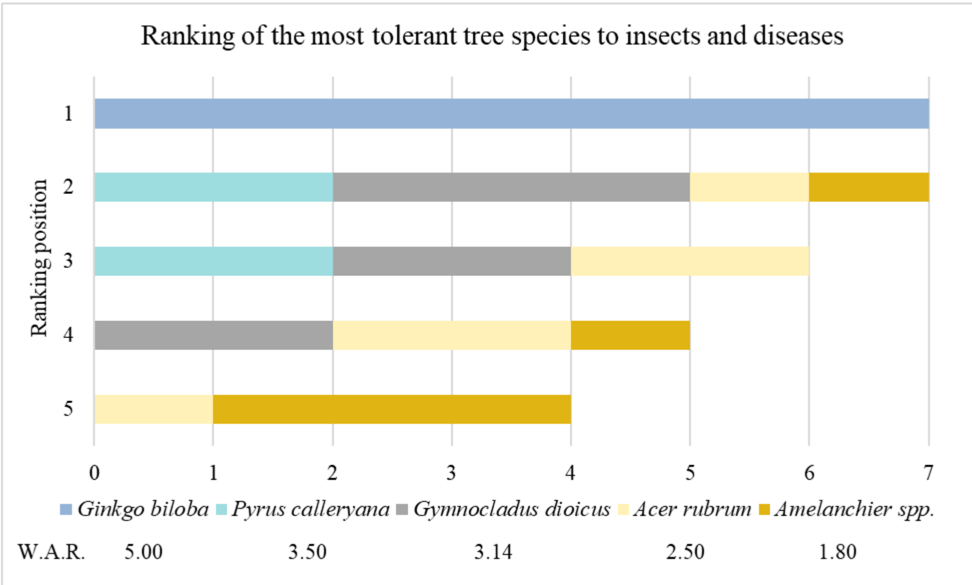

Figure 6: Ranking of the most tolerant tree species to insects and diseases obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

The ranking of species chosen as the most intolerant shows a wide dispersion of data across all species as all of the trees SD are above one. Among the most intolerant, *Fraxinus pennsylvanica*, *Betula s*pp. and the *Fraxinus* spp. in general were selected. *Ulmus americana* and *Prunus persica* were ranked in fourth and fifth positions, although the latter was also chosen in first and second position by one of the experts.

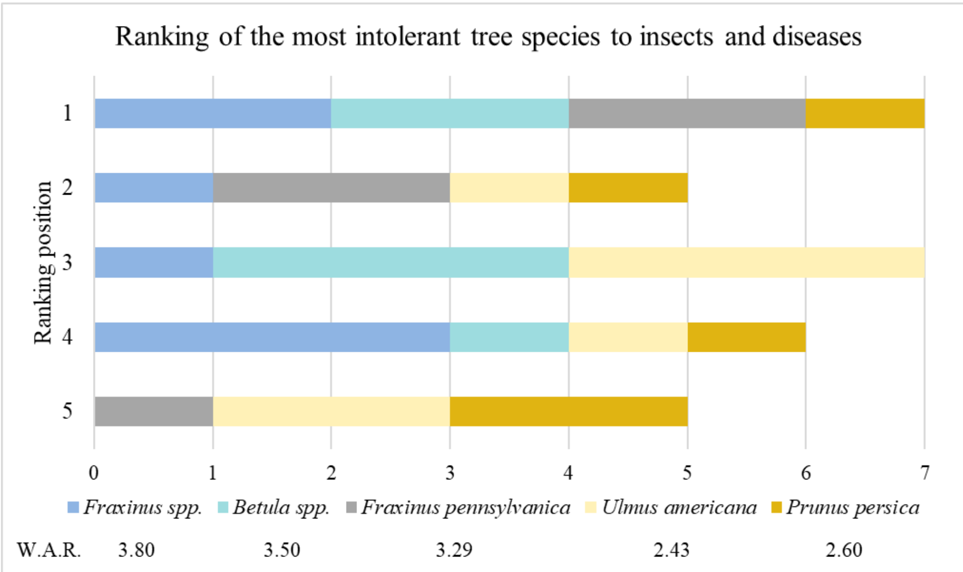

Figure 7: Ranking of the most intolerant tree species to insects and diseases obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.4 De-icing Salts

The only effect that reached an agreement was root damage, although other characteristics of trees were added. For the most most tolerant, there was a consensus that they were tolerant to soil compaction and to drought. In reference to the intolerant trees, they agreed that these were conifers, shallow-rooted, with thin bark, they required moist and well-drained soils and that they were intolerant to salts planted without protection or protocol. Of the 26 statements that were originally listed, 14 of them reached consensus by the end of round three.

In this case, according to WAR, *Gymnocladus dioicus, Celtis occidentalis* and *Gleditsia triacanthos* are among the tolerant ones, although the latter has a high SD. They are Followed by *Fraxinus pennsylvanica* and *Fraxinus americana*. The species chosen as last position is *Acer rubrum*, which has an SD close to the one of *Gymnocladus dioicus*.

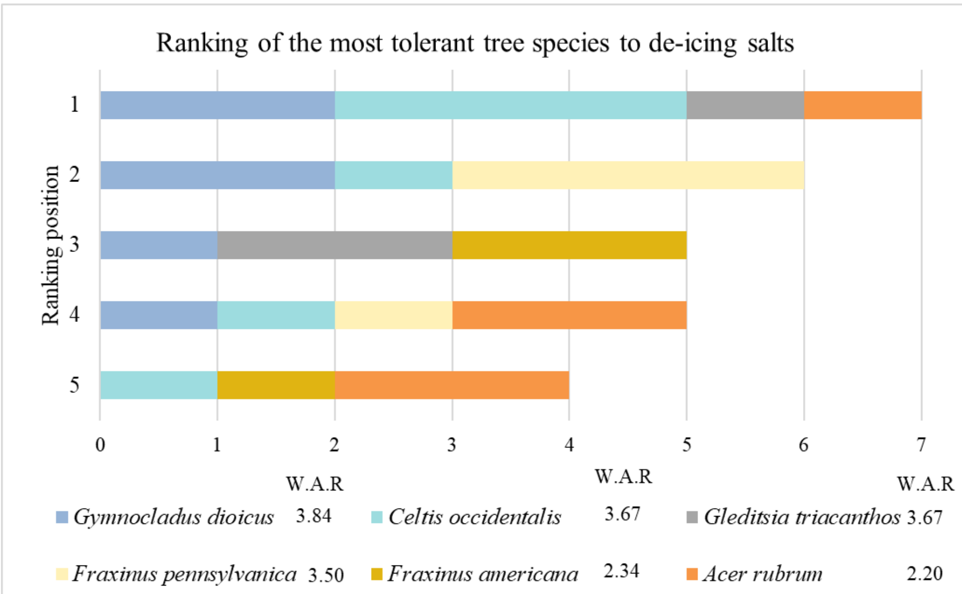

Figure 8: Ranking of the most tolerant tree species to de-icing salts obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

The ranking order of the most intolerant species can be seen more clearly than in figure 9. Furthermore, two of the SD are below one, which means a lower dispersion of the data. *Pinus strobus* and *Acer saccharum* are in first and second position. The latter has a higher dispersion. In third place we find *Abies balsamea*, followed by *Betula* spp. and *Cornus* spp.

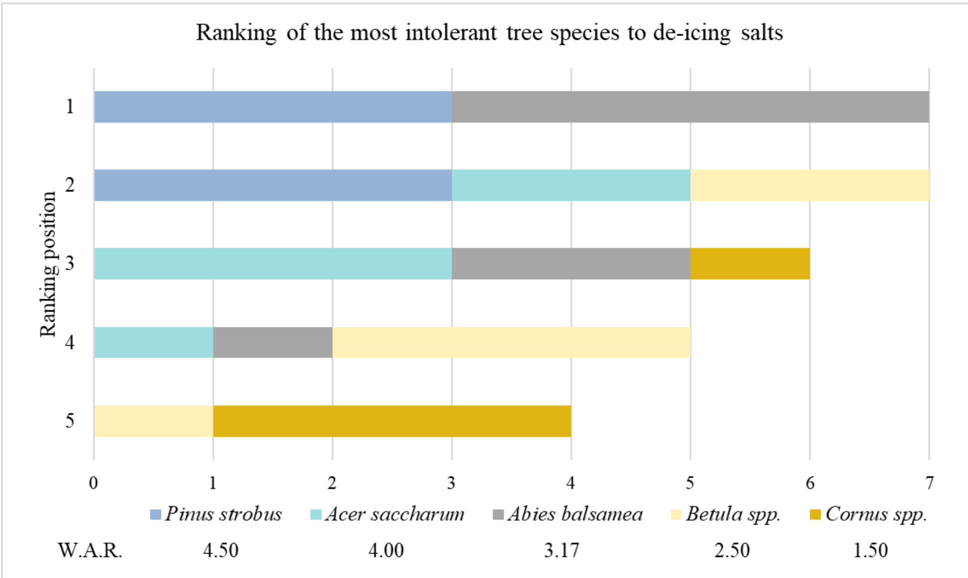

Figure 9: Ranking of the most intolerant tree species to de-icing salts obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.5 Strong Winds

In this round, the experts agreed that strong winds cause leaf damage and reduced water and nutrient uptake. For the most intolerant species, the participants affirmed that they had weak roots and a fast growth rate. In the section where we asked about the traits of the most intolerant trees, the presence of dead wood was chosen as neutral, implying that they neither agreed nor disagreed with it. The respondents agreed that being small was not a trait of the least intolerant species. The characteristics of the most tolerant trees were dense wood and good health of the tree. In this section of the Delphi questionnaire, out of a total of 25 statements, 17 reached an agreement.

Among the most tolerant species to strong winds, there are different *Quercus* spp. ranked in number one, two and four. Once more, in this list, the dispersion of the data tends to be high. *Quercus rubra* and *Juglans nigra* have the same WAR and mean, though the SD is higher in *Juglans nigra*.

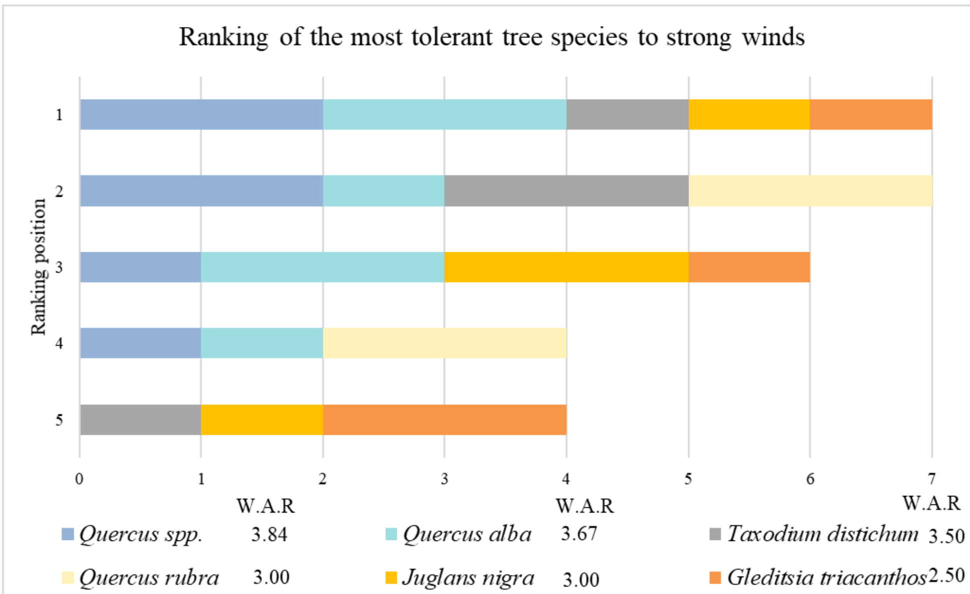

Figure 10: Ranking of the most tolerant tree species to strong winds obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

As the most intolerant trees, the experts have selected *Pyrus calleryana* and *Salix* spp. in the top positions, even though *Salix* species have a wider dispersion than *Pyrus* species. *Pinus strobus* and *Picea abies* were also chosen in the first and third position by one participant. *Fraxinus* spp. were also listed.

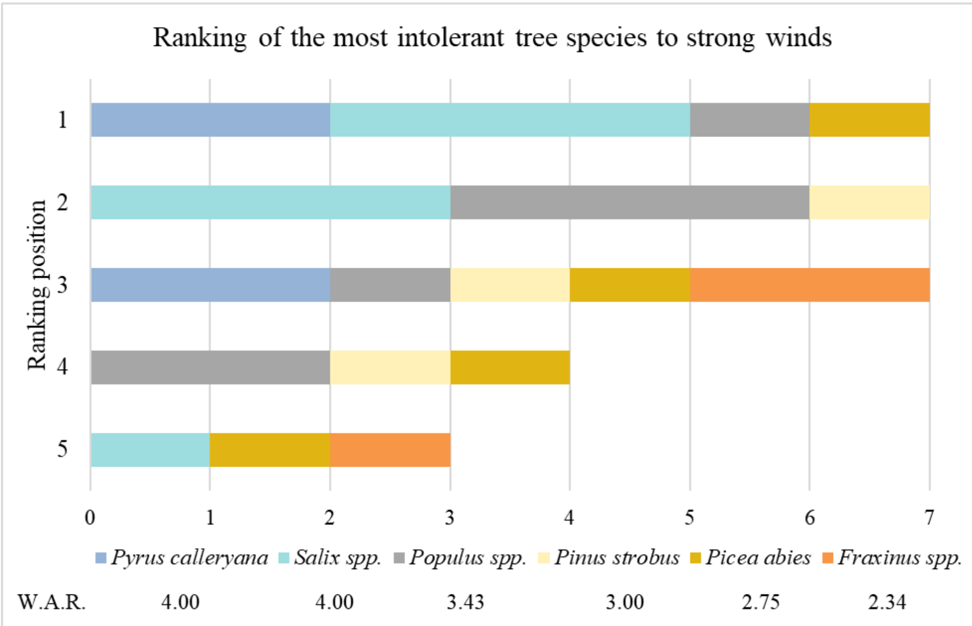

Figure 11: Ranking of the most intolerant tree species to strong winds obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.6 Drought

For drought, there was no agreement on its effects. The experts agreed that the most intolerant trees have shallow roots. As for the most tolerant trees, they coincided that species tolerant to drought were also tolerant to salt and had good water storage capacity. Slow growth rate was determined as a neutral statement. From the 22 statements in this section, 13 reached a consensus at the end of the third round.

The species rated on the top positions as the most tolerant were *Ulmus* spp., *Ginkgo biloba* and *Celtis* spp. The latter one had a high SD. Following, the species *Quercus macrocarpa, Gleditsia triacanthos* and *Gymnocladus dioicus* were listed.

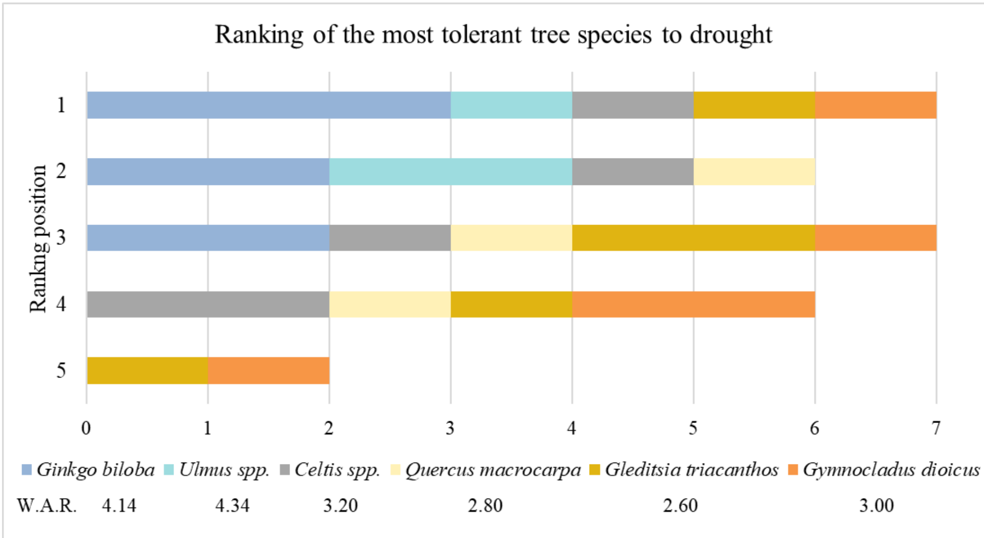

Figure 12: Ranking of the most tolerant tree species to drought obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

In the ranked species below, *Acer saccharum* and *Betula* spp. have been chosen in the top positions according to WAR and with a SD lower than one. *Acer saccharinum*, in the last position, has the biggest SD of the table. It has also been chosen in number one and two of the ranking, which creates a big SD.

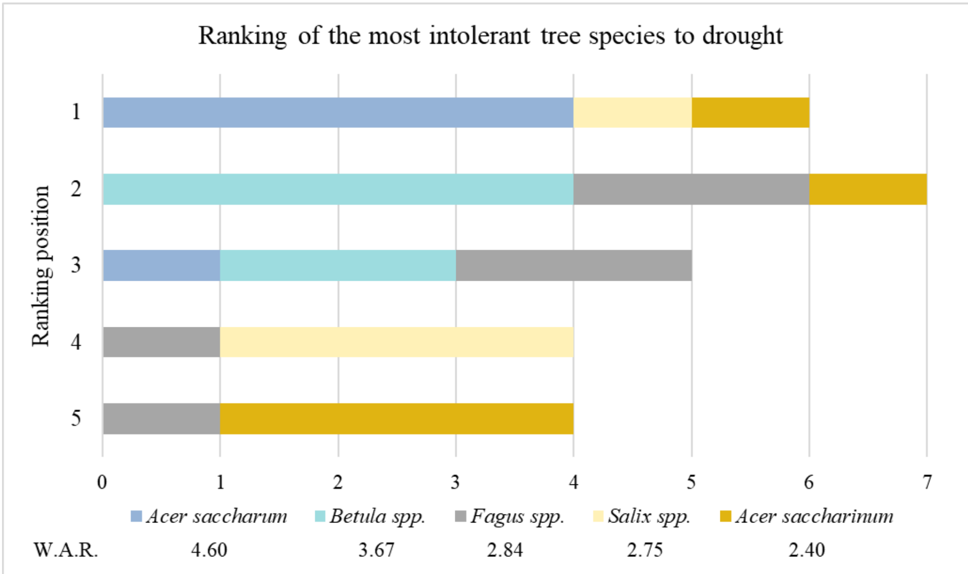

Figure 13: Ranking of the most intolerant tree species to drought obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.7 Extreme Temperatures

For the extreme temperatures, the experts agreed that it caused early leaf defoliation, slow growth rate and branch breakage. In relation to rodent girdling, the respondents disagreed that it was an effect of this disturbance. It was stated that the characteristics of the most intolerant were being non-native and shade tolerant. For the characteristics of the most intolerant trees, the experts chose the neutral response for having a wide crown and being non-native. For the most tolerant ones, the following characteristics were chosen: waxy surfaces, leaf pubescence, regulation of water loss and age. Of the 28 statements in this section of the Delphi questionnaire, consensus was reached on 17 of them.

There has been a clear agreement that *Ginkgo biloba* is the most tolerant to extreme temperatures, followed by *Celtis occidentalis*. With the other species there is no such clear agreement, although *Fraxinus* spp. is in last position with an SD of 0.58, which is reasonably low.

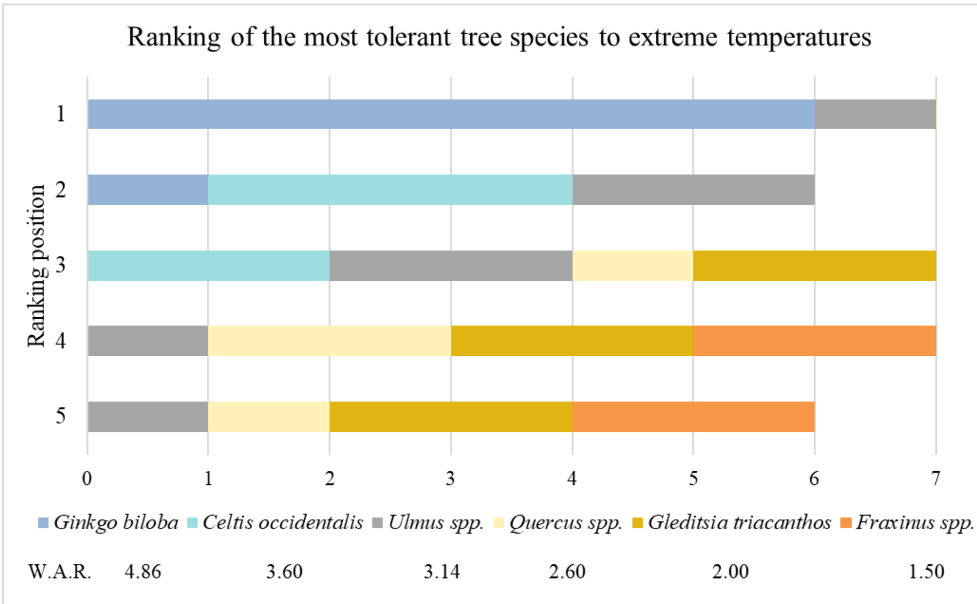

Figure 14: Ranking of the most tolerant tree species to extreme temperatures obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

For the species more intolerant to this disturbance, the agreement was not so clear. The SD of all species is higher than one, with the exception of *Betula alleghaniensis*, which is in third position with an SD of 0.82.

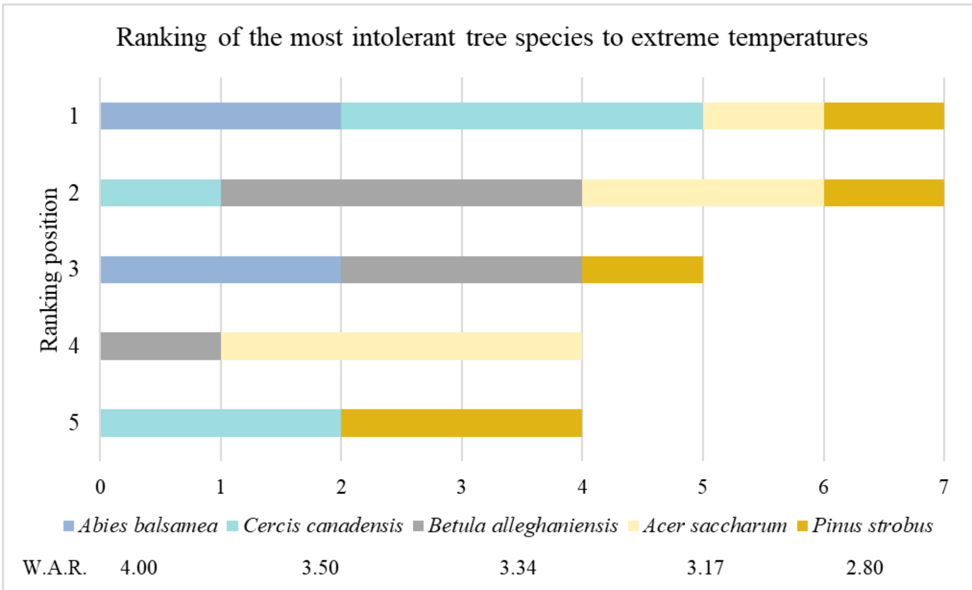

Figure 15: Ranking of the most intolerant tree species to extreme temperatures obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.8 Ice Storms

For the experts, the most intolerant trees have a wide crown, whereas the most tolerant species have a small crown and a slow growth rate. There were 26 statements in the Delphi questionnaire on this disturbance. At the end of the third round, 17 of them reached consensus

In the ranking of the most tolerant ice storm species, *Quercus* spp. and *Juglans* spp. also have an SD lower than one. In contrast, *Quercus macrocarpa* and *Gleditsia triacanthos* are in fourth and fifth position but with an SD higher than 1.5.

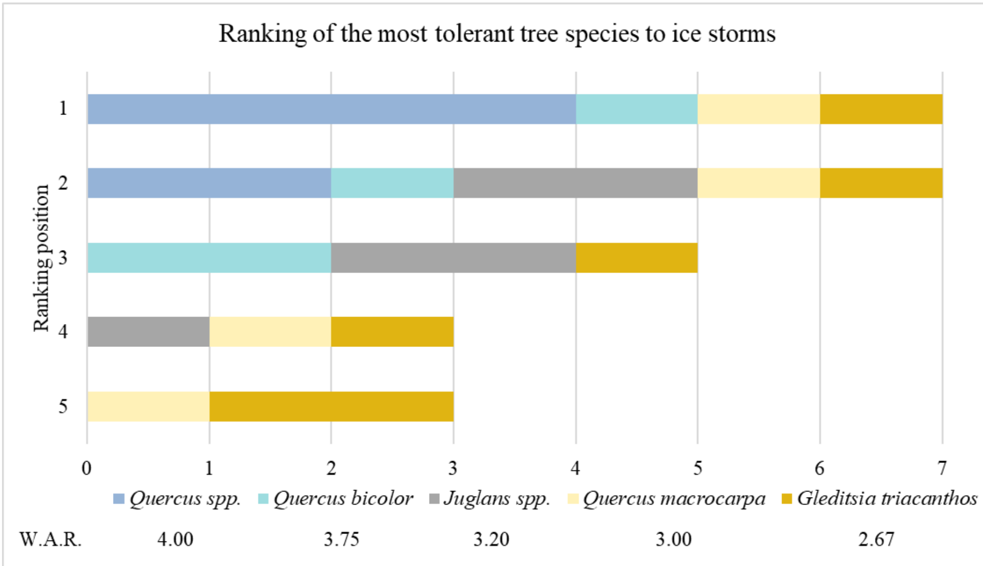

Figure 16: Ranking of the most tolerant tree species to ice storms obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

Similar to table 16, the first species (*Quercus* spp.) ranked have an inferior SD. *Pinus strobus*, *Pyrus calleryana* and *Betula papyrifera* have SD bigger than 1.3. This means that the experts had quite different opinions about these species tolerances.

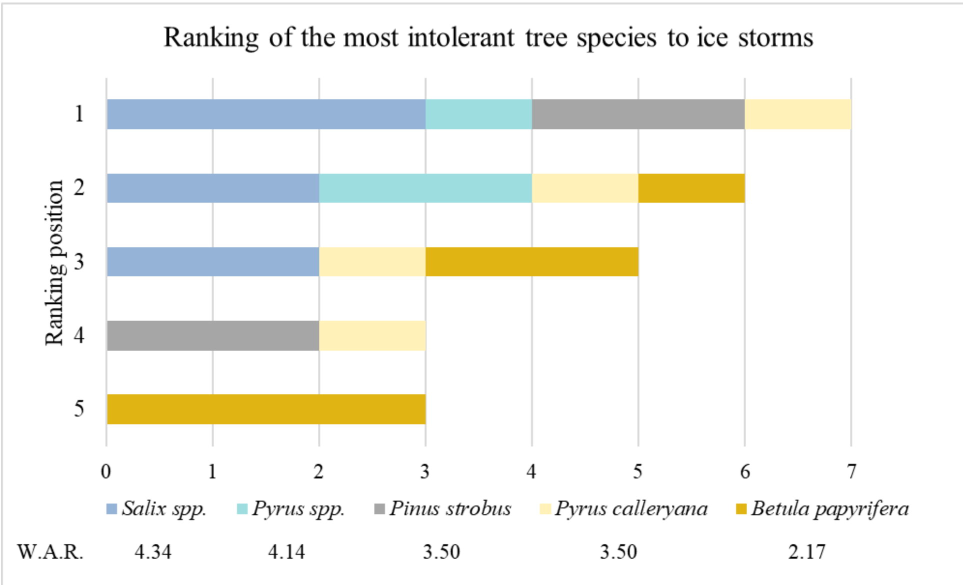

Figure 17: Ranking of the most tolerant tree species to ice storms obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.9 Snow

The effects of snow on which there was an agreement were branch loss and bud loss. In the statement "increased vulnerability to other disturbances" respondents chose the neutral response, implying that they neither agreed nor disagreed with it. The characteristics of the most intolerant species were wide branches, deciduous trees and fast growth. To have a good structure was one of the suggested traits of the most tolerant urban trees. The Delphi questionnaire had 28 statements about snow tolerance. Consensus was achieved in 17 of them.

The table of the species ranked as the most tolerant shows that the experts had quite a polarized opinion about *Quercus alba, Quercus rubra, Abies* spp. and *Pinus* spp. Picea abies, ranked in second position is the one that has a lower dispersion of the data.

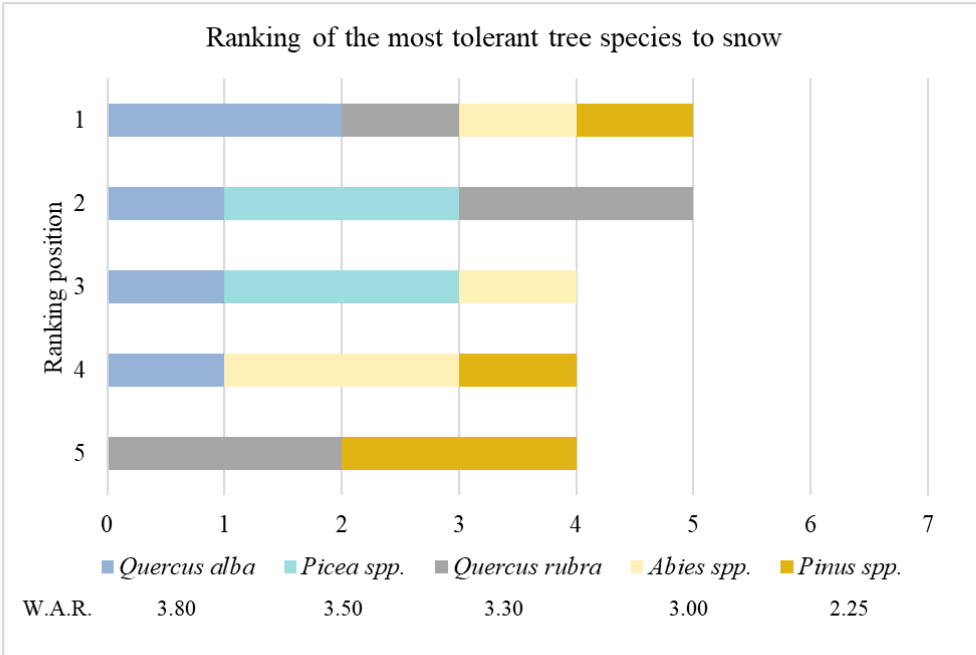

Figure 18: Ranking of the most tolerant tree species to snow obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

In this last ranking, *Pyrus calleryana* and *Pinus strobus* have been selected in the top positions. Even though, one expert chose both them in the fifth position, resulting in a high SD. As for the other species, *Thuja* spp. and *Cercis canadensis* had less diverse opinions than *Populus* spp.

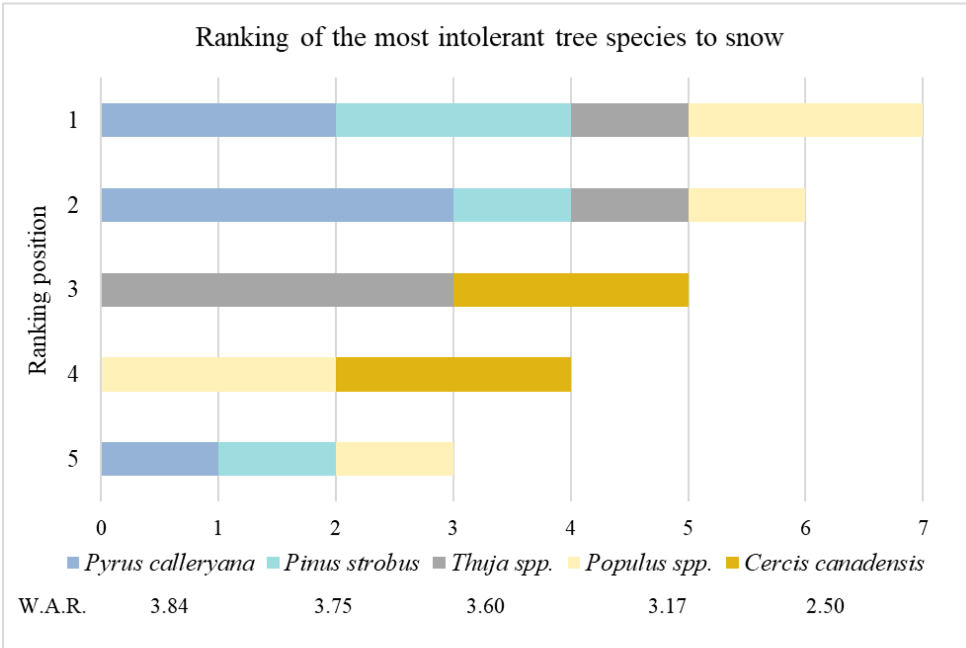

Figure 19: Ranking of the most intolerant tree species to snow obtained from the final round results. The bars are proportional to the number of times that each species was selected in each ranking position.

4.1.4.10 Interaction of Disturbances

In the third round, the experts agreed that strong winds interacted with all the other disturbances above mentioned and increased their effects on trees. Also, it was agreed that when drought and diseases interacted, it caused the increase of fungal infections. They stated that when soil compaction and de-icing salts interacted, it could cause tree death. Finally, the experts affirmed that in the urban disturbances list from this project, they would add poor water quality and changes in the pH to the list.

4.1.4.11 Global view

In general, the most mentioned species as tolerant was *Gleditsia triacanthos*, which was found to be tolerant to seven of the nine disturbances analysed here (with the exception of insects and diseases and de-icing salts). It was followed by the genus *Quercus*, which was chosen in six of the disturbances, although the same species were not named all the time. The other most frequent species were *Ginkgo biloba,* chosen in the first position for four stresses and *Ulmus* spp., which was found to be tolerant to four disturbances.

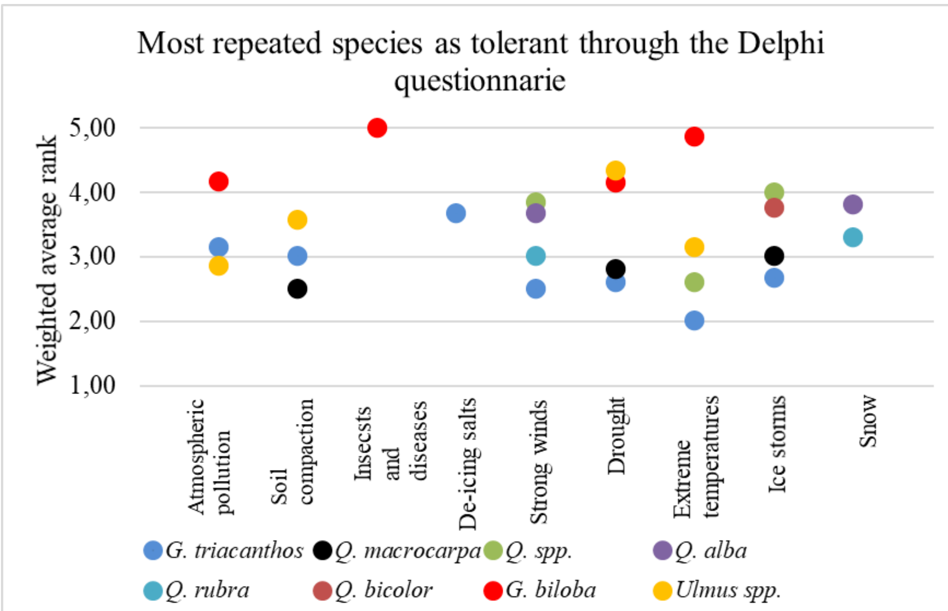

Figure 20: Weighted average rank of the most repeated species chosen as the most tolerant to the different disturbances in the Delphi method.

On the other hand, the species that were the most recurrent throughout the questionnaire as the most intolerant were *Pinus strobus* and *Betula* spp., which appeared in six of the disturbances. There is also *Acer saccharum*, which was named as intolerant in five of the disturbances.

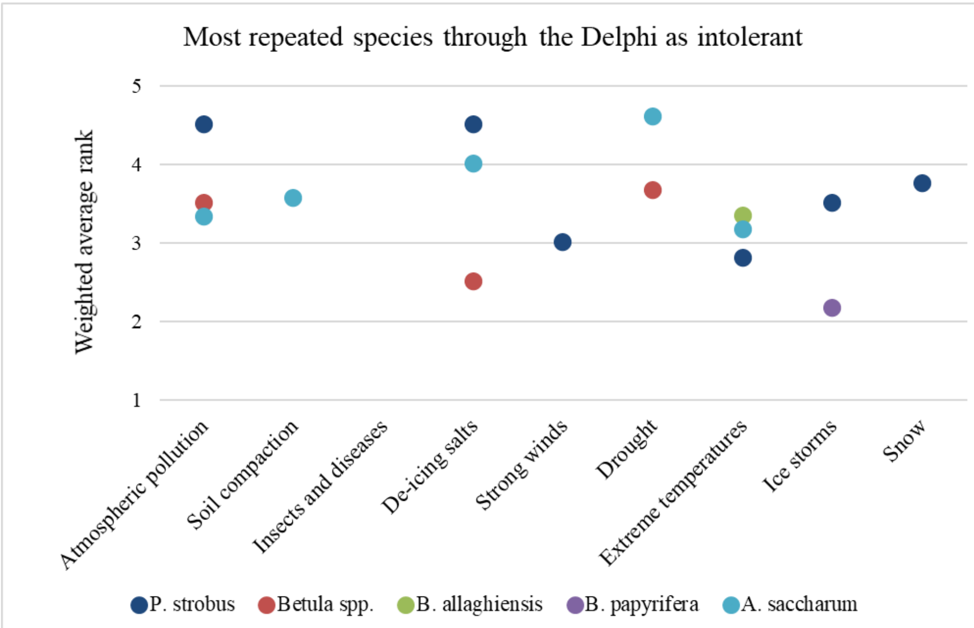

Figure 21: Weighted average rank of the most repeated species chosen as the most intolerant to the different disturbances in the Delphi method.

4.2 Results closed-ended survey

4.2.1 Demographic Questions

This section is dedicated to the observations from the results of the closed-ended survey. In total, 98 people started the questionnaire but only 36 individuals with experience or education in city trees completed it. Almost all of the survey participants have worked or studied in cities in north-eastern North America. Most of these cities are in the United States, although some of them are in Canada.

Of the 36 respondents, 31 have a university degree, of which 14 have postgraduate studies and 4 have a PhD related to urban trees (Table 14). The jobs of the participants vary between researchers, municipal arborists, technicians in horticulture and arboriculture and university teachers among others (Table 15).

The participants have worked or studied in cities from Québec, Ontario, New Brunswick, Pennsylvania, Minnesota, New York, Ohio, Massachusetts, Illinois, North Carolina, New Jersey, Colorado, California, Washington, Virginia, Texas, Rhode Island, Missouri, Michigan, Maryland, Maine, Kentucky, Florida and Connecticut. Although some of these states do not belong to north-eastern North America, the people who worked in them also worked in Northeastern states. For this reason, they were taken into account.

Table 14: Education of the survey participants.

Education	**Number of participants**
PhD	4
Master's degree	14
Bachelors degree	13
Diploma below bachelor's level	5

Table 15: Jobs of the survey participants.

Job position	**Number of participants**
Researcher	6
Arborist	9
Natural Resources Coordinator	2
Technician horticulture and arboriculture	3
Agent for the conservation of living plant collections and phytoprotection	1
Associate Extension Educator - Urban and Community Forestry	1

Deputy Director, Forestry	1
Director of Forestry	3
Founder of Online Seminars for Municipal Arborists	1
University teacher	2
Sustainable landscape designer	1
Did not answer	6

Figure 22 shows the years of experience for 29 of the respondets (the rest did not answer the question). Also, 44.3% of the participants have studied urban trees for sixteen years or more. Most of them (30.5%) have studied street trees for more than 25 years, which means more knowledge about the subject when answering the questions. In Figure 22, the years of work experience with urban trees are shown. Of all the respondents (N=29), 55.4% have sixteen years of experience or more. Of these, 38.8% have more than 25 years of experience. In addition to this, for each question, a certainty variable was added.

Figure 22: Graphic with particpant's years of experience and years of study.

4.2.2 Atmospheric Pollution

In the following section, the answers that were obtained from the online survey are listed. The trees that were ranked as the most tolerant to air pollution were *Gleditisa triacanthos*, *Fraxinus pennsylvanica, Acer negundo, Acer platanoides,* and *Acer saccharinum* in this order (Fig. 24). For all the species, the SD was superior to one, with the exception of *Acer saccharinum*, which had a value of 0.9. These numbers are large, which means that all trees rated as the most tolerant to this disturbance have a wide range of responses. For example, one subject rated *Gleditsia triacanthos* as very intolerant and stated that he was very confident in his choice. Two other people selected it as intolerant (with a certainty of 3 and 2). This was the case for all the species.

On the question of certainty, between 57.14% and 69.23% of the individuals who selected these trees as the most tolerant were very certain or somewhat certain of their answers.

Finally, for atmospheric pollution, none of the listed trees were chosen with more than a 75% of agreement as intolerant. Only *Acer saccharum* was selected as less tolerant by 53% of agreement. Among those who chose it as intolerant, the majority were very sure and somewhat sure. Still, 25% rated it as tolerant. Its SD was 2.60, which means opinions were polarized with this species.

Table 16: Most tolerant trees to atmospheric pollution and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**SD**	**Option 4 + 5 %**
Gleditsia triacanthos	4.38	1.01	80.56
Fraxinus pennsylvanica	4.18	1.22	80.56
Acer platanoides	4.11	1.23	77.78
Acer negundo	4.20	1.13	77.78
Acer saccharinum	4.11	0.90	75.00

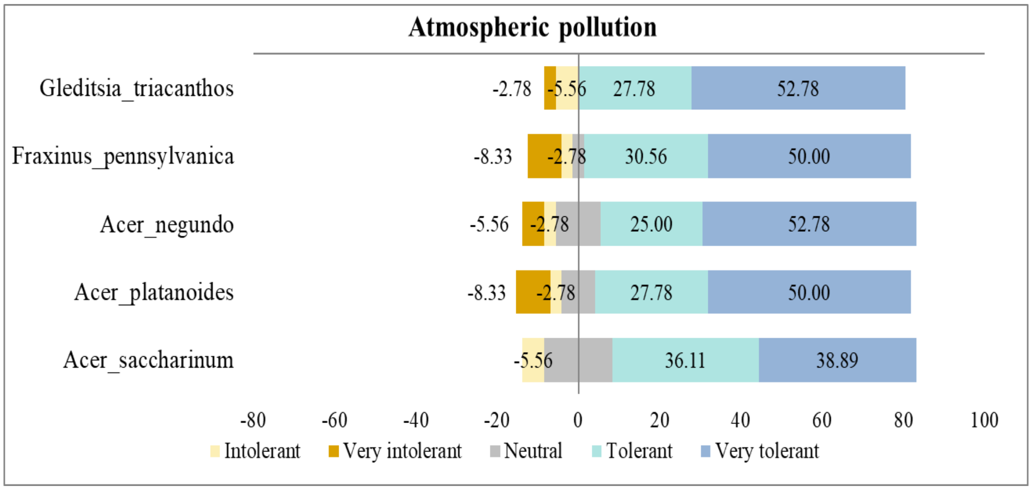

Figure 23: Frequencies of species ranked by the respondents as the most tolerant to atmospheric pollution.

4.2.3 Soil Compaction

The trees that were rated as the most tolerant to soil compaction were *Gleditisa triacanthos, Fraxinus pennsylvanica, Ulmus americana, Acer saccharinum* and *Acer negundo,* in this order (Fig. 25). Only the first two were chosen as tolerant with more than 75% of agreement.

For this disturbance, all the species had a SD value near one (see Table 17). Again, this means that the responses related to the most tolerant to soil compaction were quite diverse. The species with the highest SD were *Acer saccharinum* and *Acer negundo*, which had a mean of 4.00 (1.15) and 4.06 (1.14). Although for all of them, there were people that also chose them as not tolerant.

On the question of certainty, between 64% and 72% of the individuals who selected these trees as the most tolerant were very certain or somewhat certain of their answers.

As with the previous disturbance, none of the listed trees were selected with more than 75% as intolerant. Only *Tsuga canadensis* was chosen as less tolerant by a percentage of 58.33% with a high level of certitude. Its mean was 2.21 (0.98) although there was a 30.56% who used the neutral option for this species.

Table 17: Most tolerant species to soil compaction and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	Mean	S.d.	Option 4 + 5%
Gleditsia triacanthos	4.35	0.95	77.78
Fraxinus pennsylvanica	4.21	0.91	75.00
Ulmus americana	4.20	1.08	72.22
Acer saccharinum	4.00	1.15	72.22
Acer negundo	4.06	1.14	69.44
Acer platanoides	3.86	1.09	69.44

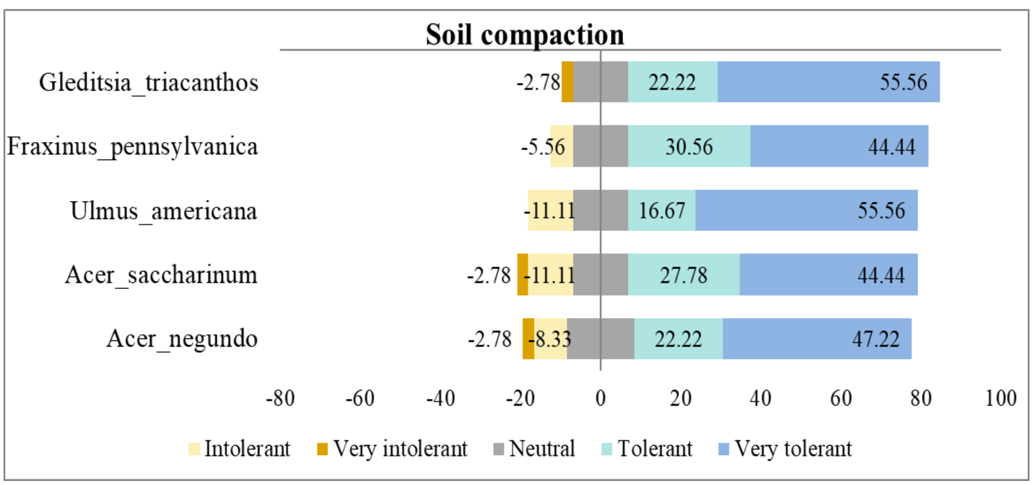

Figure 24: Frequencies of species ranked by the respondents as the most tolerant to soil compaction.

4.2.4 Insects and Diseases

The trees selected as the most tolerant to insects and diseases were *Acer saccharinum*, *Acer negundo*, *Platanus x acerifolia, Gleditisa triacanthos* and *Rhamnus cathartica (*Fig. 26*)*. In this case, the respondents did not reach an agreement of 75%. The participants stated with 72.22%, the highest percentage in this section, that *Acer saccharinum* was tolerant to insects and diseases. The remaining species were chosen with percentages lower than 70%. This is too low to affirm that there has been an agreement on the answers.

Again, all the trees had a SD value near one (see Table 18). The species with the highest SD were also the ones chosen as tolerant with the highest percentages: *Acer saccharinum* (4.05 ±1.12) and *Acer negundo* (4.05±1.14).

On the question of certainty, between 50% and 60% of the individuals who selected these species as the most tolerant were very certain or somewhat certain of their answers. Standing out from the rest, 93.75% of people who chose *Acer saccharinum* as tolerant were certain about their answers.

For this disturbance, respondents selected *Fraxinus pennsylvanica* and *Ulmus americana* as intolerant with a 63.89% of agreement. *Malus* spp. Were also classified as intolerant, although with 58.33%. It should be noted that these percentages are still below 75% and that there was a divergence in the opinions.

Table 18: Most tolerant species to insects and diseases and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**S.d.**	**Option 4+ 5 %**
Acer saccharinum	4.06	1.12	72.22
Acer negundo	4.06	1.14	69.44

Platanus x acerifolia	3.97	0.91	66.67
Gleditsia triacanthos	3.97	1.14	66.67
Rhamnus cathartica	4.45	0.97	63.89

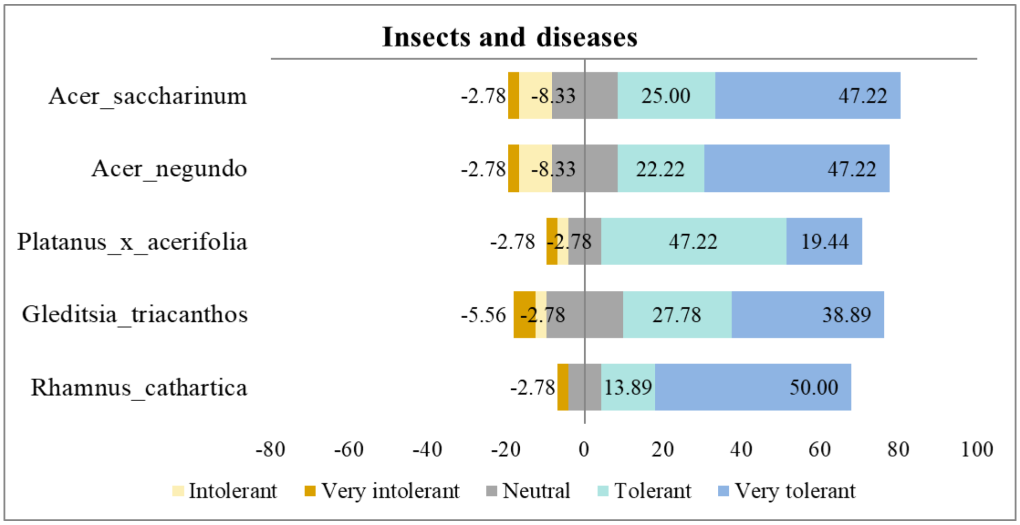

Figure 25: Frequencies of species ranked by the respondents as the most tolerant to insects and diseases.

4.2.5 De-icing Salts

For de-icing salts, the respondents agreed that *Gleditsia triacanthos* was tolerant to it with a 77.78%. The rest of the species did not reach a percentage of 75%. *Fraxinus pennsylvanica* and *Rhamnus cathartica*, had a 63.89% and 61.11% of agreement (Fig. 27). The other two species that followed in the resulting list were *Acer platanoides* and *Ulmus Americana*, both with a percentage of 55.56%. For these two species, approximately 25% of the participants chose the neutral response, so it cannot be affirmed that there was an agreement on these species.

All the trees had a SD value around one (see Table 19) and the answers were diverse. Regarding certainty, between 63% and 70% of the individuals who selected these trees as the most tolerant were very certain or somewhat certain of their answers. Except for *Rhamnus cathartica,* just 50% of the respondents said they were certain of their choices.

Finally, the species *Acer rubrum*, *Acer saccharum* and *Tsuga canadensis* were found to be the most intolerant with percentages of 58.33%, 63.89% and 66.67%. Even so, they do not exceed 75% and their means are 2.44 (±1.18), 2 (±1.21) and 2.09 (±0.98) correspondingly.

Table 19: Most tolerant sepcies to de-icing salts and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**S.d.**	**Option 4 + 5 %**
Gleditsia triacanthos	4.29	1.00	77.78
Fraxinus pennsylvanica	3.80	1.13	63.89
Rhamnus cathartica	4.21	1.07	61.11
Acer platanoides	3.63	1.19	55.56
Ulmus americana	3.71	1.13	55.56

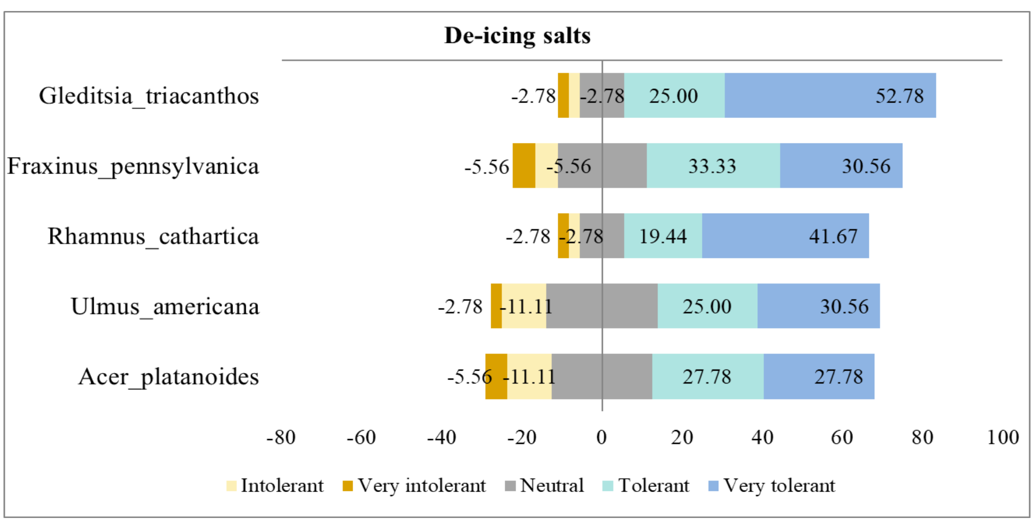

Figure 26: Frequencies of species ranked by the respondents as the most tolerant to de-icing salts.

4.2.6 Strong Winds

The species that were chosen among the most tolerant to strong winds were *Quercus rubra*, *Quercus palustris* and *Gleditsia triacanthos* in this order. The trees that followed were *Rhamnus cathartica* and *Ulmus americana*, although just 52.78% of the respondents selected them as tolerant, which is not enough to state that an agreement has been reached with these species (Fig. 28). Their means and SD are shown in table below (table 20).

On the question of certainty, between 70% and 82% of the individuals who chose these trees as the most tolerant were very certain or somewhat certain of their answers, except for *Rhamnus cathartica,* which in the previous disturbance just 47.37% of the respondents stated they were sure of their decision.

For strong winds, the species with the highest percentages as intolerant were *Acer negundo* (55.56%) and *Acer saccharinum* (63.89%). Their means were 2.5 (±1.14) and 2.33 (±1.01), which shows that they have a large data dispersion.

Table 20: Most tolerant species to strong winds and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**S.d.**	**Option 4 + 5 %**
Quercus rubra	4,17	1,06	86,11
Quercus palustris	4,06	0,97	80,56
Gleditsia triacanthos	4,06	1,07	77,78
Rhamnus cathartica	4,00	1,19	52,78
Ulmus americana	3,64	1,25	52,78

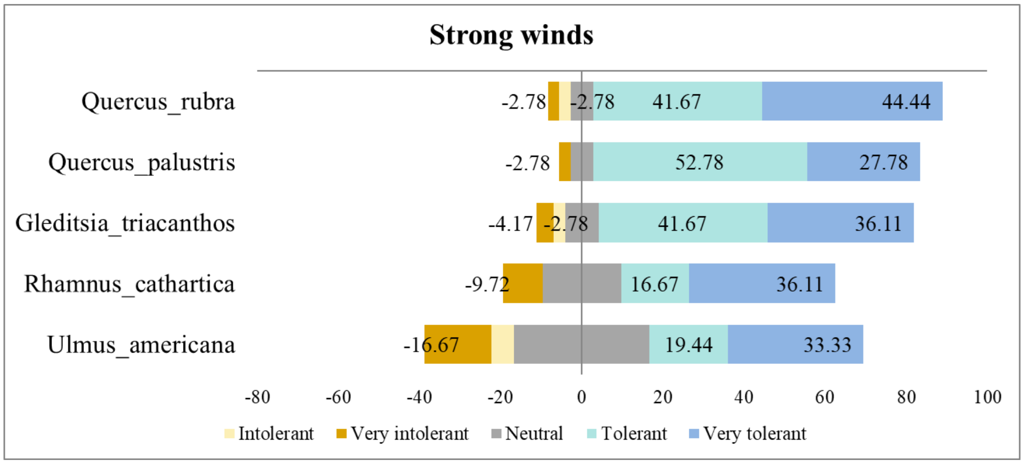

Figure 27: Frequencies of species ranked by the respondents as the most tolerant to strong winds.

4.2.7 Drought

The tree species that were rated as the most tolerant to drought were *Gleditsia triacanthos*, *Fraxinus pennsylvanica, Ulmus Americana, Acer negundo* and *Quercus rubra* (Fig. 29). Just *Gleditsia triacanthos* reached a 75% of agreement in reference to its tolerance. Their means and SD are shown in table 21.

On the question of certainty, around a 70% of the respondents who selected these species as the most tolerant were certain about the answers. For the *Fraxinus pennsylvanica*, the percentage was 94.44%.

In this case, *Acer saccharum* and *Tsuga Canadensis* were chosen as the most intolerant species by the participants, but with percentages of 55.56 and 52.78, which does not reach an agreement. The SD value for both species was 0.9, which shows a divergence of opinion. Approximately 35% of the respondents also rated them as neutral.

Table 21: Most tolerant species to drought and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	Mean	S.d	Option 4 + 5 %
Gleditsia triacanthos	4.24	1.09	75.00
Fraxinus pennsylvanica	3.86	1.03	69.44
Ulmus americana	3.78	1.05	63.89
Acer negundo	3.77	1.11	61.11
Quercus rubra	3.78	1.02	61.11

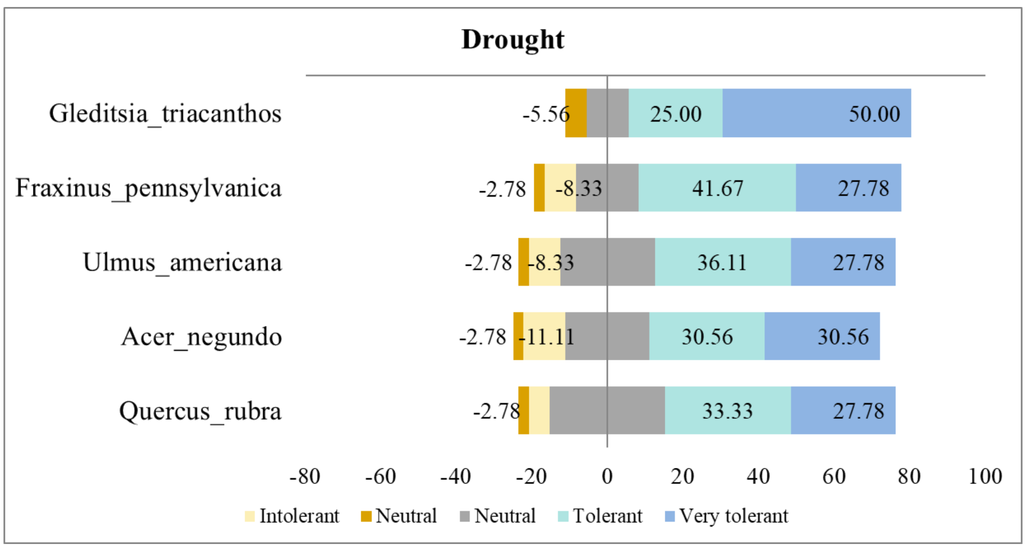

Figure 28: Frequencies of species ranked by the respondents as the most tolerant to drought.

4.2.8 Extreme Temperatures

The trees that had a higher percentage of agreement as the most tolerant were *Gleditsia triacanthos*, *Acer negundo, Fraxinus pennsylvanica, Rhamus cathartica* and *Ulmus*

Americana (Fig. 30). None of the species reached a 75% of agreement in reference to their tolerance, though. Specifically, *Rhamnus cathartica* and *Ulmus Americana* had the lowest percentages (55.56%). The percentages, means and SD are shown in table 22.

On the question of certainty, between a 60% and a 70% of the participants who chose these trees as the most tolerant were certain about the answers.

Tsuga canadensis was the only species that exceeded a percentage of 50% as intolerant to extreme temperatures, although by no great margin. Its mean was 2.47 (±1.1), which shows variability in the responses.

Table 22: Most tolerant species to extreme temperatures and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**S.d**	**Option 4 + 5 %**
Gleditsia triacanthos	4.10	0.94	72.22
Acer negundo	3.85	1.15	61.11
Fraxinus pennsylvanica	3.90	1.11	61.11
Rhamnus cathartica	4.08	1.22	55.56
Ulmus americana	3.76	1.09	55.56

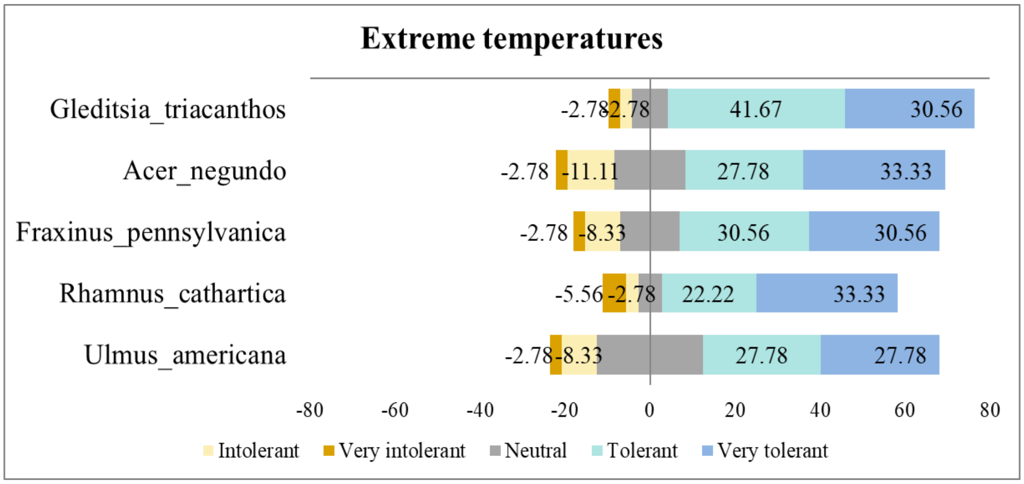

Figure 29: Frequencies of species ranked by the respondents as the most tolerant to extreme temperatures.

4.2.9 Ice Storms

The respondents chose *Quercus rubra*, *Gleditsia triacanthos* and *Quercus palustris* as the most tolerant, though with low percentages (Table 23). The other two species that followed, *Picea pungens* and *Tsuga canadensis*, had been identified as tolerant by less than 50% of the participants. An important number of respondents (27%, 25% and 19%) selected the neutral answer for *Tsuga canadensis, Picea pungens, Quercus palustris* and *Quercus rubra* (Fig. 31). As shown in table 23, their means were low as well, between 3.82 and 3.20. Between 60% and 80% of the participants answered these questions being really sure or somewhat sure.

The tree species that had a high score in the intolerant category were *Acer saccharinum* (63.89%), *Acer negundo* (55.56%) and *Pyrus calleryana* (52.78%).

Table 23: Most tolerant species to ice storms and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**S.d**	**Option 4+5 %**
Quercus rubra	3.82	0.97	63.89
Gleditsia triacanthos	3.68	1.25	61.11
Quercus palustris	3.67	0.96	58.33
Picea pungens	3.58	1.35	47.22
Tsuga canadensis	3.20	1.18	41.67

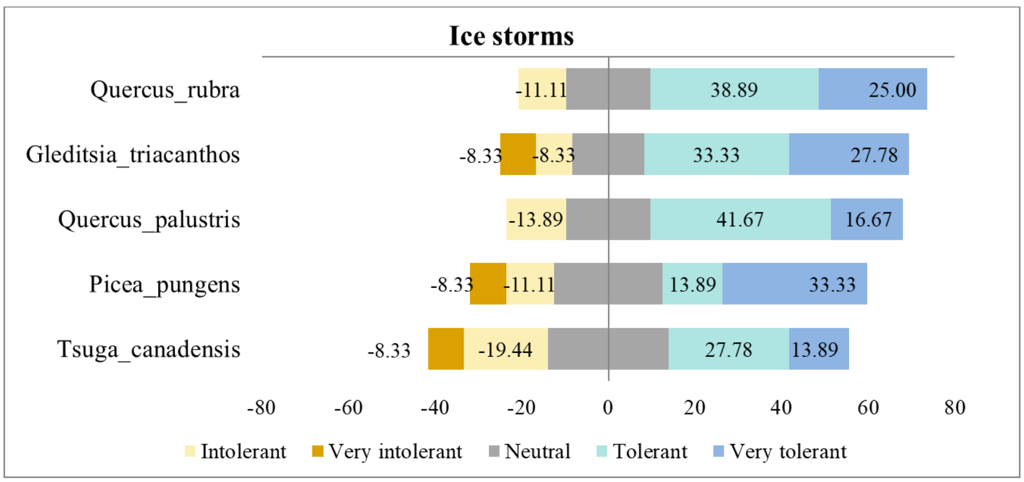

Figure 30: Frequencies of species ranked by the respondents as the most tolerant to ice storms.

4.2.10 Snow

Among the most tolerant trees, the following species were chosen: *Quercus palustris* and *Quercus rubra*. Both oaks with percentages over 75% (see table 24). The three other trees that followed were *Gleditsia triacanthos*, *Acer saccharum* and *Acer platanoides,* though none of them surpassed a 75% of agreement (Fig. 32). The majority of the participants who identified these species as tolerant were certain or somewhat certain from a 66.6% to a 73.91%.

In this section, just one species reached an accord of 50% in its intolerance: *Pyrus calleryana* (2.44±1.34).

Table 24: Most tolerant species to snow and their mean, standard deviation and percentage of participants that chose them as tolerant and very tolerant.

Species	**Mean**	**S.d**	**Option 4 + 5 %**
Quercus palustris	4.27	0.76	80.56
Quercus rubra	4.14	0.88	77.78
Gleditsia triacanthos	4.00	1.09	66.67
Acer saccharum	3.80	1.16	66.67
Acer platanoides	3.88	1.04	63.89

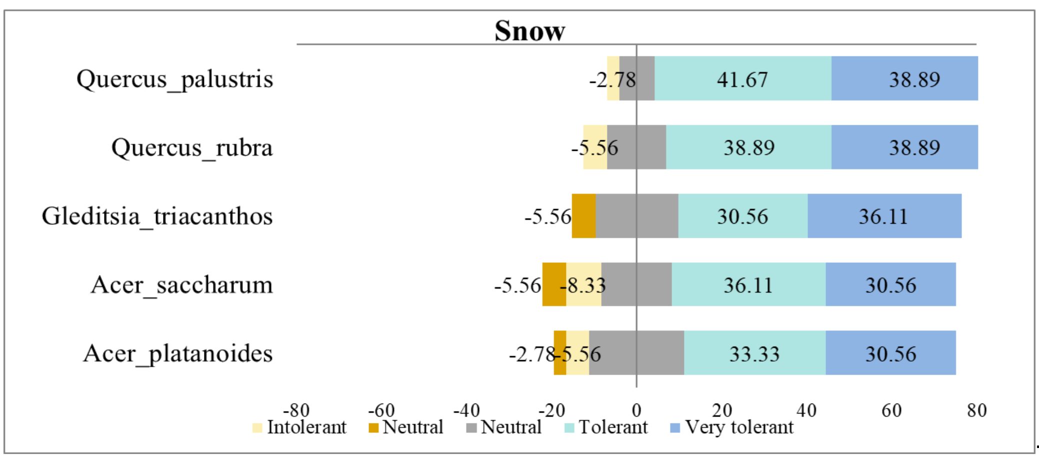

Figure 31: Frequencies of species ranked by the respondents as the most tolerant to snow.

4.2.11 General results

In general, the species that was mentionned for all the disturbances among the most tolerant was *Gleditsia triacanthos* (Figure 33). For atmospheric pollution, soil compaction, drought, de-icing salts and extreme temperatures, this species has been ranked as the most tolerant to all these disturbances. For ice storms, it was ranked as number two and it was chosen in third position for strong winds and snow. For the sensitivity to insects and disease, it was rated as tolerant in the fifth place. This species was also selected by the Delphi method as tolerant for six of the disturbances.

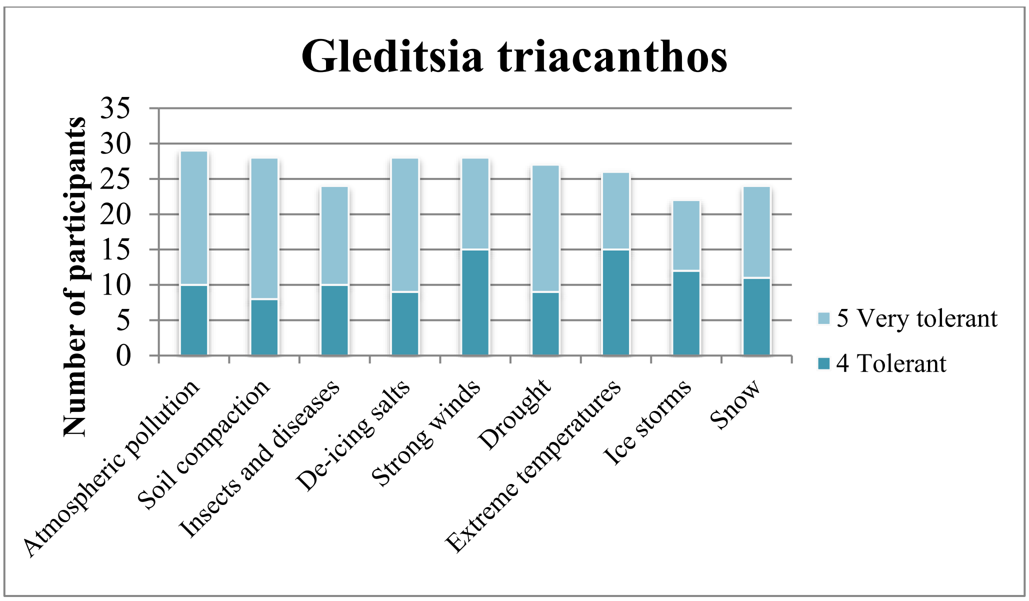

Figure 32: Frequencies of *Gleditisia triacanthos* ranked as tolerant and very tolerant by the respondents for all the disturbances.

4.3 Knowledge gap

From the results presented above, it can be seen that for some disturbances, the opinions among the experts of the Delphi questionnaire and among the participants in the closed survey were not very conclusive with regard to the most tolerant and intolerant species to urban disturbances. The following table shows the disturbances where the results were the least clear. By doing two questionnaires with two different target populations, it is possible to see in each sample population where there was a lack of agreement.

Table 25: Disturbances to which the opinion about the tolerance of the species was the least clear.

Closed survey	**Delphi method: most tolerant species**	**Delphi method: most intolerant species**
Insects and diseases	De-icing salts	Insects and diseases
De-icing salts	Strong winds	Drought
Drought	Snow	Snow
Extreme temperatures		
Ice storms		

This may indicate that there is lack of knowledge on the tolerance of the species to these disturbances and that there is a need for further research on these urban disturbances and tree species responses.

DISCUSSION

Having two questionnaires on urban trees of north-eastern North America targeting two different groups allowed us to achieve the objectives of this research in two different ways. As we had the opinion of two different populations, it allowed us to see where there might be a possible gap in knowledge about the tolerance of urban trees and where it would be interesting to go further, perhaps with empirical experiments, for a better understanding of the sensitivity urban tree species to disturbances.

On one hand, the lists of tree species from the Delphi method were not influenced by the questionnaire (Murphy et al., 1998), as the questions were open-ended. With this, we aimed to obtain new insights on the most tolerant and intolerant species to the different disturbances. For example, *Ginkgo biloba* was chosen as the most tolerant species for atmospheric pollution, insects and diseases, drought and extreme temperatures, and it is not among the species from the closed survey, as it was not among the most common species in the area of study. For de-icing salts, where there was not a lot of agreement, *Gymnocladus dioicus* was chosen as one of the most tolerant tree species and it is also not on the list of the closed questionnaire.

On the other hand, the list of species obtained from the closed questionnaire allowed us to have a rating of the tree species already common in the cities of the study area from a point of view other than that of experts, such as academics and young workers. The most mentionned species as tolerant throughout the closed questionnaire was *Gleditsia triacanthids*, which was chosen for all disturbances. This species was also chosen as tolerant to all disturbances except insects and diseases and snow in the Delphi method. As this species has been chosen in both questionnaires, this confirms that *Gleditsia triacanthos* can adapt well to urban environments

5.1 Atmospheric Pollution

The statements on which the experts agreed for this disturbanceare in line with recent studies that have shown that air pollution can diminish the growth of different species (Locosselli et al., 2019; Mikulenka et al., 2020).Even though, these studies did not target North American species. On the contrary, other articles suggest that in spite of the disturbances that urban trees might suffer, they grow faster due to higher levels of CO_2 and higher temperatures on urban areas (Moser et al., 2017; Smith et al., 2019). However, in this case, where the species grow faster in urban areas, the species also die young.

For the question about the characteristics of the most tolerant trees to atmospheric pollution, the traits that were selected were good health of the tree, which is not intrinsic to one species, and thick leaves. The statement “large leaves” was chosen as neutral, meaning that for the experts this characteristic did not influence the tolerance of urban trees to atmospheric pollution.

In the section on the characteristics of the least tolerant trees to atmospheric pollution, “thin leaves” was the only statement on which consensus was reached. In the typical leaf, chlorophyll content increases gradually as a function of depth, so having thin leaves would mean that the levels of chlorophyll are lower than in thick leaves (Borsuk et al., 2019). In addition, pollutants, when absorbed by the leaves, may cause a reduction in the concentration of photosynthetic pigments, like chlorophyll and carotenoids, which directly affect the plant productivity (Joshi et al., 2009). This could have more serious consequences for trees with thin leaves as these have less chlorophyll per se (Borsuk et al., 2019).

Ginkgo biloba was ranked in the first position as tolerant to atmospheric pollution . Originally from China, this species has been introduced in North America for its resistance to urban environments (Dmuchowski et al., 2019; Gilman et al., 1993) but it is not among the most commonly planted species in north-eastern North American cities, hence it was excluded from the list of species presented in the closed questionnaire.

If we compare the results of the Delphi method with those of the closed questionnaire, two species are among the most tolerant in both: *Gleditsia triacanthos* and *Fraxinus* spp. *Ulmus* spp., which was chosen as part of the most tolerant in the Delphi survey, was ranked eighth out of 20 in the closed survey.

Finally, the species that have not been listed in the Delphi method but have been chosen as the most tolerant in the closed questionnaire are *Acer negundo, Acer platanoides and Acer saccharinum*. In a study where the effects of pollution were tested on *Acer negundo* (Dineva, 2005), it was shown that the thickness of the upper cuticle was increased when compared to those from an region with low pollution level. The thickness of lower epidermal cells was decreased as well. All changes of the leaf-blade structure were significant and were in the direction of increasing the xerophyte characteristics of the leaves, meaning that the species could be considered to be relatively tolerant. On the other hand, *Acer platanoides*, present in the list of the closed survey, is listed as invasive in Massachusetts and Connecticut (USDA, 2020). This species was introduced to North America in 1700 and it tends to be invasive and compete with native species (Tree Canada, 2020.). It was widely planted throughout much of North America, especially along streets and in yards due to its rapid growth and high tolerance to urban stressors (CVC, 2020), but in many areas it escaped into the surrounding forest and woodland, where it became invasive (Munger, 2003). Finally, *Acer saccharinum* has been heavily planted as an ornamental tree in different urban spaces because of its ease of transplanting and establishment, adaptability to a wide range of sites, rapid growth, and good form. The species has also been used for vegetative rehabilitation of surface mined lands as well as for bottomland reforestation (Nesom & Lincoln, 2000).

Among the species that were selected as the most intolerant by the Delphi experts was *Pinus strobus*, which according to a report from the Ohio State University(OSU, 2021d) is not well adapted to urban stresses. If we compare the most tolerant species from the Delphi method with the results from the closed survey, we see that only *Acer saccharum* appeared in both questionnaires.

5.2 Soil Compaction

Regarding the characteristics of the most tolerant trees, the experts stated that being adapted to seasonal flooding was a relevant trait of the most tolerant species to soil compaction. In wetlands, as the soil is always waterlogged at the surface or at root level, the species living there have to be accostumed to anoxic conditions (Pataki et al., 2013). Likewise, soil compaction, by not allowing porosity in the soil and therefore reducing the oxygen amount that can reach the deeper soil layers, can lead to anoxia (Shah et al., 2017). Compacted soils cause lack of drainage, which translates to a soil filled with water (Pineo et al., 2009). Hence, according to experts, wetland species are those that are accustomed to these characteristics. In addition, plants adapted to wetlands have special enzymes that allow them to survive in saturated soils (Pineo et al., 2009). In the third round, it was also mentionned that being drought tolerant was important for being resistant to soil compaction, although the species chosen for the two disturbances were not the same, except for *Ulmus* spp. and *Gleditisia triacanthos*.

For the characteristics of the most intolerant trees, the experts stated that drought intolerance was also a sign of intolerance to soil compaction and in this case, *Fagus* spp. and *Acer saccharum* were listed among the most intolerant to both stresses.

When comparing the most tolerant species from both questionnaires, except for *Quercus macrocarpa* and *Acer rubrum*, all the species chosen by the Delphi experts are amongst the most abundant in the targeted cities and hence were included in both questionnaires. Even though *Quercus macrocarpa* is not on the list, it is used as a shade tree in cities as it resists compacted soils and atmospheric pollution (USDA et al., 2020). Furthermore, in both questionnaires, *Gleditsia triacanthos* is among the most tolerant to this disturbance. The genus *Ulmus* is ranked third in the Delphi questionnaire and *Ulmus americana* is also third in the closed survey.

Among the most common trees, one of the most tolerant was *Fraxinus pennsylvanica*, although its planting is not recommended given its susceptibility to emerald ash borer (NC State University, 2021a; Nowak et al., 2016). These species are among the most tolerant to compacted soils in both questionnaires but if we take into account the characteristics chosen for the most intolerant trees to soil compaction – it was stated that having a shallow root system was a trait associated with the most vulnerable tree species –these two facts are inconsistent with each other. Further research is thus needed to clarify this. Finally, other species that are among the most tolerant in the list of the most abundant urban species but were not mentioned in the Delphi were *Acer saccharinum* and *Acer negundo*. *Acer saccharinum*, as well as *Acer negundo*, has shallow roots, though they have been shown to be resistant to soil compaction (Coder, 2000; Moore & Nesom, 2001; NCSU, 2020; Nesom & Lincoln, 2000).

Finally, in relation to the most intolerant species, both *Fagus grandifolia* and *Fagus sylvatica* have been selected by experts as the most intolerant to soil compaction and are not among the most abundant in north-eastern North American cities.

5.3 Insects and Diseases

The participants agreed that the effects of insects and diseases on trees were defoliation, early leaf discoloration, leaf damage, mortality, aesthetic impacts, disruption of the tree vascular system and also trunk damage. These effects are concordant with the effects from a number of pests and diseases such as the emerald ash borer (NCFS, 2020), the Hemlock woolly adelgid (Letheren et al., 2017) or the Dutch elm disease among others (Tree Canada, 2020).

For this disturbance, there was considerable divergence between the most tolerant species in each questionnaire. The Delphi experts chose *Ginkgo biloba* and *Gymnocladus dioicus* among the most tolerant urban tree species to insects and diseases. These species were not listed in the closed survey. Both species are really resistant to pests and diseases (Pan et al., 2016). The latter is best suited for large areas such as parks because it produces lots of litter (University of Kentucky, 2020.). The other species that were listed were: *Pyrus calleryana*, *Acer rubrum* and *Amelanchier* spp. The first one can be found in the list of the closed questionnaire although in the 13th place out of 20. *Pyrus calleryana* is not recommended as its cultivars cannot self-pollinate but can produce viable seeds through crosspollination between different cultivars (Culley & Hardiman, 2007; USDA, 2020a). The descendents are aggressively invasive in natural and disturbed open areas, displacing native plant communities and disrupting natural succession (USDA, 2020). *Acer rubrum* was ranked eighth in the closed questionnaire and among the most tolerant species in the Delphi method. More species from the genus *Acer* have also been chosen as very tolerant in the closed questionnaire (*Acer saccharinum* and *Acer negundo*). As for *Acer rubrum*, as well as for the other tree species of *Acer*, they are susceptible to the Asian longhorned beetle (Meng et al., 2015; Moore & Nesom, 2001; Nesom & Lincoln, 2000). *Amelanchier* spp. have been selected number 15 out of 20 in the closed survey. This genus may have the diseases or pests that affect the *Rosaceae* family but its effects are mainly aesthetic (Sheahan, 2015). The rest of the species chosen in the closed survey had percentages of agreement lower than 67%, which indicate that the experts could not reach an agreement. *Gleditsia triacanthos* was found to be tolerant and *Platanus x acerifolia* to be moderately tolerant (Morton Arboretum, 2020; Nesom, 2000). *Rhamnus cathartica* was selected in the last place, but it is not recommended and has even been banned in some states as it is a pioneer species and tends to be invasive. For instace, in Syracuse, NY, the population of this species has tripled in eight years (Nowak et al., 2016).

Some of the urban tree species chosen as the most intolerant to insects and diseases were similar in the two questionnaires. It should be noted, however, that the percentages obtained in the closed survey were not higher than 75%, so it cannot be stated that the participants reached an agreement (Diamond et al., 2014). In both questionnaires, *Fraxinus pennsylvanica* and *Ulmus americana* were selected as intolerant. *Fraxinus pennsylvanica* adapts quite well to the street tree planting pits and other confined soil spaces and it can tolerate flooded and wet soil (Dickerson, 2002). However this species is not recommended anymore because it is highly affected by the emerald ash borer (Dickerson, 2002; Robertson et al., 2016). The emerald ash borer, native to Asia, was detected in 2002 in USA and has since spread to different states in the USA and in some provinces in Canada. It has caused the death of at least 50 million ash trees in forested and urban areas (Herms & McCullough, 2014; NRCAN, 2021). *Ulmus americana* is an urban tree appreciated for its shade. It was the most popular tree to plant in cities in the 19th century, so that by the 20th century many streets were lined with only elms (Morton Arboretum, 2021). As it was abundantly planted, when the Dutch elm disease arrived in North America, it killed over 40 million of *U. americana* (Colombo, 2016; D'Arcy, 2000; Sjöman et al., 2016). Even though, currently there are some cultivars that can resist the dutch elm disease (Morton Arboretum, 2020b). Also, some cities in Canada (Tree Canada, 2021b) have been able to control this disease. The expert panel of the Delphi method also chose *Prunus persica* as one of the most intolerant tree species. Another tree specieslisted in the other questionnaire as intolerant is *Prunus serotina*. Only 36% of the participants classified it as vulnerable, although there were only three other species with higher intolerance percentages. These species are known to suffer from various pests and diseases such as aphids, scale, borers, leafhoppers, caterpillars, tent caterpillars and Japanese beetles (NCSU, 2021; University of Illinois, 2019a) The other species that appeared in the Delphi was *Betula* spp, which can be affected by several insects and diseases (NCU, 2020.; NRC, 2020.; Eshenaur et al., 2018).

5.4 De-icing Salts

. For this disturbance, several sentences about the effects that de-icing salts can cause on urban trees achieved an agreement. Still, the impact of this stress on urban trees has not been widely researched, but some studies have found that de-icings salts can affect the uptake of water and nutrients -(Clatterbuck, 2010; Equiza et al., 2017; Ordóñez et al. 2018). When the soil has a high level of salt, it lacks good drainage and proper oxygen concentrations and leads to reduced moisture uptake by the roots. The availability of water to plants is decreased because of increased osmotic tension, by which water is held in the soil. Water does not move into the plant and could not even move osmotically from the cells to the soil with elevated salt content (Clatterbuck, 2010).

In the second and third round, it was agreed that urban trees that had the highest tolerance to this disturbance had waxy leaves, were adapted to salt, to soil compaction and also to drought. Also, experts affirmed that drought tolerant species were salt tolerant species. This could be because, in principle, increased vacuolar solute accumulation could confer both salt and drought tolerance (Gaxiola et al., 2001). Furthermore, it was agreed that species tolerant to soil compaction were also tolerant to salt. .Almost all of the species listed in this section as tolerant are also tolerant to soil compaction, except for *Fraxinus americana* (Fountain, 2011; Nesom, 2000; Nesom & Moore, 2000; OSU, 2021a, 2021c).

For the most intolerant tree species to salt, the conifers, they tend to show their intolerance to salt by turning its foliage yellow or brown in the early spring. If salt spray causes damage, discolored needles are soon masked by a new year's growth. If the salt damage results from de-icing salts in the soil, new needles may die as chloride ions accumulate in them. Either type of damage could be lethal to a plant if it occurs for several consecutive years (University of New Hampshire, 1996). Previous studes have shown that there are also different species of broadleaves that are vulnerable to de-icing salts such as *Fagus grandifolia, Platanus occidentalis* and *Quercus bicolor* among others (Hughes et al., 2015).

Another characteristic of the most intolerant tree species to salt is shallow roots with thin bark, which makes the trees susceptible to spray salts (Clatterbuck, 2010). The experts from the Delphi agreed that shallow roots is one of the traits from the most intolerant trees., .

The ranking of the most tolerant species to de-icing salts was not very conclusive according to the Delphi method. In this questionnaire, as well as in the closed survey, *Gleditisa triacanthos* and *Fraxinus pennsylvanica* were qualified among the species with the highest tolerance. Although for *Fraxinus pennsylvanica* there is some discrepancy about its tolerance depending on the source (OSU, 2021c; R.U, 2020). For *Acer platanoides*, rated within the most tolerant in the closed questionnaire, additional attention must be given to it as it is qualified as invasive in two states in the United States (Munger, 2003). The other species from genre *Acer* named in the Delphi method was *Acer rubrum*. It is the 15th from the most abundant trees and has indeed been reported to have low tolerance to de-icing salts (Gilman & Watson, 1993). Of the most common species, *Rhamnus cathartica* also appears on the list but this species is not recommended and has even been banned in some states (Nowak et al., 2016).

The intolerant tree species varied considerably from the two questionnaires; only *Acer saccharum* was mentionned in both. Tirmenstein et al. (1991) also confirms that this species is among the most intolerant. The other urban species listed as not resistant to salt, according to the Delphi experts, were the conifers *Pinus strobus* and *Abies balsamea*, which is consistent with the traits they stated. Identified within the most intolerant trees of the closed survey, the conifer *Tsuga canadensis*, a species that generally does not tolerate the urban stresses, was also listed (Nesom, 2002). Finally, among the most intolerant species in the Delphi method were *Cornus* spp. and *Betula* spp. For the first genus, there is some divergence between its tolerance, even within the same species (Hughes et al., 2015; Salon & Miller, 2012). The tolerance of the *Betula* genus to de-icing salts changes among the species (The Morton Arboretum, 2021a, 2021b). Between the species that can be found in north-eastern North America, *B. alleghaniensis* is intolerant; *B. lenta* is tolerant to salt spray but intolerant to soil salt; and *B. nigra* (Hughes et al., 2015) and *B. papyrifera* are tolerant to salts. Finally, among the species least tolerant to de-icing salts in the closed questionnaire was *Acer rubrum*, which the Delphi experts agreed with.

5.5 Strong Winds

Extreme weather events are likely to increase in the future, which means that trees are going to be more exposed to strong winds and other disturbances that can induce damage to them (McPherson et al., 2018).

In this section it was stated that having a good structure, deep roots, stable rooting, a slow growth rate, dense wood and general good health were characteristics of the most tolerant trees to winds.(Curran et al., 2008; Paz et al., 2018). For strong winds, it is also important to know that receiving a good structural pruning can help to reduce damages (Gilman et al., 2008; Harris et al., 2008).

The majority of the characteristics from the most intolerant species were also related to structure. Some of these characteristics can be found in Pax et al. (2018). Among the traits named, trees with extended crowns are expected to present the greatest damage because, when trees are subjected to lateral wind forces, such structural traits act to increase the tension transmitted to the pole and roots.

Concerning the trees chosen as the most tolerant, both in the Delphi and in the closed questionnaire, the genus *Quercus* was listed. The species named were Q*. alba*, *Q. rubra* and *Q. palustris*, which are known for being windthrown tolerant. (GNPS, 2020.; PFAF, 2004a; USDA, 2020e). Even though these are tall trees, Zimmerman et al. (1994) concluded that generalizations on the effects of tree shape on resistance to really strong winds are difficult to make, partly because different components of a complex architecture play a role. The other species that were listed by the experts of the Delphi method were *Taxodium distichum*, *Juglans nigra* and *Gleditsia triacanthos*. The latter is also among the most tolerant in the list of most abundant species and it is an excellent option for windbreaks (USDA, 2021a). *Taxodium distichum* has the characteristic that its root system forms conical knee-shaped projections below the ground and makes this species extremely resistant to wind (Williams, 2008). Finally, the two other species that have been rated as the most tolerant among the most abundant urban trees were *Ulmus americana*, which although affected by Dutch elm disease, there are variants that are resistant to this disease and maintain wind resistance (Williams, 2008); and *Rhamnus cathartica* was also named.

In the list of species that have been chosen as the most intolerant, there was little agreement between the two questionnaires. Only *Pyrus calleryana*, which tends to be susceptible to limb breakage or splitting because of the wind, was selected as intolerant

(Missouri botanical garden, 2021). The other species from the Delphi method were *Salix* spp. and *Populus* spp. In the *Salix* genus differences between species can be found. For example, the wood of *Salix nigra* is weak and tends to crack with the wind (NC State University, 2021), though *Salix alba* is tolerant (PFAF, 2004b) and is planted as a windbreaker outside of cities (Williams, 2008).

Fraxinus spp. were also listed but only a 28.57% of respondents chose it. They have shallow roots and even if they are considered extensive, the tree may topple with high winds (USDA, 2020c). Other species selected were *Pinus strobus* and *Picea abies*. *Pinus strobus* is usually planted for windbreaks and screens along fields, new right-of ways and around campsites. As for *Picea abies,* it is also usually planted as windbreak (Williams, 2008). In contrast, some studies show that the influence of changes in the disturbance regime on forests will most likely be amplified by the interactions between different stressors (linked disturbances). Hence, it has been shown that *Picea abies*, when affected by linked disturbances, its susceptibility to wind increases. The following traits should also be taken into account as they have significant influence on the probability of wind damage: the slenderness ratio, the stand age, the stand density, and the soil type (Snepsts et al., 2020).

Finally, the other species chosen among the most abundant were *Acer saccharinum* and *Acer negundo*, which are frequently damaged by wind (Nesom & Anderson, 2002; Rosario, 1988; Tirmenstein, 1991; USDA, 2020h).

5.6 Drought

As climate change will bring warmer wetter winters and warmer drier summers (Johnston, 2004), the resistance to drought will be an important asset for urban trees. In addition, urban areas are characterized by impervious surfaces, increased temperatures and reduced water availability to plants (Dale & Frank, 2017).

The experts agreed that the characteristics of the most tolerant trees were as follows: soil compaction tolerance, deep root system, waxy cuticle, good health, native from drought stressed places, salt tolerance and having good water storage ability. As mentioned above, compacted soils lead to reduced nutrient and water uptake as roots cannot penetrate the soil, thus creating a drought-like effect (Pineo et al., 2009). The participants in the questionnaire stated that drought tolerance is related to salt tolerance. Both disturbances induce osmotic stress. Hence, cross-tolerance responses and mechanisms may occur (Leksungnoen, 2012). Some of the species listed here as the most tolerant were also selected for soil compaction (*Ulmus* spp. and *Gleditsia triacanthos*) and for de-icing salts (*Celtis* spp., *Gleditsia triacanthos* and *Gymnocladus dioicus*). In addition, all the species from the Delphi survey were drought tolerant and ice tolerant, though for the genus *Ulmus* tolerance might change between species (M.A, 2020.-b; Moore, 2003; Nesom, 2000b; OSU, 2020-a; USDA,2020-h).

As characteristics of the most drought-intolerant, a consensus was only reached with shallow roots. Even though experts agreed in this characteristic, a study from 2019 (Shugartet al., 2019) showed that, as drought persisted, mortality is 1.5–2.7 times higher in large-tree than in medium and small trees. They attributed this temporal differentiation in height-dependent mortality risk to the strong relationship between leaf area, water, and carbon requirements for sustained productivity. Also, another study confirmed that needleleaf and native trees were more affected by drought than broadleaf and non-native trees, respectively, but with considerable interspecific variability (Alonzo et al., 2020).

Two species were chosen as the most tolerant in the two questionnaires:*Gleditsia triacanthos* and *Quercus rubra*. Another genus listed in both was *Ulmus*. The experts selected *Ulmus* spp. and in the list of most abundant species it was *Ulmus americana*. This species is reasonably drought resistant, but prolonged exposure reduces growth and may cause death (Bey & USDA, 2020).

The other tree species mentioned as tolerant to drought in the Delphi method that were not among the most abundant were *Ginkgo biloba* and *Gymnocladus dioicus*. On the other hand, within the most abundant species that did not appear in the Delphi method were *Fraxinus americana*, which can be greatly affected by the emerald ash borer, and *Acer negundo.*

Acer saccharum was the most intolerant species in both questionnaires. This species was also chosen as intolerant to soil compaction and de-icing salts. From the same genus, *A. saccharinum* was rated in fifth place by the Delphi experts. The trees that were only named in the Delphi were *Betula* spp. and *Fagus* spp., which also appeared as intolerant to de-icing salts and soil compaction respectively.

Of the most abundant species, the one classified as the least tolerant to drought was *Tsuga canadensis*, which is also intolerant to de-icing salts.

5.7 Extreme Temperatures

Similar to drought, extreme temperatures will become more and more frequent due to climate change, so tolerance to this disturbance will eventually be more and more important (Dale & Frank, 2017; Johnston, 2004).

The experts agreed that the effects of extreme temperatures on urban trees were early leaf loss, leaf damage, mortality, desication, early leaf defoliation, slow growth and branch breakage. Along with the effects that participants listed, a recent study showed that root growth may also be disturbed by high soil temperatures – because of the pavement, the temperature of the soil can be up to 16°C higher than on grass (Czaja et al., 2020).

The characteristics of the most tolerant species to extreme temperatures according to the experts are waxy surfaces, leaf pubescence, regulation of water loss, age, adaptation to hot dry conditions and deep roots. Waxy surfaces provide protection against heat and intense UV rays, as well as protection against the cold (Sevanto, 2020; University of Illinois, 2019b). Having leaf pubescence tends to be more beneficial in the heat. It has several important roles, including regulating heat balance, reducing damage from UV radiation, and minimizing water loss (Moles et al., 2020). Having deep roots can help in cold temperatures, as roots are more insulated, and in hot temperatures, as they can get water deeper in the soil. One of the biggest problems is the intense fluctuations in temperature, which do not allow the trees to acclimatize, and this is when the most damage is done (Ambroise et al., 2020; Berube, 2021.; Luo, Chu et al., 2020). Not all species chosen as more tolerant to this disturbance contain all the characteristics that have been stated to define trees resistant to extreme temperatures. For example, the majority of the species stated as most tolerant do not have waxy leaves or pubescences (Bey & USDA, 2020; Krajicek & Williams, 2020; Moore, 2003; OSU, 2021c; USDA, 2020e, 2021b), with the exception of a variety of *Ulmus* named *Ulmus 'Morton Plainsman',* an hybrid raised by the Morton Arboretum which has waxy leaves and it has a good resistance to the Dutch Elm disease (Morton Arboretum, 2020b).

Shade tolerant tree species were considered the most intolerant to extreme temperature. This agreed with the tree species selected as intolerant in the Delphi (Frank, 2020; Gilman & Watson, 1993c; Mahr, 2021; OSU, 2021d; Sullivan & USDA, 2020). The fact that these two disturbances may be related could be because adaptations that allow woody species to grow in shade can compromise their ability to do so in dry and hot conditions (Godoy et al., 2017). The restricted co-tolerance of these two key stress factors is considered the main constraint limiting the combinations of species in forests across gradients of cold and water availability. Thus, further thoughts should be given to this when planning to plant trees in urban settlements (Laanisto & Niinemets, 2015; Rueda et al., 2017).

When comparing the trees that have been chosen as the most tolerant to this disturbance, *Gleditisia triacanthos* can be found in both questionnaires. This species is hardy (survives freezing) at -30ºC (USDA, 2021b). The genus *Fraxinus* and *Ulmus* have also been selected. The wide range occupied by *Fraxinus pennsylvanica* implies a wide tolerance of climatic conditions (USDA, 2020) and the same is true for *Ulmus americana* (Bey & USDA, 2020). This matches the trees that were among the most abundant: *F. pennsylvanica* and *U. americana.* The species listed by the Delphi experts that were not in the other survey were *Ginkgo biloba, Celtis occidentalis* and the genus *Quercus. Ginkgo biloba* is the only one which had an agreement of 85.71%, meaning that it is the only one that received consensus in its position. In the closed questionnaire, *Rhamnus cathartica* and *Acer negundo* were chosen among the most tolerant. It should be noted that the percentages of the closed survey are not very conclusive and that the only species on which they agreed by 75% was *Gleditsia triacanthos*. *Ginkgo biloba* is very cold hardy thriving (Moore, 2003). Also, *Celtis occidentalis* can be subjected to great extremes of temperature, with variations of 60 °C (Krajicek & Williams, 2020). All the trees listed by the experts as tolerant to extreme temperatures have deep roots, a feature mentioned in the answers of the Delphi survey as belonging to these trees, with an exception in *Fraxinus* spp, which tends to have shallow roots (OSU, 2020-b; USDA, 2020.-c).

In the section on the most intolerant species to extreme temperatures, *Acer saccharum* was listed in the two questionnaires, although just 50% of participants chose it as intolerant in the closed survey. This species' sensitivity to compaction, heat, drought and road salt limits its usage for urban street plantings, but it is still recommended for parks and other areas away from roads where soil is loose and well-drained (Gilman & Watson, 1993). The other species that was chosen as less tolerant to extreme temperature by more than 50% of participants in the closed survey was *Tsuga canadensis*, which grows well in shade (Godman & Lancaster, 2020).

The remaining species selected in the Delphi method as most intolerant were not in the list of the most abundant. These species were *Cercis canadensis*, *Abies balsamea*, *Betula alleghaniensis* and *Pinus strobus*. All of them tend to be intolerant to high temperatures. For example, *Pinus strobus* has shown sensitivity to high temperatures in winter and summer, and susceptibility to cold temperature in the spring and fall (i.e. at the beginning and end of the growing season) (Brissette et al., 2018; Mahr, 2021.; Sæbø et al., 2012; Sullivan & USDA, 2020).

5.8 Ice Storms

Ice storms result from a stratified mixing of warm, moist air and cold, dry air producing liquid precipitation that freezes upon contact with solid features at or near the surface (Hansen & Cranson, 2016). They have a great impact on cities, as well as on the fauna and flora (Groisman et al., 2016) and with climate change, freezing rain will happen more frequently (Groisman et al., 2016).

. According to the experts, one of the effects caused by this perturbation was branch breakage. When accumulations between ¼ and ½ inch happen, small branches and weak limbs can break. If the accretion is ½ inch or more, greater damage can result, like tree failure or structural damage, which were stated by the experts (Hauer et al., 2006).

The characteristics of the most tolerant species upon which the experts agreed were: dense wood, good structure, strong attachments, decay free, flexible branches, small crown and slow growth. These characteristics, when interacting, can decrease the vulnerability of trees to this disturbance (Hansen & Cranson, 2016; Warrillow & Mou, 1999). For example, in purely deciduous forests, species with weaker wood, finer branches, and larger canopy surface areas are particularly susceptible to ice damage. Also the damage to trees depends on different factors like the amount and duration of accumulated ice, exposure to wind, and the length of the storm (Hansen & Cranson, 2016).

For the most intolerant tree species, the experts agreed that they tended to have poor structure, narrow branch unions, weak wood, fast growth rate, wide crown, were evergreen and deciduous with included bark (“ingrown” bark tissues that often develop where two or more stems grow closely together causing weak, under-supported branch angles). A recent study from Lu et al. (2020) confirmed that evergreen broadleaf species were the most susceptible to glaze damage. Also they found that deciduous trees were the least susceptible, although as the experts stated, having included bark (ingrown bark tissues often develop where two or more stems grow closely together causing weak, under-supported branch angles) could make them vulnerable to ice storms (Hauer et al., 2006). According to other research (R. Hauer & Hruska, 1994; Hauer et al., 2006), many conifers have an excurrent branching pattern (the main trunk comprises the entire height of the tree, with branches establishing a lateral formation all around it) and can resist storm damage. Also, in some deciduous species, young individuals have an excurrent growth pattern that can create tolerance to ice storms. Although, later in life, it changes to decurrent growth pattern, which is not resistant to ice storms.

Related to another of the most tolerant characteristics, trees with fast growth rate often develop weak V-shaped crotches that easily split apart under the added weight of ice. These trees usually take some damage from storms throughout the year, internal rot, decay and included bark that lead to weakened trunks and limbs (Nix, 2021).

Among the species chosen as the most tolerant by the Delphi experts and the participants of the closed questionnaire were several species of the genus *Quercus*. In the Delphi ranking, *Q. bicolor* and *Q. macrocarpa* were listed and from the most abundant species, *Q. rubra* and *Q. palustris* were selected. *Quercus bicolor* and *Q. macrocarpa*, which are not in the list of the most abundant species, have a high resistance to ice storms (Coder, 2015; Fair, 2021). On the other hand, the species of the closed questionnaire (*Q. rubra* and *Q. palustris*) have an intermediate tolerance to this disturbance (Coder, 2015; Fair, 2021).

Among the experts of the Delphi method, the other species that were listed are *Juglans* spp and *Gleditisia triacanthos*. Their resistance is acknowledged by different articles (Coder, 2015; Fair, 2021; USDA, 2021b). The first species is usually cited as one of the most tolerant to ice storms. Finally, among the most abundant species *Picea pungens* and *Tsuga canadensis* were chosen. Even though both of them are evergreen, they are resistant to ice storms, with *Tsuga* being more tolerant than *Picea* (Berube, 2021.; Coder, 2015; Khan & Conway, 2020).

The species that were selected as most intolerant to ice storms in the two questionnaires coincided with the species *Pyrus calleryana*. The *Salix* species were named by the Delphi participants. This genus is often cited as one of the most intolerant to ice damage (Coder, 2015). The other species classified as intolerant were *Betula papyrifera* and *Pinus strobus*, though this last one is considered to be at moderate risk to this disturbance (Coder, 2015; Khan & Conway, 2020). For the most abundant species, we see that two of them are from the genus Acer: *A. saccharinum* and *A. negundo*. Of these species, *A. negundo* has been named in other reports as being among the most intolerant, even more so than *A. saccharinum* and *A. rubrum* (Coder, 2015; Khan & Conway, 2020).

5.9 Snow

Although the experts agreed on the neutral response, trees suffering snow damage are actually more prone to consequential damage through insects or fungal attacks (Broadgate et al.,1997). Also, even though the respondents of the Delphi method affirmed that bud loss was not an effect of snow, there are studies that show that bud injury can happen (Bidlack et al., 2019).

Trees that were deciduous, free of decay, had dense wood, good health, flexibility in its limbs, good structure and early leaf drop were rated as the most tolerant to this disturbance. Since snow damage is caused by large amounts of snow, characteristics related to tree structure are important (Nykänen et al., 1997). In addition, an early leaf drop helps the tree to avoid the risks of snow or ice loading (Pearse & Karban, 2013). Apart from these features, conifers have the ability to survive and thrive in cool climates. It allows them to dominate temperate and boreal forests throughout the world. In addition, its flexible wood and its structure allow them to bend slightly when they have a lot of snow and let it fall out of their conical canopy (Bansal et al., 2015; Satterlund & Haupt, 1967).

On the other hand, as characteristics of the most intolerant species, the following were mentioned: poor structure, weak attachments, weak wood, late leaf drop, wide branches, deciduous trees, and a fast growth rate, which is linked to low wood density (Pretzsch et al., 2018). Again, traits related to tree structure were the ones selected.

For the most tolerant species, we see that both questionnaires agree that the genus *Quercus* is one of them. The Delphi experts selected *Q.alba* and *Q. rubra*. The latter is also classified as tolerant among the list of the most abundant species. The other species classified as tolerant in the list of most abundant species was *Q. palustris*. These species tend to have stout limbs that support the load of snow with minimal damage. In addition, oaks have a slow growth rate, which means they have dense wood (Houser, 2013; Hewins et al., 2016). The other species which emerged from the Delphi method were *Picea* spp*., Abies* spp*. and Pinus* spp. Finally, the most abundant species chosen as the most tolerant to this disturbance were *Gleditsia triacanthos*, *Acer saccharum* and *Acer platanoides*. Even though conifers are mentioned as more resistant to snow load than deciduous, in the closed survey, species of the genus *Acer* were selected as more tolerant than conifers. Branches from *Acer saccharum* often form poor attachments with trunk resulting in branch failure in old, mature specimens. Also, snow loads and ice can cause branch failure in younger trees. So even if it has been chosen among the most tolerant, it might not be the best suited in cases of heavy snow loads (Maple et al., 1993). However, *Acer platanoides*, even if belongs to the same genre as *Acer saccharu*m, its branches are more resistant and it is rare that branch failure happens by weight (Gilman & Watson, 1993). As well, *Gleditsia triacanthos* wood is dense, hard, strong, stiff and shock-resistant, so it can be quite resistant to snow (Nesom, 2000).

The species that were chosen as the most intolerant in the Delphi method included *Pyrus calleryana*, which can crack with snow load (Morris, 2020). It was also selected vulnerable to ice storms, as well as *Pinus strobus*. *Populus* spp*, Thuja* spp.*,* which were also susceptible to ice storms and strong winds (Morton Arboretum, 2020a), and *Cercis Canadensis* have all a fast to moderate growth rate, which was a characteristic of the most intolerant trees that the experts selected (Gilman & Watson, 1994; Mahr, 2021; Towndsend et al., 2021; USDA, 2020a, 2020h).

In the closed survey, the species that had the highest consensus as intolerant to snow was *Acer saccharinum.* A 38.8% of participants chose it as intolerant. This species is susceptible to breakage either at the crotch due to poor collar formation, or the wood itself is weak and tends to break. It is also a fast growing species (Gilman & Watson, 1993b; Nesom & Lincoln, 2000).

5.10 Interactions

The complexity of urban environments encompasses several factors, both environmental and anthropogenic, that can affect tree growth and its health. There are various disturbances that can affect urban species, but a lack of information remains on the effects that these disturbances can have when they interact (Locosselli et al., 2019). Delphi experts mentioned winter stresses could interact and worsen its impacts on urban trees. They agreed that **wind, ice and snow** could interact as well as **wet snow**

and ice. It is proven that strong winds can increase the potential for damage from ice accumulation (Hauer et al., 2006b). Residual damage from ice storms can occur several months to years later when wood of branches and trunks weakened by ice loading falls. Another winter stress that tends to happen in early spring and late autumn is wet snow. This type of snow is warm with a high moisture content, which makes it easier for it to adhere with itself or to a stem in strong winds, unlike dry snow. Hence, it can add a lot of weight on the tree, which, if not structurally stable, can eventually break (Nykänen et al., 1997). In addition, if there is sticky ice, the weight of these two can be worse for the tree.

Other stresses that can act together on urban trees are **soil compaction with de-icing salts** and **soil compaction with drought**. The first two can easily be found in cities where it often snows. Physical characteristics of the soil, such as the level of compaction and soil texture, have been found to influence the amount of salts that accumulate in the soil (Ordóñez et al., 2018). More research is needed to know if this happens in all species or if it depends on the species. Also, if there are de-icing salts in soils that are not compacted, depending on the composition of the soil, compaction can occur. This mostly happens in clay soils because salts can bind with them. In sandy soils this phenomenon is less frequent (Appleton et al., 2015).

On the other hand, even if there is little research on the subject, a study pursued in Michigan (McClung & Ibáñez, 2018) found that detrimental effects of impervious surface cover eliminated any of the beneficial effects of growing in a wet year for the species *Acer saccharum* and *Quercus rubra*. This study illustrated how the combination of drought events and increasing impervious surface cover could have a differential impact on coexisting species in urban forests, which could further alter the species composition and functioning of these ecosystems. Although, the same study showed that not all species followed this rule. Another article (Chan et al., 1999) concluded that soil drying and compaction have large species-specific effects on the distribution, growth and physiology of roots, since they found that drought enhanced the effects of soil compaction on root hydraulic conductivity.

Another interaction which was mentioned is **drought with diseases**. A study pursued in the boreal forest in Alberta and Quebec suggests that negative feedback in tree responses to drought and insect attacks may be weaker than predicted for defoliator-dominated boreal forest systems. They concluded that it may offset the impacts of water deficit on boreal tree growth by reducing transpirational water demand (Itter et al., 2019). Further research is needed to see if this could be confirmed in urban settlements. On the other hand, another study focusing on urban trees (Dale & Frank, 2017) found support for the additive effects of warm and drought stress in increased embryo production and size of *Melanaspis tenebricosa*, species that affect *Acer rubrum*. This provides further evidence that drivers of pest insect outbreaks act in concert, rather than independently, and calls for more research that manipulates multiple abiotic factors related to urbanization and climate change to predict their effects on ecological interactions.

Finally, the last interaction where a consensus was achieved among the experts was **extreme temperatures, drought and climate change**. It is known that with climate change, extreme temperatures and drought will happen more frequently (Colombo, 2016). There are studies that state that future climate change scenarios will bring a shift towards a warmer, drier climate would exacerbate declines in radial growth, caused by drought, and thereby health, highlighting that the studied species are vulnerable to climate change (Meineke & Frank, 2018; Nitschke et al., 2017).

In relation to interactions between disturbances, it should be taken into consideration that while dormancy enables broad leaf trees to more successfully face additional stress factors besides shade and drought, conifers have lower polytolerance, but can better tolerate shade and drought when other environmental factors are favorable (Laanisto & Niinemets, 2015; Rueda et al., 2017).

5.11 Additional Disturbances

The experts agreed that direct human impact on urban trees is an important disturbance that was not included in our questionnaire. The human impacts on urban trees can be divided in three categories: urban development (e.g., infrastructure, construction…), fragmentation, and isolation (Referowska-Chodak, 2019). Thus, according to this, soil compaction and pollution could be included in this stress. If we take a more global view, climate change is induced by human activity like fossil fuels being burned, aerosol releases and land alteration from agriculture and deforestation (Donev, 2021.; Ordóñez & Duinker, 2015b), so defining human impact as a single stress is complicated as it comprise several disturbances simultaneously.

Another disturbance the participants suggested in the Delphi method was mechanical damage. It includes any activity that damages the roots, root collar, stem, branches or leaves (USU, 2021). For example, lawn mowers and weed trimmers can cause injuries that create a hazard when an injury leads to tree disease or death (Purcell, 2013; USU, 2020).

The last stress that respondents agreed with was the absence of basic conditions for tree growth and establishment. For the good growth of the tree when planted, considerations should be given to various environmental factors that will impact the first 2–3 years of plant growth and establishment. Exposure to various environmental factors should be assessed at each location, as well as manmade influences like building vents, utilities, drainage systems and much more (Kuser, 2000).

5.12 Limitations of the study

For this research, it should be remembered that the Delphi methodology lies in the assumption that the respondents are experts who have a high level of knowledge in urban forestry and that they were honest and accurate in their answers and comments. Therefore, it is assumed that the results obtained are useful and have valuable knowledge about the subject studied.

As this project is based on expert opinion, it is important to be aware that the word "opinion" itself carries with it a level of uncertainty (Cooke, 1991). However, this does not mean that expert opinion cannot be used. The respondents answered according to their knowledge gained from experience or observations (the experts had between 15 and 25 years of experience) and the Delphi method was the most appropriate methodology for the objectives of this research. Direct empirical evidence was not available to achieve our objectives. This does not mean that the results obtained substitute empirical evidence. They belong to a context of discovery rather than justification and can help focus research on understudied topics that can improve the future of urban forests.

In addition, it should be noted that the total number of participants who made it to round 3 of the questionnaire was only seven, which is just below the minimum (Okoli & Pawlowski, 2004). This may imply not having a representative sample of the targeted people and may result in low response reliability. Even so, the fact that there has also been a closed survey with more participants can add strength to this project.

After having carried out the Delphi method, I would take into consideration the way in which I engaged the experts. Since the recruiting and response process was quite long, I would try to contact the experts by skype or phone. In a more personal way so that they would feel engaged with the research.

The closed survey also has its limitations. One of them is that this type of question cannot elicit in-depth responses, since participants are given a list of possible answers (Hyman & Sierra, 2016). As the potential responses are given to them, neither it is possible to obtain new insights on the questions (Manfreda et al., 2003). It is also highly unlikely that participants will come up with answers that are not in the questionnaire. Thus, this type of questionnaire can condition responses and prevent new ideas from being contributed.

Also, even if the closed questionnaire was sent through organizations, the number of people that answered was not as high as expected. This may imply not having a representative sample of the targeted people and may result in low response reliability. Given this limitation, it would have been advantageaous to have more time and more visibility. In order to attract more people, an incentive could have been offered, like for example a lottery ticket (Rea & Parker, 2005).

In the discussions, when referring to the two questionnaires at the same time, it should be kept in mind that we are talking about two different questionnaires, methodologies and that the targeted population is different in the two questionnaires. Therefore, these two surveys cannot give a single, definitive result (Boylston, 2020). Even so, this has been made clear throughout the discussions and throughout the project. In the discussions, it should be clear that the intention is not to make a direct comparison of the results obtained by the two different methods, but rather to give a more general overview of the two questionnaires and to complement one with the other.

CONCLUSION

This project, through the use of two questionnaires, has shown that there are tree species in north-eastern North America that are tolerant to urban disturbances but are not among the most abundant tree species in the area, according to the experts in the urban forestry field. In reference to the traits of the tree species that the experts listed, this is an interesting subject because in most cases, the characteristics were related to the species they chose throughout the questionnaire. However, sometimes these did not match.

Among the species that have been most often mentionned by experts as tolerant to several disturbances are *Gleditsia triacanthos (*in the Delphi questionnaire and the closed survey*)* which might be why it tends to be overused in urban landscapes (Morton arboretum, 2021). The other species that were most often repeated by the experts as tolerant to different disturbances were *Quercus* sp., *Ginkgo biloba* and *Ulmus* sp. (though none of them have been rated as tolerant for all the disturbances). The species that most often selected as intolerant were Pinus strobus and Betula alleghaniensis In order to select tree species best suited to cities, additional site-specific information such as soil conditions, root and crown growth space, the likelihood of de-icing salt spray and other environmental and anthropogenic factors are relevant to the good health of trees. Also, the particular stresses of urban conditions must be taken into account (Barwise & Kumar, 2020). For example, urban roadside environments present extremely stressful conditions for trees, such as high soil compaction, pollution and de-icing salts (Barwise & Kumar, 2020; Czaja et al., 2020) and trees in city parks receive less stress from disturbance than in the roadside (Czaja et al., 2020). Tiwary et al. (2016) suggest that the tolerance of vegetation to relevant environmental disturbances should be prioritized as an indicator of its sustainability. Furthermore, several articles show that the viability of individual tree species varies from one planting site to another if conditions are different, in addition to the care given to the tree while growing (Kuser, 2000; Jankovska et al., 2015; Roman et al., 2014).

Another variable to consider when choosing an urban tree and of which more information is needed is how adaptable and how quickly urban tree species can rebound from potential damage that urban disturbances may cause (Endreny et al., 2020). As we have seen in this project, aptation to different abiotic stresses in woody plants is highly complex. For example, trees are less capable of tolerating both shade and drought in habitats where vegetation period is relatively short and the water table high.

Furthermore, with the Delphi method we have seen that the participants have agreed on some of the effects that interactions between urban disturbances cause, especially those occurring in winter. Still, there is a lack of information about the effects that they can generate. Only some studies have tried to address this problem and a considerable gap exists around the combined effects of these interactions in urban forests (Millward et al., 2017). To obtain a better understanding, urban forests need to be considered as a complex ecological system, from a holistic point of view (Traverso, 2020).

There is no easy answer about which trees species are the best for the different challenges that urban spaces and climate change bring, and will continue to cause in the uncertain future. This project has helped to understand a little more about the tolerance of trees to different disturbances that are the most damaging in urban settings. Consulting the experts allowed us to obtain the results through the delphi method avoiding the costs and time involved in conducting a field experience. Also, this method let the experts think deeply about the questions and contribute for a better understanding of the different points of view. At the same time, as we had the opinion of two different populations (experts in the Delphi method and academics and young workers in the closed survey) it has allowed us to see where there might be a possible gap in knowledge about the tolerance of urban trees. This can be used as an argument for conducting empirical experiments or more in-depth research on disturbances where there is a lack of agreement.

Steps could be taken to favour urban tree species that are resilient and adaptable to a wide panoply of disturbances and the use of tree species with a wide diversity of functional traits as proposed by Paquette et al. (2021) The use of suitable tree species for urban conditions will not only ensure maximum environmental benefits and ecosystem services, but also will help in reducing the costs that are associated with the replacement of trees.

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ANNEX A
RÉSUMÉ

L'importance des forêts urbaines et leurs avantages sont de plus en plus reconnus et valorisés. Cependant, les perturbations potentielles que peuvent subir les arbres urbains dans les villes sont moins bien documentées. Pour le développement futur des villes, des recherches plus approfondies sont nécessaires car on s'attend à ce que le changement climatique augmente le risque de perturbations sur les arbres. Le but de ce projet est de recueillir des informations sur la tolérance de différentes espèces d'arbres urbains à plusieurs perturbations affectant les arbres dans les villes du nord-est de l'Amérique du Nord en utilisant la méthode Delphi et une enquête à questions fermées. La méthode Delphi consiste en différentes séries de questions visant à obtenir un consensus sur les opinions des différents répondants (dans ce cas, experts en foresterie urbaine). Nous voulions ainsi obtenir de nouvelles informations sur les espèces les plus tolérantes et intolérantes aux différentes perturbations. La liste des espèces obtenue à partir du questionnaire fermé nous a permis d'avoir une évaluation des espèces d'arbres déjà plantées dans les villes de la zone d'étude d'un point de vue autre que celui des experts, comme les universitaires ou les jeunes travailleurs. Cela a permis d'avoir un aperçu des espèces d'arbres urbains et de savoir si les villes sont préparées au changement global et aux perturbations plus prononcées qui l'accompagnent. Cette recherche a montré que les environnements urbains sont très complexes, de même que la tolérance aux différentes perturbations qui existent dans les villes. Parmi les espèces qui ont été le plus souvent citées par les experts comme tolérantes aux différents stress, on trouve *Gleditsia triacanthos*, *Quercus* sp., *Ginkgo biloba* et *Ulmus* sp. Dans l'enquête fermée, l'espèce qui a été choisie parmi les plus tolérantes aux perturbations

urbaines était également *Gleditsia triacanthos*. Bien qu'aucune d'entre elles n'ait été jugée tolérante à toutes les perturbations. En plus, dans les deux questionnaires, il y a eu un manque consensus concernant certaines perturbations. Cela nous a permis de voir où il pourrait y avoir une éventuelle lacune dans les connaissances sur la tolérance des arbres urbains. Cela peut servir d'argument pour mener des expériences empiriques ou des recherches plus approfondies sur les perturbations pour lesquelles il y a un manque de consensus.

APPENDIX A

RESULTS FROM QUESTIONNAIRES

Answers Delphi round 1

Table 26: Effects of atmospheric pollution on urban trees. Answers from round 1 of the Delphi in groups.

Effects of atmospheric pollution on urban trees	
Groups	**Statements**
Effects on leaves	Defoliation
	Leaf damage
Increased vulnerability to other disturbances	Higher presence of fungal and bacterial issues
	Increased vulnerability to other disturbances
Precise particles/ Localized effect	The effects depend on the pollutant, plant cultivar, timing and concentration
	Direct sources of pollution can be identified
Effects not recognizable	The effects are not recognizable
Effects affect whole tree	Slow growth

Table 27: Tree characteristics related to low atmospheric pollution tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low atmospheric pollution tolerance	
Groups	**Statements**
General tree characteristics	Soft wood
	Needle leaves shape
	Thin leaves
	Thin bark
	Drought intolerant
	Shadow tolerant
Environment	Non-native

Table 28: Tree characteristics related to high atmospheric pollution tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high atmospheric pollution tolerance	
Groups	**Statements**
General tree characteristics	Fast growth
	Good compartmentalization
	Large leaves
	Health of the tree
	Thick leaves
	Rough bark

	Drought tolerant
Environment	Non native trees

Table 29: Effects of soil compaction on urban trees. Answers from round 1 of the Delphi in groups.

Effects of soil compaction on urban trees	
Groups	**Statements**
Leaves	Defoliation
	Leaf damage
	Branch failure
Root	Improper root development
	High number of surface roots
Increases their vulnerability to other disturbances	Increased vulnerability to other disturbances
Growth	Weak growth
	Basal shoots
	Tree stability affected
	Tree death
	Delay in injury recovery
Inability to obtain nutrients and water properly	Inability to obtain nutrients and water properly

Table 30: Tree characteristics related to low compacted soil tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low compacted soil tolerance	
Groups	**Statements**
General tree characteristics	Bad compartmentalization
	Reduced growth
	Drought intolerance
	Shallow root system
Depends on factors (climate, locations)	Depends on the climate area (continental environment summer heat and drought)

Table 31: Tree characteristics related to high compacted soil tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high compacted soil tolerance	
Groups	**Statements**
General tree characteristics	Drought tolerance
	Deciduous
	Leaf pubescence
	Rough bark
	Hard wood
	Wetland species
	Shallow roots
	Deep roots

Depends on factors (climate, locations)	Adapted to seasonal flooding

Table 32: Effects of insects and diseases on urban trees. Answers from round 1 of the Delphi in groups.

Effects of insects and diseases on urban trees	
Groups	**Statements**
Leaves	Defoliation
	Early leaf discoloration
	Leaf damage
Whole tree	Basal shoots
	Tree mortality
	Aesthetic impacts
	Trunk damage
	Disruption of the tree vascular system
Increased vulnerability to other disturbances	Apparition of fungal fruiting bodies

Table 33: Tree characteristics related to low isects and diseases tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low tolerance insects and diseases tolerance	
Groups	**Statements**

Origin	Native species (affected by non-native pests)
	Non-native species
General tree characteristics	Thin leaves
	Drought intolerant trees

Table 34: Tree characteristics related to high isects and diseases tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high insects and diseases tolerance	
Groups	**Statements**
Origin	Native trees
	Non native
General tree characteristics	Adapted to different environmental conditions
	Waxy leaves
	Thick leaves
	Goof health of the tree
	Drought resistant

Table 35: Effects of de-icings salts on urban trees. Answers from round 1 of the Delphi in groups.

Effects of de-icing salts on urban trees

Groups	Statements
Leaves	Leaf damage
Whole tree	Reduced growth
	Reduced water and nutrient uptake
	Witches brooms
	Tree failure
	Death
	Trunk cankers
	Root damage
	Increase of vulnerability to other disturbances

Table 36: Tree characteristics related to low de-icings salts tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low de-icing salts tolerance	
Groups	**Statements**
General tree characteristics	Evergreen
	Conifers lacking thick cuticle
	Shallow rooted tree species with thin bark
	Large exposed buds
	High alkalinity intolerance
	Requirement of moist and well drained soils
Location	Planted at the margins of their normal climatic range
	Intolerant to salts planted without protection or protocols

Table 37: Tree characteristics related to high de-icings tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high de-icing salts tolerance	
Groups	**Statements**
Origin	Wetland species
General tree characteristics	Soil compaction tolerance
	Waxy leaves
	Drought tolerant
	Thick bark
	Adapted to salt
	Adapted to arid environments
	Adapted to high alkalinity
	Late leaf out

Table 38: Effects of strongs winds urban on urban trees. Answers from round 1 of the Delphi in groups.

Effects of strong winds on urban trees	
Groups	**Statements**
Whole tree	Tree failure
Leaves	Leaf damage
Roots	Root damage
	Reduced water and nutrient uptake
	Uprooting

Table 39: Tree characteristics related to low strong winds tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low strong winds tolerance	
Groups	**Statements**
Structure	Poor structure
	Shallow root system
	Dense crown
	High height
	Presence of dead wood
	Small trees
	Weak rooting
	Asymmetrical rooting
General tree characteristics	Old trees
	Evergreen
Growth	Fast growth

Table 40: Tree characteristics related to high strong winds tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high strong winds tolerance	
Groups	**Statements**
Structure	Good structure
	Dense wood
	Diffuse canopy

	Deep roots
	Horizontal branching
	Absence of dead wood
	Stable rooting
Growth	Slow growth
General tree characteristics	Good health of the tree

Table 41: Effects of drought on urban trees. Answers from round 1 of the Delphi in groups.

Effects of drought on urban trees	
Groups	**Statements**
Leaves	Leaf damage
	Death
Whole tree	Tree failure
	Slow growth
Increased vulnerability	Vulnerable to other disturbances

Table 42: Tree characteristics related to low drought tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low drought tolerance	
Groups	**Statements**
	Evergreen

General tree characteristics	Shallow roots
	Thin bark
	Quick to loose turgor pressure
	Thin leaves
Growth	Fast growth rate

Table 43: Tree characteristics related to high drough tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high drought tolerance	
Groups	**Statements**
General tree characteristics	Salt tolerance
	Soil compaction tolerance
	Deep rooting
	Good water storage
	Leaves reflect the light
	Leaf pubescence
	Waxy cuticle
	Good health of the tree
Origin	Wetland species
	Native from drought stressed places
Growth	Slow growth rate

Table 44:Effects of extreme temperatures on urban trees. Answers from round 1 of the Delphi in groups.

Effects of extreme temperatures on urban trees	
Groups	**Statements**
Leaves	Early leaf discoloration
	Early leaf loss
	Leaf damage
Growth	Slow growth
Whole tree	Tree mortality
	Desiccation
	Injuries
	Rodent girdling
	Branch breakage

Table 45: Tree characteristics related to low extreme temprerratures tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low extreme temperatures tolerance	
Groups	**Statements**
Origin	Non-native trees
General tree characteristics	Shallow root system
	Thin leaves
	Shade tolerant species
	Early blooming
	Weak wood

Structure	Thin twigs
	Wide crown

Table 46: Tree characteristics related to high atmospheric pollution tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high extreme temperatures tolerance	
Groups	**Statements**
Origin	Non-native
	Adapted to hot and/or dry conditions
	Native
Leaves	Large leaves
	Waxy surface
	Leaf pubescence
Roots	Deep roots
General tree characteristics	Regulation of water loss
	Age
	Late blooming
	Thick twigs
	Well-established

Table 47: Effects of atmospheric pollution on urban trees. Answers from round 1 of the Delphi in groups.

Effects of ice storms on urban trees

Groups	Statements
Leaves	Defoliation
Structure	Branch breakage
	Tree failure
	Structural damage
Increased vulnerability	Increased vulnerability to other disturbances

Table 48: Tree characteristics related to low ice storms tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low ice storms tolerance	
Groups	**Statements**
Leaves	Late defoliation
General tree characteristics	Evergreen
	Deciduous tree species with included bark
	Bad health of the tree
	Conifer
Structure	Narrow branch unions
	Poor structure
	Weak wood
	Wide crown
	Upright form
Growth	Fast growth

Table 49: Tree characteristics related to high ice storms tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high ice storms tolerance	
Groups	**Statements**
Leaves	Early defoliation
Structure	Dense wood
	Good structure
	Strong attachments
	Decay free
	Small crown
	Weeping form
	Flexible branches
Growth	Slow growth
General tree characteristics	Good health of the tree
Other	Maintained trees

Table 50:Effects of atmospheric pollution on urban trees. Answers from round 1 of the Delphi in groups.

Effects of snow on urban trees	
Groups	**Statements**
Whole tree	Branch loss
	Bud loss
	Trunk bending
	Structural damage

	Desiccation
Environment	Salt damage
Browsing	Browsing damage
Increased vulnerability	Increased vulnerability to other disturbances

Table 51: Tree characteristics related to low snow tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to low snow tolerance	
Groups	**Statements**
General tree characteristics	Poor structure
	Conifer
	Evergreen
Structure	Wide branching
	Weak attachments
	Weak wood
	Upright form
	Deciduous trees with included bark
	Inability of crown to retain moisture
	Large crown
Leaves	Late defoliation
Growth	Fast growth

Table 52: Tree characteristics related to high snow tolerance. Answers from round 1 of the Delphi in groups.

Tree characteristics related to high snow tolerance	
Groups	**Statements**
Tree characteristics	Deciduous
Structure	Dense wood
	Good structure
	Pendulous form
	Strong branch attachment
	Free of decay
	Flexibility of limbs
General	Good health of the tree
Leaves	Early defoliation

APPENDIX B
ONLINE QUESTIONNAIRES

DELPHI ROUND ONE

IDENTIFICATION OF THE MOST DAMAGING ENVIRONMENTAL PRESSURES FOR URBAN TREES OF NORTH EASTERN AMERICA: A DELPHI APPROACH

The importance of urban forests and their benefits is being increasingly acknowledged and valued. However, the potential disturbances that urban trees can suffer from in cities are less well documented. For the future development of cities, further research is needed as climate change is expected to increase the risk of disturbances in trees

This questionnaire is part of a project of my Master's degree in sustainable development at Université du Québec en Outaouais (UQO). Its purpose is to gather information about the tolerance of different urban tree species to several disturbances affecting trees in cities of northeastern North America to bridge that gap, using the Delphi method.

This method consists of different rounds of questions aiming to achieve consensus on the opinions of the different respondents. The link to the questionnaires will be sent by e-mail. Usually it takes 2 or 3 rounds to achieve consensus. To complete each round, one or two weeks of time will be left.

Data collection will be done through two separate but related questionnaires and answers will be kept anonymous.

If you have questions you can reach us at carm126@uqo.ca (Maria Isabel Carol, master's student at UQO). This project is supervised by Jérôme Dupras and Christian Messier.

This questionnaire takes approximately 40 minutes to complete this first round. In case you cannot finish it at once, you will have the option to 'Resume later' and continue later.

Research ethics

This research project has received the approval of the ethics commitee of the Université du Québec en Outaouais. Your responses to this survey will be kept confidential and anonymous. Your name will not be recorded on any rounds; instead, you will be allocated a unique code that can only be identifiable to the researcher. You will remain anonymous to the other participants throughout this Delphi study and only the researchers will be able to identify your specific answers.

If you agree with the conditions please click next.

There are 41 questions in this survey.

In the table below, you will find different disturbances affecting trees in cities of northeastern North America. These disturbances can significantly damage urban trees and their associated benefits. One of the challenges facing urban forests is to resist to the different disturbances that come with climate change and urban conditions.

Table 1

Disturbances
Atmospheric pollution
Soil compaction
Insects and diseases
De-icing salts
Strong winds
Drought
Extreme temperatures
Ice storms
Snow

Click next to start de survey.

✱1. For how long have you worked with urban trees?

❶ Choose one of the following answers

- ◯ 0-2 years
- ◯ 3-5 years
- ◯ 6-10 years
- ◯ 11-15 years
- ◯ 16-20 years
- ◯ 21-25 years
- ◯ More than 25 years

✱2. In which city or cities have you worked with urban trees?

For atmospheric pollution:

Atmospheric pollution can affect the growth of trees and affect their photosynthesis. The air pollutants that affect urban trees are ozone, nitrogen, sulfur and hydrogen compounds, as well as the presence of micro particles .

✱3.1 Which are the effects of atmospheric pollution in urban trees ? (ie: leaves necrosis, defoliation, etc)

*3.2 Which are the characteristics of the **most intolerant** urban trees to atmospheric pollution?

*3.3 Which are the characteristics of the **most tolerant** urban trees to atmospheric pollution?

3.4 List the most intolerant urban trees and the most tolerant urban trees to atmospheric pollution. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	**Most tolerant**
1		
2		
3		
4		
5		

For soil compaction:

Soil compaction is very common in urban areas and can result in severe root restriction. When this happens, it is difficult for roots to get oxygen. Furthermore, it increases soil density and decreases permeability, which stops water to percolate and roots suffocate because of that or because there is not enough oxygen in the soil.

✱4.1. Which are the effects of soil compaction in urban trees? (ie: leaves necrosis, defoliation, etc).

✱4.2. Which are the characteristics of the **most intolerant** urban trees to soil compaction?

✱4.3 Which are the characteristics of the **most tolerant** urban trees to soil compaction?

4.4. List the most intolerant urban trees and the most tolerant urban trees to soil compaction. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	**Most tolerant**
1		
2		
3		
4		
5		

For insects and diseases

With climate change, warmer and drier conditions may increase urban forest susceptibility to insects and diseases, as the ranges of these disturbances are projected to expand to higher latitudes. Insects can injure trees and as a result, cause significant and extensive damage to the urban forest.

✱5.1. Which are the effects of insects and diseases in urban trees? (ie: leaves necrosis, defoliation, etc)

✱5.2. Which are the characteristics of the **most intolerant** urban trees to insects and diseases?

✱5.3 Which are the characteristics of the **most tolerant** urban trees to insects and diseases?

5.4. List the most intolerant urban trees and the most tolerant urban trees to insects and diseases. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	Most tolerant
1		
2		
3		
4		
5		

For the de-icing salts:

De-icing salts are used to help melting the snow. The most commonly used are NaCl, $CaCl_2$ and $MgCl_2$. Sometimes we can also find organic compounds. These salts may alter the soil structure, decreasing its permeability and increasing salinity levels, which makes the uptake of nutrients and water by trees more difficult. Following these effects, there is also the hydric stress.

✱6.1. Which are the effects of de-icing salts in urban trees? (ie: leaves necrosis, defoliation, etc)

✱6.2. Which are the characteristics of the **most intolerant** urban trees to de-icing salts?

✱6.3 Which are the characteristics of the **most tolerant** urban trees to de-icing salts?

6.4. List the most intolerant urban trees and the most tolerant urban trees to de-icing salts. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge' category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	Most tolerant
1		
2		
3		
4		
5		

For the strong winds:

Strong winds can also cause damage in urban forest. Hurricane winds and storm surges can severely damage individual trees and landscapes.

✱7.1. Which are the effects of strong winds in urban trees? (ie: leaves necrosis, defoliation, etc)

✱7.2. Which are the characteristics of the **most intolerant** urban trees to strong winds?

*7.3. Which are the characteristics of the **most tolerant** urban trees to strong winds?

7.4. List the most intolerant urban trees and the most tolerant urban trees to strong winds. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	Most tolerant
1		
2		
3		
4		
5		

For the drought:

As climate change brings warmer, wetter winters and warmer drier summers, the resistance to drought will become an important requirement for urban trees. In addition, urban trees under stress will be increasingly vulnerable to other disturbances such insects and diseases.

✱8.1. Which are the effects of drought in urban trees? (ie: leaves necrosis, defoliation, etc).

✱8.2. Which are the characteristics of the **most intolerant** urban trees to drought?

✱8.3. Which are the characteristics of the **most tolerant** urban trees to drought?

8.4. List the most intolerant urban trees and the most tolerant urban trees to drought. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	Most tolerant
1		
2		

3	**Most intolerant**	**Most tolerant**
4		
5		

For the extreme temperatures:

As climate change brings warmer, wetter winters and warmer drier summers, the resistance to extreme temperatures will become an important requirement for urban trees . In addition, urban trees under stress from future higher temperatures will be increasingly vulnerable to other disturbances.

✱9.1. Which are the effects of extreme temperatures in urban trees? (ie: leaves necrosis, defoliation, etc)

✱9.2. Which are the characteristics of the **most intolerant** urban trees to extreme temperatures?

✱9.3. Which are the characteristics of the **most tolerant** urban trees to extreme temperatures?

9.4. List the most intolerant urban trees and the most tolerant urban trees to extreme temperatures. For each category name five tree species .

	Most intolerant	**Most tolerant**
1		
2		
3		
4		
5		

For the ice storms :

Ice storms can severely damage the urban trees. The most common form of damage is stem breakage, but trees can also be bent or uprooted.

✱10.1. Which are the effects of ice storms in urban trees? (ie: leaves necrosis, defoliation, etc).

✱10.2. Which are the characteristics of the **most intolerant** urban trees to ice storms?

✱10.3. Which are the characteristics of the **most tolerant** urban trees to ice storms?

10.4. List the most intolerant urban trees and the most tolerant urban trees to ice storms. For each category name five tree species. If you can not name five, please write 'I don't have the knowledge'.

	Most intolerant	Most tolerant
1		
2		
3		

	Most intolerant	Most tolerant
4		
5		

For the snow:

The most common form of damage of snow in trees is stem breakage, but trees can also be bent or uprooted. Trees suffering snow damage are also more prone to consequential damage through insect or fungal attacks. Snow accumulation on trees is strongly dependent upon weather and climatological conditions.

✱11.1. Which are the effects of snow in urban trees? (ie: leaves necrosis, defoliation, etc) .

✱11.2. Which are the characteristics of the **most intolerant** urban trees to snow?

✱11.3. Which are the characteristics of the **most tolerant** urban trees to snow?

11.4. List the most intolerant urban trees and the most tolerant urban trees to snow. For each category name five tree species .

	Most intolerant	Most tolerant
1		
2		
3		
4		
5		

✱12. In your opinion, which of the aforementioned disturbances tend to interact which each other the most and increase the negative effect they have on trees?

*13. What effects might they cause on trees when interacting (leaf necrosis, root suffocation,etc)?

*14. Would you add a disturbance that, in your opinion, has an important negative effect on trees and is not on our list? If yes, please explain why.

Submit

9.1.1.1.1.1.1.1.1 DELPHI ROUND TWO

ROUND 2: IDENTIFICATION OF THE MOST DAMAGING ENVIRONMENTAL PRESSURES FOR URBAN TREES OF NORTH EASTERN AMERICA: A DELPHI APPROACH

UQO DÉPARTEMENT DES SCIENCES NATURELLES

This questionnaire is the second part of the project, which its purpose is to gather information about the tolerance of different urban tree species to several disturbances affecting trees in cities of northeastern North America to bridge that gap, using the Delphi method.

This method consists of different rounds of questions aiming to achieve consensus on the opinions of the different respondents. Usually it takes 2 or 3 rounds to achieve consensus. To complete each round, one or two weeks of time will be left. Data collection will be done through two separate but related questionnaires and answers will be kept anonymous.

The second round of this Delphi lists all the responses from experts in the first round. Responses from Round 1 have been analyzed and grouped together, when similar, to ensure that the questionnaire is not repetitive and easily completed.

If you have questions you can reach me at maribel.2818@gmail.com (Maria Isabel Carol, master's student at UQO). This project is supervised by Jérôme Dupras and Christian Messier.

Research ethics

This research project has received the approval of the ethics commitee of the Université du Québec en Outaouais. Your responses to this survey will be kept conf anonymous. Your name will not be recorded on any rounds; instead, you will be allocated a unique code that can only be identifiable to the researcher. You anonymous to the other participants (or experts) throughout this Delphi study and only the researchers will be able to identify your specific answers.

Thank you for taking part in this survey, which will take approximately 30 minutes to complete. In case you cannot finish it at once, you will have the option to save and continue later.

ATMOSPHERIC POLLUTION

1.1 The following statements correspond to the answers to question 3.1 of round one of the questionnaire (what are the effects of atmospheric pollution on urban trees?). Please rate the degree to which you agree with each statement.

Effects of atmospheric pollution on trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Defoliation	○	○	○	○	○	○
Leaf damage	○	○	○	○	○	○
Higher presence of fungal and bacterial issues	○	○	○	○	○	○
Increased vulnerability to other disturbances	○	○	○	○	○	○
Slow growth	○	○	○	○	○	○
The effects depend on the pollutant, plant cultivar, timing and concentration	○	○	○	○	○	○
Direct sources of pollution can be identified	○	○	○	○	○	○
The effects are not recognizable	○	○	○	○	○	○

1.2 The following tree characteristics are the answers to question 3.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to atmospheric pollution?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 3.3 of round one (what are the characteristics of the most tolerant urban trees to atmospheric pollution?). Please rate them in the same way.

Tree characteristics related to low atmospheric pollution tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Soft wood	○	○	○	○	○	○
Needle leaves shape	○	○	○	○	○	○
Thin leaves	○	○	○	○	○	○
Thin bark	○	○	○	○	○	○
Drought intolerant	○	○	○	○	○	○
Shadow tolerant	○	○	○	○	○	○
Non-native	○	○	○	○	○	○

Tree characteristics related to high atmospheric pollution tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Fast growth	○	○	○	○	○	○
Good compartmentalization	○	○	○	○	○	○
Large leaves	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○
Thick leaves	○	○	○	○	○	○
Rough bark	○	○	○	○	○	○
Drought tolerant	○	○	○	○	○	○
Non native trees	○	○	○	○	○	○

1.3 In the left table, the following nine tree species were, in the previous round, listed as the most tolerant urban trees to atmospheric pollution. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The eleven species in the right table were, in the previous round, listed as the most intolerant urban trees to atmospheric pollution. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Fraxinus spp.*
2	*Gleditsia triacanthos*
3	*Gymnocladus dioicus*
4	*Platanus x acerifolia*
5	*Thuja spp.*
6	*Ulmus spp.*
7	*Celtis spp.*
8	*Ginkgo biloba*
9	*Pyrus spp.*

	Most intolerant species
1	*Acer saccharum*
2	*Acer spp.*
3	*Acer rubrum*
4	*Betula spp.*
5	*Cornus spp.*
6	*Liriodendron tulipifera*
7	*Platanus spp.*
8	*Salix spp.*
9	*Tilia spp.*
10	*Fraxinus pennsylvanica*
11	*Pinus strobus*

❶ Only numbers may be entered in these fields.

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.

❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

SOIL COMPACTION

2.1 The following statements are the answers to question 4.1 of round one of the questionnaire (what are the effects of soil compaction on urban trees?). Please rate the degree to which you agree with the statement.

Effects of atmospheric pollution on trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Defoliation	○	○	○	○	○	○
Leaf damage	○	○	○	○	○	○
Branch failure	○	○	○	○	○	○
Improper root development	○	○	○	○	○	○
High number of surface roots	○	○	○	○	○	○
Increased vulnerability to other disturbances	○	○	○	○	○	○
Weak growth	○	○	○	○	○	○
Basal shoots	○	○	○	○	○	○
Tree stability affected	○	○	○	○	○	○
Tree death	○	○	○	○	○	○
Delay in injury recover	○	○	○	○	○	○
Inability to obtain nutrients and water properly	○	○	○	○	○	○

2.2 The following tree characteristics are the answers to question 4.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to soil compaction?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 4.3 of round two (what are the characteristics of the most tolerant urban trees to soil compaction?). Please rate them in the same way.

Tree characteristics related to low compacted soil tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Bad compartmentalization	○	○	○	○	○	○
Drought intolerance	○	○	○	○	○	○
Shallow root system	○	○	○	○	○	○
Reduced growth	○	○	○	○	○	○
Depends on the climate area (continental environment summer heat and drought)	○	○	○	○	○	○

Tree characteristics related to high compacted soil tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Drought tolerance	○	○	○	○	○	○
Deciduous	○	○	○	○	○	○

Tree characteristics related to high compacted soil tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Leaf pubescence	○	○	○	○	○	○
Rough bark	○	○	○	○	○	○
Hard wood	○	○	○	○	○	○
Wetland species	○	○	○	○	○	○
Shallow roots	○	○	○	○	○	○
Deep roots	○	○	○	○	○	○
Adapted to seasonal flooding	○	○	○	○	○	○

2.3 In the left table, the eleven tree species were, in the previous round, listed as the most tolerant urban trees to soil compaction. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The ten tree species in the right table were, in the previous round, listed as the most intolerant urban trees to soil compaction. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Acer platanoides*
2	*Acer rubrum*
3	*Acer saccharinum*
4	*Cercis canadensis*
5	*Ginkgo biloba*
6	*Gleditsia triacanthos*
7	*Fraxinus pennsylvanica*
8	*Quercus rubra*
9	*Quercus macrocarpa*
10	*Ulmus americana*
11	*Ulmus spp.*

	Most intolerant species
1	*Acer saccharum*
2	*Acer rubrum*
3	*Betula alleghaniesis*
4	*Carya ovata*
5	*Fagus grandifolia*
6	*Fagus sylvatica*
7	*Nyssa sylvatica*
8	*Pinus strobus*
9	*Quercus alba*
10	*Tilia spp.*

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 11

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

INSECTS AND DISEASES

3.1 The following statements correspond to the answers to question 5.1 of round one of the questionnaire (what are the effects of insects and diseases on urban trees?). Please rate the degree to which you agree with the statement.

Effects of insects and diseases on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Defoliation	○	○	○	○	○	○
Early leaf discoloration	○	○	○	○	○	○

Effects of insects and diseases on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Leaf damage	○	○	○	○	○	○
Basal shoots	○	○	○	○	○	○
Tree mortality	○	○	○	○	○	○
Aesthetic impacts	○	○	○	○	○	○
Trunk damage	○	○	○	○	○	○
Disruption of the tree vascular system	○	○	○	○	○	○
Apparition of fungal fruiting bodies	○	○	○	○	○	○

3.2 The following tree characteristics are the answers to question 5.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to insects and diseases?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 5.3 of round two (what are the characteristics of the most tolerant urban trees to insects and diseases?). Please rate them in the same way.

Tree characteristics related to low tolerance insects and diseases tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Native (affected by non-native pests)	○	○	○	○	○	○
Non-native	○	○	○	○	○	○
Thin leaves	○	○	○	○	○	○
Drought intolerant trees	○	○	○	○	○	○

Tree characteristics related to high insects and diseases tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Native	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○
Adapted to different environmental conditions	○	○	○	○	○	○
Waxy leaves	○	○	○	○	○	○
Thick leaves	○	○	○	○	○	○
Drought resistant species	○	○	○	○	○	○
Non-native	○	○	○	○	○	○

3.3 In the left table, the twelve tree species were, in the previous round, listed as the most tolerant urban trees to insects and diseases. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The nine tree species in the right table were, in the previous round, listed as the most intolerant urban trees to insects and diseases. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Acer rubrum*
2	*Acer saccharinum*
3	*Amelanchier spp.*
4	*Cornus florida*
5	*Ginkgo biloba*
6	*Gleditsia triacanthos*
7	*Gymnocladus dioicus*
8	*Platanus occidentalis*
9	*Pyrus calleryana*
10	*Pyrus spp.*
11	*Quercus macrocarpa*
12	*Quercus spp.*

	Most intolerant species
1	*Betula spp.*
2	*Crataegus spp.*
3	*Fraxinus spp.*
4	*Fraxinus americana*
5	*Fraxinus pennsylvanica*
6	*Prunus persica*
7	*Tsuga canadensis*
8	*Ulmus spp.*
9	*Ulmus americana*

❗ Only numbers may be entered in these fields.
❗ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 10

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

DE-ICING SALTS

4.1 The following statements correspond to the answers to question 6.1 of round one of the questionnaire (what are the effects of de-icing salts on urban trees?). Please rate the degree to which you agree with the statement.

Effects of de-icing salts on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Leaf damage	○	○	○	○	○	○
Reduced growth	○	○	○	○	○	○
Reduced water and nutrient uptake	○	○	○	○	○	○
Witches brooms	○	○	○	○	○	○
Tree failure	○	○	○	○	○	○
Death	○	○	○	○	○	○
Trunk cankers	○	○	○	○	○	○
Root damage	○	○	○	○	○	○
Increase of vulnerability to other disturbances	○	○	○	○	○	○

4.2 The following tree characteristics are the answers to question 6.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to de-icing salts?) Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 6.3 of round two (what are the characteristics of the most tolerant urban trees to de-icing salts?). Please rate them in the same way.

Tree characteristics related to low de-icing salts tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Evergreen	○	○	○	○	○	○
Conifers lacking thick cuticle	○	○	○	○	○	○
Shallow rooted tree species with thin bark	○	○	○	○	○	○
Large exposed buds	○	○	○	○	○	○
High alkalinity intolerance	○	○	○	○	○	○
Requirement of moist and well drained soils	○	○	○	○	○	○
Planted at the margins of their normal climatic range	○	○	○	○	○	○

Tree characteristics related to low de-icing salts tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Intolerant to salts planted without protection or protocols	○	○	○	○	○	○

Tree characteristics related to high de-icing salts tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Wetland species	○	○	○	○	○	○
Soil compaction tolerance	○	○	○	○	○	○
Waxy leaves	○	○	○	○	○	○
Drought tolerant	○	○	○	○	○	○
Thick bark	○	○	○	○	○	○
Adapted to salt	○	○	○	○	○	○
Adapted to arid environments	○	○	○	○	○	○
Adapted to high alkalinity	○	○	○	○	○	○
Late leaf out	○	○	○	○	○	○

4.3 In the left table, the thirteen tree species were, in the previous round, listed as the most tolerant urban trees to de-icing salts. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The ten tree species in the right table were, in the previous round, listed as the most intolerant urban trees to de-icings salts. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Acer rubrum*
2	*Acer saccharum*
3	*Acer negundo*
4	*Celtis occidentalis*
5	*Fraxinus americana*
6	*Fraxinus pennsylvanica*
7	*Gleditsia triacanthos*
8	*Gymnocladus dioicus*
9	*Picea pungens*
10	*Pinus nigra*
11	*Populus deltoides*
12	*Quercus palustris*
13	*Zelkova serrata*

	Most intolerant species
1	*Abies balsamea*
2	*Acer rubrum*
3	*Acer saccharum*
4	*Betula spp.*
5	*Cornus spp.*
6	*Malus spp.*
7	*Picea glauca*
8	*Pinus strobus*
9	*Platanus x acerifolia*
10	*Syringa reticulata*

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 14

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 11

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

STRONG WINDS

5.1 The following statements correspond to the answersto question 7.1 of round one of the questionnaire (what are the effects of strong winds on urban trees?). Please rate the degree to which you agree with the statement.

Effects of strong winds on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Tree failure	○	○	○	○	○	○
Leaf damage	○	○	○	○	○	○
Root damage	○	○	○	○	○	○
Reduced water and nutrient uptake	○	○	○	○	○	○
Uprooting	○	○	○	○	○	○

5.2 The following tree characteristics are the answers to question 7.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to strong winds?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 7.3 of round two (what are the characteristics of the most tolerant urban trees to strong winds?). Please rate them in the same way.

Tree characteristics related to low strong winds tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Poor structure	○	○	○	○	○	○
Shallow root system	○	○	○	○	○	○
Dense crown	○	○	○	○	○	○
High height	○	○	○	○	○	○
Presence of dead wood	○	○	○	○	○	○
Small trees	○	○	○	○	○	○
Old trees	○	○	○	○	○	○
Weak rooting	○	○	○	○	○	○
Asymmetrical rooting	○	○	○	○	○	○
Fast growth	○	○	○	○	○	○
Evergreen	○	○	○	○	○	○

Tree characteristics related to high strong winds tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Good structure	○	○	○	○	○	○
Dense wood	○	○	○	○	○	○
Diffuse canopy	○	○	○	○	○	○
Deep roots	○	○	○	○	○	○
Horizontal branching	○	○	○	○	○	○
Absence of dead wood	○	○	○	○	○	○
Stable rooting	○	○	○	○	○	○
Slow growth	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○

5.3 In the left table, the nine tree species were, in the previous round, listed as the most tolerant urban trees to strong winds. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The twelve tree species in the right table were, in the previous round, listed as the most intolerant urban trees to strong winds. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Espèces plus tolérantes
1	*Abies balsamea*
2	*Cercis canadensis*
3	*Gleditsia triacanthos*
4	*Juglans spp.*
5	*Platanus spp.*
6	*Quercus alba*
7	*Quercus bicolor*
8	*Quercus macrocarpa*
9	*Quercus spp.*
10	*Quercus rubra*

	Espèces plus intolérantes
1	*Acer rubra*
2	*Acer saccharinum*
3	*Acer platanoides*
4	*Betula papyrifera*
5	*Celtis spp.*
6	*Fraxinus spp.*
7	*Pinus strobus*
8	*Pyrus spp.*
9	*Pyrus calleryana*
10	*Salix spp.*
11	*Thuja occidentalis*
12	*Zelkova serrata*

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

DROUGHT

6.1 The following statements correspond to the answers to question 8.1 of round one of the questionnaire (what are the effects of drought on urban trees?). Please rate the degree to which you agree with the statement.

Effects of drought on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Leaf damage	○	○	○	○	○	○
Death	○	○	○	○	○	○
Tree failure	○	○	○	○	○	○
Slow growth rate	○	○	○	○	○	○
Increased vulnerability to other disturbances	○	○	○	○	○	○

6.2 The following tree characteristics are the answers to question 8.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to drought?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 8.3 of round two (what are the characteristics of the most tolerant urban trees to drought?). Please rate them in the same way.

Tree characteristics related to low drought tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know

Tree characteristics related to low drought tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Evergreen	○	○	○	○	○	○
Shallow roots	○	○	○	○	○	○
Thin bark	○	○	○	○	○	○
Fast growth rate	○	○	○	○	○	○
Thin leaves	○	○	○	○	○	○
Quick to loose turgor pressure	○	○	○	○	○	○

Tree characteristics related to high drought tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Salt tolerance	○	○	○	○	○	○
Soil compaction tolerance	○	○	○	○	○	○
Deep rooting	○	○	○	○	○	○
Good water storage	○	○	○	○	○	○
Leaves reflect the light	○	○	○	○	○	○
Leaf pubescence	○	○	○	○	○	○
Waxy cuticle	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○
Wetland species	○	○	○	○	○	○
Native from drought stressed places	○	○	○	○	○	○
Slow growth rate	○	○	○	○	○	○

6.3 In the left table, the twelve tree species were, in the previous round, listed as the most tolerant urban trees to drought. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The twelve tree species in the right table were, in the previous round, listed as the most intolerant urban trees to drought. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Acer rubrum*
2	*Acer x freemani*
3	*Acer negundo*
4	*Betula nigra*
5	*Catalpa speciosa*
6	*Celtis spp.*
7	*Ginkgo biloba*
8	*Gleditsia triacanthos*
9	*Gymnocladus dioicus*
10	*Parrotia persica*
11	*Prunus americana*
12	*Quercus spp.*
13	*Quercus rubra*
14	*Quercus macrocarpa*
15	*Syringa reticulata*
16	*Ulmus spp.*

	Most intolerant species
1	*Acer saccharum*
2	*Acer platanoides*
3	*Acer rubrum*
4	*Acer saccharinum*
5	*Betula spp.*
6	*Betula lenta*
7	*Fagus spp.*
8	*Malus spp.*
9	*Prunus spp.*
10	*Salix spp.*
11	*Tilia cordata*
12	*Tilia spp.*

❗ Only numbers may be entered in these fields.
❗ Each answer must be between 1 and 17

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

EXTREME TEMPERATURES

7.1 The following statements correspond to the answers to question 9.1 of round one of the questionnaire (what are the effects of extreme temperatures on urban trees). Please rate the degree to which you agree with the statement.

Effects of extreme temperatures on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Early leaf discoloration	○	○	○	○	○	○
Early leaf loss	○	○	○	○	○	○
Leaf damage	○	○	○	○	○	○
Slow growth	○	○	○	○	○	○
Tree mortality	○	○	○	○	○	○
Desiccation	○	○	○	○	○	○
Injuries	○	○	○	○	○	○
Rodent girdling	○	○	○	○	○	○
Branch breakage	○	○	○	○	○	○

7.2 The following tree characteristics are the answers to question 9.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to extreme temperatures?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 9.3 of round two (what are the characteristics of the most tolerant urban trees to extreme temperatures?). Please rate them in the same way.

Tree characteristics related to low extreme temperatures tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Non-native	○	○	○	○	○	○
Shallow root system	○	○	○	○	○	○
Thin leaves	○	○	○	○	○	○
Shade tolerant species	○	○	○	○	○	○
Early blooming	○	○	○	○	○	○
Weak wood	○	○	○	○	○	○
Thin twigs	○	○	○	○	○	○
Wide crown	○	○	○	○	○	○

Tree characteristics related to high extreme temperatures tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know

Tree characteristics related to high extreme temperatures tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Non-native	○	○	○	○	○	○
Adapted to hot dry conditions	○	○	○	○	○	○
Native	○	○	○	○	○	○
Large leaves	○	○	○	○	○	○
Waxy surface	○	○	○	○	○	○
Leaf pubescence	○	○	○	○	○	○
Deep roots	○	○	○	○	○	○
Regulation of water loss	○	○	○	○	○	○
Age	○	○	○	○	○	○
Late blooming	○	○	○	○	○	○
Thick twigs	○	○	○	○	○	○

7.3 In the left table, the thirteen species were, in the previous round, listed as the most tolerant urban trees to extreme temperatures. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The eleven tree species in the right table were, in the previous round, listed as the most intolerant urban trees to extreme temperatures. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Abies balsamea*
2	*Acer rubrum*
3	*Celtis occidentalis*
4	*Fraxinus pennsylvanica*
5	*Fraxinus spp.*
6	*Ginkgo biloba*
7	*Gleditsia triacanthos*
8	*Gymnocladus dioicus*
9	*Koelreuteri paniculata*
10	*Parrotia persica*
11	*Picea glauca*
12	*Quercus spp.*
13	*Ulmus spp.*

	Most intolerant species
1	*Abies balsamea*
2	*Acer saccharum*
3	*Betula alleghaniensis*
4	*Betula lenta*
5	*Betula spp.*
6	*Cercis canadensis*
7	*Fagus spp.*
8	*Pinus strobus*
9	*Taxodium distichum*
10	*Tilia spp.*
11	*Zelkova serrata*

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 14

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

ICE STORMS

8.1 The following statements correspond to the answers to question 10.1 of round one of the questionnaire (what are the effects of ice storms on urban trees?). Please rate the degree to which you agree with each statement.

Effects of ice storms on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Defoliation	○	○	○	○	○	○
Branch breakage	○	○	○	○	○	○
Tree failure	○	○	○	○	○	○
Structural damage	○	○	○	○	○	○
Increased vulnerability to other disturbances	○	○	○	○	○	○

8.2 The following tree characteristics are the answers to question 10.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to ice storms?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 10.3 of round two (what are the characteristics of the most tolerant urban trees to ice storms?). Please rate them in the same way.

Tree characteristics related to low ice storms tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Poor structure	○	○	○	○	○	○
Evergreen	○	○	○	○	○	○
Late defoliation	○	○	○	○	○	○
Upright form	○	○	○	○	○	○
Narrow branch unions	○	○	○	○	○	○
Conifers	○	○	○	○	○	○
Deciduous tree species with included bark	○	○	○	○	○	○
Weak wood	○	○	○	○	○	○
Fast growing	○	○	○	○	○	○
Wide crown	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○

Tree characteristics related to high ice storms tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Dense wood	○	○	○	○	○	○
Good structure	○	○	○	○	○	○
Strong attachments	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○
Decay free	○	○	○	○	○	○
Early defoliation	○	○	○	○	○	○
Weeping form	○	○	○	○	○	○
Flexible branches	○	○	○	○	○	○
Small crown	○	○	○	○	○	○
Slow growth	○	○	○	○	○	○

8.3 In the left table, the ten tree species were, in the previous round, listed as the most tolerant urban trees to ice storms. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The twelve tree species in the right table were, in the previous round, listed as the most intolerant urban trees to ice storms. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Abies balsamea*
2	*Cercis canadensis*
3	*Gleditsia triacanthos*
4	*Juglans spp.*
5	*Platanus spp.*
6	*Quercus alba*
7	*Quercus bicolor*
8	*Quercus macrocarpa*
9	*Quercus spp.*
10	*Quercus rubra*

	Most intolerant species
1	*Acer rubra*
2	*Acer saccharinum*
3	*Acer platanoides*
4	*Betula papyrifera*
5	*Celtis spp.*
6	*Fraxinus spp.*
7	*Pinus strobus*
8	*Pyrus spp.*
9	*Pyrus calleryana*
10	*Salix spp.*
11	*Thuja occidentalis*
12	*Zelkova serrata*

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 11

	1	2	3	4	5
Most tolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

SNOW

9.1 The following statements correspond to the answers to question 11.1 of round one of the questionnaire (what are the effects of snow on urban trees?). Please rate the degree to which you agree with each statement.

Effects of snow on urban trees	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Branch loss	○	○	○	○	○	○
Bud loss	○	○	○	○	○	○
Trunk bending	○	○	○	○	○	○
Structural damage	○	○	○	○	○	○
Desiccation	○	○	○	○	○	○
Browsing damage	○	○	○	○	○	○
Salt damage	○	○	○	○	○	○
Increased vulnerability to other disturbances	○	○	○	○	○	○

9.2 The following tree characteristics are the answers to question 11.2 of round one of the questionnaire (what are the characteristics of the most intolerant urban trees to snow?). Please rate the degree to which you agree with the statement. Below, you will also find the answers of the question 11.3 of round two (what are the characteristics of the most tolerant urban trees to snow?). Please rate them in the same way.

Tree characteristics related to low snow tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Poor structure	○	○	○	○	○	○
Conifers	○	○	○	○	○	○
Evergreen	○	○	○	○	○	○
Wide branching	○	○	○	○	○	○
Weak attachments	○	○	○	○	○	○
Weak wood	○	○	○	○	○	○
Upright form	○	○	○	○	○	○
Deciduous trees with included bark	○	○	○	○	○	○
Late leaf drop	○	○	○	○	○	○
Inability of crown to retain moisture	○	○	○	○	○	○
Large crown	○	○	○	○	○	○
Fast growth	○	○	○	○	○	○

Tree characteristics related to high snow tolerance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Deciduous	○	○	○	○	○	○
Good structure	○	○	○	○	○	○
Dense wood	○	○	○	○	○	○
Pendulous forms	○	○	○	○	○	○
Good health of the tree	○	○	○	○	○	○
Free of decay	○	○	○	○	○	○
Early leaf drop	○	○	○	○	○	○
Flexibility of limbs	○	○	○	○	○	○

9.3 The following thirteen tree species were, in the previous round, listed as the most tolerant urban trees to snow. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The eleven tree species were in the right table were, in the previous round, listed as the most intolerant urban trees to snow. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

	Most tolerant species
1	*Abies spp.*
2	*Acer rubrum*
3	*Celtis occidentalis*
4	*Juglans spp.*
5	*Picea spp.*
6	*Pinus spp.*
7	*Pinus nigra*
8	*Quercus rubra*
9	*Quercus alba*
10	*Quercus spp.*
11	*Syringa reticulata*
12	*Thuja occidentalis*
13	*Tsuga spp.*

	Most intolerant species
1	*Acer spp.*
2	*Acer saccharinum*
3	*Betula nigra*
4	*Betula spp.*
5	*Cercis canadensis*
6	*Fraxinus spp.*
7	*Juniperus spp.*
8	*Pinus strobus*
9	*Populus spp.*
10	*Pyrus calleryana*
11	*Thuja spp.*

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 14

	1	2	3	4	5

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most intolerant species	Please choc	Please choc	Please choc	Please choc	Please choc

10. The following statements are the answers of the question 12 from the first round (In your opinion, which of the aforementioned disturbances tend to interact which each other the most and increase the negative effect they have on trees?). Please rate the degree to which you agree with the statement.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know
Wind, ice and snow	○	○	○	○	○	○
Strong winds and all the disturbances mentioned in the first round	○	○	○	○	○	○
Soil compaction and de-icing salts	○	○	○	○	○	○
Wet snow and ice	○	○	○	○	○	○
Extreme temperatures and drought and climate change	○	○	○	○	○	○
Drought and soil compaction	○	○	○	○	○	○
Drought and disease	○	○	○	○	○	○

11. The following statements are the answers of the question 13 from the first round (What effects might they cause on trees when interacting). Please rate the degree to which you agree with the statement.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Branch breakage from wind, ice and snow	○	○	○	○	○
Branch breakage from wet snow and ice	○	○	○	○	○
Tree stress from drought and disease	○	○	○	○	○
Tree stress from extreme temperatures and drought	○	○	○	○	○
Increased fungal infections from drought and disease	○	○	○	○	○
Stem cankers from drought and disease	○	○	○	○	○
Desiccation from strong winds and all the disturbances mentioned in the first round	○	○	○	○	○
Reduced water and nutrient uptake from soil compaction and de-icing salts	○	○	○	○	○
Leaf damage from soil compaction and de-icing salts	○	○	○	○	○

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Root slow growth from soil compaction and de-icing salts	○	○	○	○	○
Reduced water and nutrient uptake from drought and soil compaction	○	○	○	○	○
Tree death from soil compaction and de-icing salts	○	○	○	○	○

12. The following statements are the answers of the question 14 from the first round (Would you add a disturbance that, in your opinion, has an important negative effect on trees and is not on our list?). Please rate the degree to which you agree with the statement.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Poor water quality / changes the pH	○	○	○	○	○
Human impact (infrastructures construction, excavation)	○	○	○	○	○
Mechanical damage	○	○	○	○	○
Absence of basic conditions for tree growth and establishment	○	○	○	○	○

Submit

9.1.1.1.1.1.1.1.2 DELPHI ROUND THREE

ROUND 3: IDENTIFICATION OF THE MOST DAMAGING ENVIRONMENTAL PRESSURES FOR URBAN TREES OF NORTH EASTERN AMERICA: A DELPHI APPROACH.

UQO DÉPARTEMENT DES SCIENCES NATURELLES

This questionnaire is the third part of the project, which its purpose is to gather information about the tolerance of different urban tree species to several disturbances affecting trees in cities of northeastern North America to bridge that gap, using the Delphi method.

This method consists of different rounds of questions aiming to achieve consensus on the opinions of the different respondents. Usually it takes 2 or 3 rounds to achieve consensus. To complete each round, one or two weeks of time will be left. Data collection will be done through two separate but related questionnaires and answers will be kept anonymous.

The third round of this Delphi lists all the responses from experts in the first round. Responses from Round 2 have been analyzed and grouped together, when similar, to ensure that the questionnaire is not repetitive and easily completed.

If you have questions you can reach me at maribel.2818@gmail.com (Maria Isabel Carol, master's student at UQO). This project is supervised by Jérôme Dupras and Christian Messier.

Research ethics

This research project has received the approval of the ethics commitee of the Université du Québec en Outaouais. Your responses to this survey will be kept conf anonymous. Your name will not be recorded on any rounds; instead, you will be allocated a unique code that can only be identifiable to the researcher. You anonymous to the other participants (or experts) throughout this Delphi study and only the researchers will be able to identify your specific answers.

Thank you for taking part in this survey, which will take approximately 25 minutes to complete. In case you cannot finish it at once, you will have the option to save and continue later.

ATMOSPHERIC POLLUTION

1.1 The following statements correspond to the question 1.1 of the round two of the survey that have not reached consensus. (What are the effects of atmospheric pollution on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

<table>
<tr><th></th><th>Strongly disagree</th><th>Disagree</th><th>Neutral</th><th>Agree</th><th>Strongly agree</th><th>I don't know</th><th>Comment</th></tr>
<tr><td>Defoliation
scores from last round:<table><tr><td>disagree</td><td>agree</td><td>strongly agree</td></tr><tr><td>28,57%</td><td>57,14%</td><td>14,29%</td></tr></table></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Higher presence of fungal and bacterial issues
scores from last round:<table><tr><td>disagree</td><td>neutral</td><td>I don't know</td></tr><tr><td>42,86%</td><td>42,86%</td><td>14,29%</td></tr></table></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Increased vulnerability to other disturbances
scores from last round:<table><tr><td>disagree</td><td>neutral</td><td>agree</td></tr><tr><td>14,29%</td><td>28,57%</td><td>57,14%</td></tr></table></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Slow growth ***scores from last round:*** neutral 14,29% · agree 57,14% · strongly agree 14,29% · I don't know 14,29%							
Direct sources of pollution can be identified ***scores from last round:*** disagree 14,29% · neutral 57,14% · agree 28,57%							
The effects are not recognizable ***scores from last round:*** strongly disagree 14,29% · disagree 57,14% · neutral 28,57%							

1.2 The following statements correspond to the question 1.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to atmospheric pollution?). Below, you will also find the statements that correspond to the question 1.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to atmospheric pollution?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Soft wood ***scores from last round:*** disagree 14,29 · neutral 57,14% · I don't know 28,57%							
Needle leaves shape ***scores from last round:*** disagree 57,14% · agree 14,29% · strongly agree 14,29% · I don't know 14,29%							
Thin leaves ***scores from last round:*** disagree 28,57% · neutral 14,29% · agree 28,57% · strongly agree 14,29% · I don't know 14,29%							
Thin bark ***scores from last round:*** disagree 28,57% · neutral 14,29% · agree 28,57% · strongly agree 14,29% · I don't know 14,29%							
Drought intolerant ***scores from last round:*** neutral 28,57% · agree 42,86% · strongly agree 14,29% · I don't know 14,29%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Shadow tolerant *scores from last round:* disagree 28,57%; neutral 28,57%; I don't know 42,86%							
Non-native *scores from last round:* disagree 42,86%; neutral 14,29%; strongly agree 14,29%; I don't know 14,29%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Fast growth *scores from last round:* neutral 57,14%; agree 28,57%; NA 14,29%							
Good compartmentalization *scores from last round:* neutral 42,86%; agree 57,14%							
Large leaves *scores from last round:* disagree 28,57%; neutral 42,86%; agree 14,29%; I don't know 14,29%							
Rough bark *scores from last round:* neutral 42,86%; agree 42,86%; I don't know 14,29%							
Drought tolerant *scores from last round:* disagree 42,86%; neutral 28,57%; agree 28,57%							
Non native trees *scores from last round:* disagree 28,57%; neutral 14,29%; agree 28,57%; strongly agree 28,57%							

1.3 In the first table, the following five tree species were, in the previous round, listed as the most tolerant urban trees to atmospheric pollution. Please rank them from one (most tolerant) to five (least tolerant). The five species in the second table were, in the previous round, listed as the most intolerant urban trees to atmospheric pollution. Please rank them from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most intolerant species					

SOIL COMPACTION

2.1 The following statements correspond to the question 2.1 of the round two of the survey that have not reached consensus (what are the effects of soil compaction on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Defoliation							
Leaf damage							
Branch failure							
High number of surface roots							
Basal shoots							

Defoliation
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	14,29%	42,86%	28,57%

Leaf damage
scores from last round:

disagree	agree	strongly agree	I don't know
42,86%	28,57%	14,29%	14,29%

Branch failure
scores from last round:

disagree	neutral	agree	strongly agree
57,14%	14,29%	14,29%	14,29%

High number of surface roots
scores from last round:

disagree	neutral	agree	strongly agree	I don't know
14,29%	14,29%	42,86%	14,29%	14,29%

Basal shoots
scores from last round:

disagree	neutral	strongly agree	I don't know
42,86%	28,57%	14,29%	14,29%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Tree stability affected ***scores from last round:*** disagree 14,29% · neutral 14,29% · agree 57,14% · strongly agree 14,29%							

2.2 The following statements correspond to the question 2.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to soil compaction?). Below, you will also find the statements that correspond to the question 2.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to soil compaction?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Bad compartmentalization ***scores from last round:*** disagree 42,86% · neutral 28,57% · agree 28,57%							
Shallow root system ***scores from last round:*** neutral 28,57% · agree 71,43%							
Reduced growth ***scores from last round:*** neutral 42,86% · agree 28,57% · strongly agree 28,57%							
Depends on the climate area (continental environment summer heat and drought) ***scores from last round:*** neutral 28,57% · agree 42,86% · I don't know 28,57%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Drought tolerance ***scores from last round:*** disagree 14,29% · neutral 14,29% · agree 42,86% · strongly agree 28,57%							
Deciduous ***scores from last round:*** disagree 14,29% · neutral 42,86% · strongly agree 14,29% · I don't know 28,57%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Leaf pubescence ***scores from last round:*** neutral: 71,43% · I don't know: 28,57%							
Rough bark ***scores from last round:*** neutral: 71,43% · I don't know: 28,57%							
Hard wood ***scores from last round:*** disagree: 14,29% · neutral: 42,86% · strongly agree: 14,29% · I don't know: 28,57%							
Wetland species ***scores from last round:*** disagree: 28,57% · agree: 57,14% · strongly agree: 14,29%							
Shallow roots ***scores from last round:*** disagree: 71,43% · agree: 14,29% · I don't know: 14,29%							
Deep roots ***scores from last round:*** neutral: 28,57% · agree: 71,43%							

2.3 In the first table, the following five tree species were, in the previous round, listed as the most tolerant urban trees to soil compaction.Please rank them from one (most tolerant) to five (least tolerant). The five species in the second table were, in the previous round, listed as the most intolerant urban trees to soil compaction. Please rank them from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 11

	1	2	3	4	5
Most intolerant species					

INSECTS AND DISEASES

3.1 The following statements correspond to the question 3.1 of the round two of the survey that have not reached consensus (what are the effects of insects and diseases on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Basal shoots ***scores from last round:*** neutral 57,14%; agree 28,57%; strongly agree 14,29%							
Trunk damage ***scores from last round:*** neutral 42,86%; agree 42,86%; strongly agree 14,29%							
Apparition of fungal fruiting bodies ***scores from last round:*** disagree 14,29%; neutral 57,14%; agree 14,29%; strongly agree 14,29%							

3.2 The following statements correspond to the question 3.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to insects and diseases?). Below, you will also find the statements that correspond to the question 3.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to insects and diseases?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Native (affected by non-native pests) ***scores from last round:*** neutral 14,29%; agree 42,86%; strongly agree 28,57%; I don't know 14,29%							
Non-native ***scores from last round:*** srongly disagree 14,29%; disagree 42,86%; neutral 14,29%; I don't know 14,29%							
Thin leaves ***scores from last round:*** neutral 71,43%; agree 14,29%; I don't know 14,29%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Drought intolerant trees ***scores from last round:*** neutral: 57,14% / agree: 42,86%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Native ***scores from last round:*** strongly disagree: 14,29% / disagree: 42,86% / neutral: 28,57% / I don't know: 14,29%							
Waxy leaves ***scores from last round:*** neutral: 28,57% / agree: 42,86% / strongly agree: 28,57%							
Thick leaves ***scores from last round:*** neutral: 42,86% / strongly agree: 14,29% / NA: 14,29%							
Drought resistant trees ***scores from last round:*** neutral: 42,86% / agree: 14,29% / strongly agree: 28,57% / I don't know: 14,29%							
Non-native ***scores from last round:*** neutral: 42,86% / agree: 28,57% / strongly agree: 14,29% / I don't know: 14,29%							

3.3 In thefirst table, the following five tree species were, in the previous round, listed as the most tolerant urban trees to insects and diseases. Please rank them from one (most tolerant) to five (least tolerant). The five species in the second table were, in the previous round, listed as the most intolerant urban trees to insects and diseases. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 10

	1	2	3	4	5
Most intolerant species					

DE-ICING SALTS

4.1 The following statements correspond to the question 4.1 of the round two of the survey that have not reached consensus (what are the effects of de-icing salts on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Witches brooms *scores from last round:*							
Tree failure *scores from last round:*							
Trunk cankers *scores from last round:*							
Root damage *scores from last round:*							

Witches brooms – scores from last round:

neutral	agree	strongly agree	I don't know
28,57%	28,57%	28,57%	14,29%

Tree failure – scores from last round:

disagree	neutral	agree
28,57%	42,86%	28,57%

Trunk cankers – scores from last round:

disagree	neutral	agree	I don't know
14,29%	28,57%	28,57%	28,57%

Root damage – scores from last round:

neutral	agree	strongly agree	I don't know
14,29%	28,57%	28,57%	28,57%

4.2 The following statements correspond to the question 4.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to de-icing salts?). Below, you will also find the statements that correspond to the question 4.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to de-icing salts?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Evergreen *scores from last round:*							

Evergreen – scores from last round:

neutral	agree	strongly agree
28,57%	42,86%	28,57%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Conifers lacking thick cuticle ***scores from last round:*** disagree 14,29% · neutral 28,57% · agree 57,14%							
Shallow rooted tree species with thin bark ***scores from last round:*** neutral 28,57% · agree 57,14% · strongly agree 14,29%							
Large exposed buds ***scores from last round:*** neutral 42,86% · agree 42,86% · I don't know 14,29%							
High alkalinity intolerance ***scores from last round:*** disagree 14,29% · neutral 42,86% · agree 28,57% · I don't know 14,29%							
Requirement of moist and well drained soils ***scores from last round:*** neutral 28,57% · agree 42,86% · I don't know 28,57%							
Planted at the margins of their normal climatic range ***scores from last round:*** neutral 42,86% · agree 42,86% · I don't know 14,29%							
Intolerant to salts planted without protection or protocols ***scores from last round:*** neutral 28,57% · agree 57,14% · I don't know 14,29%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Wetland species ***scores from last round:*** disagree 14,29% · neutral 28,57% · agree 28,57% · strongly agree 14,29% · I don't know 14,29%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Soil compaction tolerance *scores from last round:*							
Drought tolerant *scores from last round:*							
Thick bark *scores from last round:*							
Adapted to arid environments *scores from last round:*							
Adapted to high alkalinity *scores from last round:*							
Late leaf out *scores from last round:*							

Soil compaction tolerance — scores from last round:

neutral	agree	I don't know
14,29%	71,43%	14,29%

Drought tolerant — scores from last round:

agree	I don't know
71,43%	14,29%

Thick bark — scores from last round:

disagree	neutral	agree	strongly agree
14,29%	28,57%	42,86%	14,29%

Adapted to arid environments — scores from last round:

neutral	agree	strongly agree	I don't know	NA
28,57%	28,57%	14,29%	14,29%	14,29%

Adapted to high alkalinity — scores from last round:

neutral	agree	strongly agree	I don't know
28,57%	28,57%	14,29%	28,57%

Late leaf out — scores from last round:

disagree	neutral	agree	strongly agree
28,57%	28,57%	28,57%	14,29%

4.3 In the first table, the following seven tree species were, in the previous round, listed as the most tolerant urban trees to deicing salts. Please rank them from one (most tolerant) to five (least tolerant). The six species in the second table were, in the previous round, listed as the most intolerant urban trees to deicing salts. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 14

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 11

	1	2	3	4	5
Most intolerant species					

STRONG WINDS

5.1 The following statements correspond to the question 5.1 of the round two of the survey that have not reached consensus (what are the effects of strong winds on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Tree failure							
Leaf damage							
Root damage							
Reduced water and nutrient uptake							

Tree failure
scores from last round:

neutral	agree	strongly agree
14,29%	14,29%	57,14%

Leaf damage
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	14,29%	42,86%	14,29%

Root damage
scores from last round:

disagree	neutral	agree	strongly agree	NA
42,86%	28,57%	28,57%	14,29%	14,29%

Reduced water and nutrient uptake
scores from last round:

disagree	neutral	I don't know	NA
42,86%	28,57%	14,29%	14,29%

5.2 The following statements correspond to the question 5.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to strong winds?). Below, you will also find the statements that correspond to the question 5.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to de-icing salts?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
High height							
Presence of dead wood							

High height
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	28,57%	48,26%	14,29%

Presence of dead wood
scores from last round:

disagree	neutral	agree	strongly agree
28,57%	28,57%	28,57%	14,29%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Small trees							
Old trees							
Weak rooting							
Asymmetrical rooting							
Fast growth							
Evergreen							

Small trees
scores from last round:

strongly disagree	disagree	agree	I don't know
28,57%	42,86%	14,29%	14,29%

Old trees
scores from last round:

strongly disagree	disagree	neutral	agree
14,29%	14,29%	42,86%	28,57%

Weak rooting
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	14,29%	57,14%	14,29%

Asymmetrical rooting
scores from last round:

neutral	agree	strongly agree	I don't know
14,29%	57,14%	14,29%	14,29%

Fast growth
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	14,29%	57,14%	14,29%

Evergreen
scores from last round:

disagree	neutral	agree	strongly agree
42,86%	28,57%	14,29%	14,29%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Dense wood							
Diffuse canopy							
Horizontal branching							

Dense wood
scores from last round:

neutral	agree
28,57%	71,43%

Diffuse canopy
scores from last round:

neutral	agree	strongly agree
42,86%	42,86%	14,29%

Horizontal branching
scores from last round:

neutral	agree
42,86%	57,14%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Absence of dead wood *scores from last round:* disagree 14,29%; neutral 57,14%; agree 28,57%							
Good health of the tree *scores from last round:* neutral 28,57%; agree 28,57%; strongly agree 42,86%							

5.3 In the first table, the following six tree species were, in the previous round, listed as the most tolerant urban trees to strong winds. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The six species in the seciond table were, in the previous round, listed as the most intolerant urban trees to strong winds. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species					

DROUGHT

6.1 The following statements correspond to the question 6.1 of the round two of the survey that have not reached consensus (what are the effects of drought on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Tree failure *scores from last round:* disagree 14,29%; neutral 28,57%; agree 28,57%; strongly agree 28,57%							

6.2 The following statements correspond to the question 6.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to drought?). Below, you will also find the statements that correspond to the question 6.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to drought?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Evergreen ***scores from last round:*** strongly disagree 14,29%; disagree 28,57%; neutral 42,86%; strongly agree 14,29%							
Shallow roots ***scores from last round:*** neutral 28,57%; agree 57,14%; strongly agree 14,29%							
Thin bark ***scores from last round:*** neutral 57,14%; agree 42,86%							
Fast growth rate ***scores from last round:*** neutral 42,86%; agree 42,86%; I don't know 14,29%							
Thin leaves ***scores from last round:*** neutral 57,14%; agree 42,86%							
Quick to lose turgor pressure ***scores from last round:*** neutral 14,29%; agree 28,57%; I don't know 42,86%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Salt tolerance ***scores from last round:*** neutral 14,29%; agree 57,14%; strongly agree 14,29%; I don't know 14,29%							
Good water storage ***scores from last round:*** neutral 14,29%; agree 71,43%; I don't know 14,29%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Leaves reflect the light ***scores from last round:*** neutral 57,14% / agree 28,57% / I don't know 14,29%							
Leaf pubescence ***scores from last round:*** neutral 42,86% / agree 42,86% / I don't know 14,29%							
Wetland species ***scores from last round:*** disagree 14,29% / neutral 42,86% / agree 28,57% / strongly agree 14,29%							
Slow growth ***scores from last round:*** neutral 42,86% / agree 42,86% / I don't know 14,29%							

6.3 In the first table, the following nine tree species were, in the previous round, listed as the most tolerant urban trees to drought. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The six species in the second table were, in the previous round, listed as the most intolerant urban trees to drought. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 17

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species					

EXTREME TEMPERATURES

7.1 The following statements correspond to the question 7.1 of the round two of the survey that have not reached consensus (what are the effects of extreme temperatures on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Early leaf discoloration *scores from last round:* neutral 28,57%; agree 57,14%; strongly agree 14,29%							
Slow growth *scores from last round:* neutral 28,57%; agree 71,43%							
Injuries *scores from last round:* disagree 14,29%; neutral 14,29%%; agree 71,43%							
Rodent girdling *scores from last round:* disagree 28,57%; neutral 57,14%; I don't know 14,29%							
Branch breakage *scores from last round:* disagree 42,86%; neutral 28,57%; agree 14,29%; I don't know 14,29%							

7.2 The following statements correspond to the question 7.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to extreme temperatures?). Below, you will also find the statements that correspond to the question 7.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to extreme temperatures?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Non-native *scores from last round:* neutral 28,57%; agree 28,57%; strongly agree 14,29%; I don't know 28,57%							
Shallow root system *scores from last round:* disagree 14,29%; neutral 42,86%; agree 42,86%							
Thin leaves *scores from last round:* neutral 28,57%; agree 71,43%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Shade tolerant species							
Early blooming							
Weak wood							
Thin twigs							
Wide crown							

Shade tolerant species
scores from last round:

disagree	neutral	agree	I don't know
14,29%	28,57%	42,86%	14,29%

Early blooming
scores from last round:

Disagree	neutral	agree	I don't know
14,29%	28,57%	42,86%	14,29%

Weak wood
scores from last round:

disagree	neutral	agree	I don't know
14,29%	28,57%	28,57%	28,57%

Thin twigs
scores from last round:

disagree	neutral	agree	I don't know
14,29%	14,29%	57,14%	14,29%

Wide crown
scores from last round:

disagree	neutral	I don't know
14,29%	71,43%	14,29%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Non-native							
Native							
Large leaves							
Waxy surface							

Non-native
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	28,57%	42,86%	14,29%

Native
scores from last round:

strongly disagree	disagree	neutral	agree
14,29%	14,29%	42,86%	28,57%

Large leaves
scores from last round:

disagree	neutral	agree	NA
14,29%	42,86%	28,57%	14,29%

Waxy surface
scores from last round:

neutral	agree
28,57%	71,43%

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Leaf pubescence *scores from last round:*							
Regulation of water loss *scores from last round:*							
Late blooming *scores from last round:*							
Age *scores from last round:*							
Thick twigs *scores from last round:*							

Leaf pubescence – scores from last round:

neutral	agree
28,57%	71,43%

Regulation of water loss – scores from last round:

neutral	agree	strongly agree	I don't know
14,29%	57,14%	14,29%	14,29%

Late blooming – scores from last round:

neutral	agree	strongly agree	I don't know
42,86%	28,57%	14,29%	14,29%

Age – scores from last round:

neutral	strongly agree	I don't know
50%	25%	25%

Thick twigs – scores from last round:

neutral	agree
57,14%	42,86%

7.3 In the first table, the following s seven species were, in the previous round, listed as the most tolerant urban trees to extreme temperatures. From this list, please choose the five most tolerant and rank those five from one (most tolerant) to five (least tolerant). The five species in the second table were, in the previous round, listed as the most intolerant urban trees to extreme temperatures. Please rank them from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 14

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 12

	1	2	3	4	5
Most intolerant species					

ICE STORMS

8.1 The following statements correspond to the question 8.1 of the round two of the survey that have not reached consensus (what are the effects of ice storms on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Defoliation ***scores from last round:*** disagree 42,86%; neutral 28,57%; agree 14,29%; strongly agree 14,29%							
Increased vulnerability to other disturbances ***scores from last round:*** neutral 42,86%; agree 28,57%; strongly agree 28,57%							

8.2 The following statements correspond to the question 8.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to ice storms?). Below, you will also find the statements that correspond to the question 8.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to ice storms?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Late defoliation ***scores from last round:*** disagree 28,57%; neutral 28,57%; agree 28,57%; strongly agree 14,29%							
Upright form ***scores from last round:*** disagree 28,57%; neutral 42,86%; I don't know 14,29%; NA 14,29%							
Conifers ***scores from last round:*** neutral 48,86%; agree 48,86%%; strongly agree 14,29%							
Wide crown ***scores from last round:*** neutral 57,14%; agree 28,57%; strongly agree 14,29%							
Good health of the tree ***scores from last round:*** strongly disagree 14,29%; disagree 57,14%; neutral 28,57%							

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Good health of the tree ***scores from last round:*** disagree: 14,29% · neutral: 14,29% · agree: 57,14% · strongly agree: 14,29%							
Early defoliation ***scores from last round:*** neutral: 42,86% · agree: 57,14%							
Weeping form ***scores from last round:*** disagree: 28,57% · neutral: 14,29% · agree: 28,57% · strongly agree: 14,29% · I don't know: 14,29%							
Small crown ***scores from last round:*** neutral: 42,86% · agree: 57,14%							
Slow growth ***scores from last round:*** neutral: 42,86% · agree: 57,14%							

8.3 In the first table, the following five tree species were, in the previous round, listed as the most tolerant urban trees to ice storms. Please rank them from one (most tolerant) to five (least tolerant). The seven species in the right table were, in the previous round, listed as the most intolerant urban trees to ice storms. From this list, please choose the five most intolerant and rank those five from one (most intolerant) to five (least intolerant).

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 11

	1	2	3	4	5
Most tolerant species					

❶ Only numbers may be entered in these fields.
❶ Each answer must be between 1 and 13

	1	2	3	4	5
Most intolerant species					

9.2 The following statements correspond to the question 9.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most intolerant urban trees to snow?). Below, you will also find the statements that correspond to the question 9.2 of the round two of the survey that have not reached consensus (what are the characteristics of the most tolerant urban trees to snow?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Conifers ***scores from last round:*** disagree 14,29%; neutral 57,14%; agree 14,29%; strongly agree 14,29%							
Evergreen ***scores from last round:*** disagree 14,29%; neutral 42,86%; agree 28,57%; strongly agree 14,29%							
Wide branching ***scores from last round:*** disagree 14,29%; neutral 28,57%; agree 57,14%							
Upright form ***scores from last round:*** disagree 14,29%; neutral 57,14%; agree 14,29%; I don't know 14,29%							
Deciduous trees with included bark ***scores from last round:*** neutral 28,57%; agree 57,14%; strongly agree 14,29%							
Inability of crown to retain moisture ***scores from last round:*** strongly disagree 14,29%; disagree 14,29%; neutral 42,86%; I don't know 28,57%							
Large crown ***scores from last round:*** neutral 71,43%; agree 28,57%							
Fast growth ***scores from last round:*** neutral 28,57%; agree 71,43%							

SNOW

9.1 The following statements correspond to the question 9.1 of the round two of the survey that have not reached consensus (what are the effects of snow on urban trees?). Please rate the degree to which you agree with each statement. If you have comments about the statement, please write them in the comments column.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I don't know	Comment
Branch loss							
Bud loss							
Trunk bending							
Structural damage							
Desiccation							
Browsing damage							
Salt damage							
Increased vulnerability to other disturbances							

Branch loss
scores from last round:

disagree	neutral	agree
14,29%	28,57%	57,14%

Bud loss
scores from last round:

strongly disagree	disagree	neutral	agree	I don't know
14,29%	42,86%	14,29%	14,29%	14,29%

Trunk bending
scores from last round:

disagree	neutral	agree	strongly agree	I don't know
28,57%	14,29%	28,57%	14,29%	14,29%

Structural damage
scores from last round:

disagree	neutral	agree	strongly agree
14,29%	28,57%	42,86	14,29%

Desiccation
scores from last round:

strongly disagree	disagree	neutral	agree	I don't know
14,29%	28,57%	28,57%	14,29%	14,29%

Browsing damage
scores from last round:

strongly disagree	disagree	neutral	agree	strongly agree
28,57%	28,57%	14,29%	14,29%	4,29%

Salt damage
scores from last round:

strongly disagree	disagree	neutral	strongly agree	I don't know
14,29%	14,29%	42,86%	14,29%	14,29%

Increased vulnerability to other disturbances
scores from last round:

strongly disagree	disagree	neutral	agree
14,29%	14,29%	42,86%	28,57%

9.1.1.1.1.1.1.1.3 CLOSED SURVEY

IDENTIFICATION OF THE MOST DAMAGING ENVIRONMENTAL PRESSURES FOR URBAN TREES OF NORTH-EASTERN AMERICA

UQO DÉPARTEMENT DES SCIENCES NATURELLES (/upload/surveys/117779/images/UQO%20SCEAU.JPG)

The importance of urban forests and their benefits is being increasingly acknowledged and valued. However, the potential disturbances that urban trees can suffer from in cities are less well documented. For the future development of cities, further research is needed as climate change is expected to increase the risk of disturbances in trees.

This questionnaire is part of a project of my Master's degree in sustainable development at UQO. Its purpose is to gather information about the tolerance of different urban tree species to several disturbances affecting trees in cities of northeastern North America to bridge that gap.

If you have questions you can reach us at carm126@uqo.ca (Maria Isabel Carol, Master's student). This project is supervised by Jérôme Dupras and Christian Messier.

This questionnaire takes approximately 30 minutes to complete.Please take the time to be as thorough as possible. If you want to save your progress and continue at a later time, simple click on "Resume Later" on the top right-hand corner of the screen.

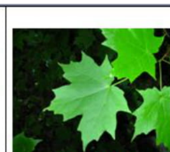
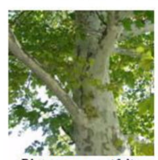
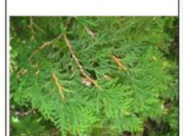
Research ethics

This research project has received the approval of the ethics commitee of the Université du Québec en Outaouais. Your responses to this survey will be kept confidential and anonymous. Your name will not be recorded; instead, you will be allocated a unique code that can only be identifiable to the researcher. You will remain anonymous to the other participants and only the researchers will be able to identify your specific answers.

If you agree with the conditions please click next.

There are 21 questions in this survey.

In the table below, you will find the 20 tree species most frequently planted in the largest cities of north-eastern North America.

 *Acer platanoides*	 *Acer negundo*	 *Acer rubrum*	 *Acer saccharum*	 *Tilia cordata*
 *Acer saccharinum*	 *Amelanchier sp.*	 *Fraxinus pennsylvanica*	 *Gleditsia triacanthos*	 *Quercus palustris*
 *Malus sp*	 *Picea pungens*	 *Platanus x acerifolia*	 *Prunus serotina*	 *Tsuga canadensis*
 *Pyrus calleryana*	 *Quercus rubra*	 *Rhamnus cathartica*	 *Thuja occidentalis*	 *Ulmus americana*

Please click next to start the survey.

✱1. What is the highest degree or level of education you have completed? Please pecify major or subject (for example biology, ecology, forest ecology, etc) .

❶ Comment only when you choose an answer.

☐ Ph. D.

- [ ] Master's degree

- [ ] Bachelor's degree

- [ ] University certificate or diploma below bachelor level

✱2. What is your occupation?

❗ Choose one of the following answers

- ○ Salaried employee
- ○ Self employed
- ○ Student
- ○ Retired
- ○ Other

✱3. Do you study or have you studied urban trees?

❗ Choose one of the following answers

- ○ Yes
- ○ No

✱4. Do you work or have you worked with urban trees?

❗ Choose one of the following answers

- ○ Yes

○ No

The following questions have the purpose to gather information about the tolerance of different urban tree species to several disturbances affecting trees in cities of northeastern North America. You will have to rate the different species to the indicated disturbance.

Atmospheric pollution

Atmospheric pollution can affect the growth of trees and affect their photosynthesis. The air pollutants that affect urban trees are ozone, nitrogen, sulfur and hydrogen compounds, as well as the presence of micro particles .

5. Please rank from 1 (very intolerance) to 5 (very tolerant) the following species with regard to atmospheric pollution. In the certainty column write with a number from 1 to 3 how sure you are of what you have answered (1, not really sure; 2, somewhat sure; 3 for really sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer platanoides)							
Box elder (Acer negundo)							

	1	2	3	4	5	Don't know the species	Certainty
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							

	1	2	3	4	5	Don't know the species	Certainty
Apple tree species (Malus sp)							
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							

	1	2	3	4	5	Don't know the species	Certainty
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Soil compaction

Soil compaction is very common in urban areas and can result in severe root restriction. When this happens, it is difficult for roots to get oxygen. Furthermore, it increases soil density and decreases permeability, which stops water to percolate and roots suffocate because of that or because there is not enough oxygen in the soil.

6. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to soil compaction. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer platanoides)							
Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							

	1	2	3	4	5	Don't know the species	Certainty
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							

	1	2	3	4	5	Don't know the species	Certainty
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							

	1	2	3	4	5	Don't know the species	Certainty
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Insects and diseases

With climate change, warmer and drier conditions may increase urban forests susceptibility to insects and diseases, as the ranges of these disturbances are projected to expand to higher latitudes. Insects can injure trees and as a result, cause significant and extensive damage to the urban forest.

7. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to insects and diseases. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty

Norway maple (Acer platanoides)							
	1	2	3	4	5	s	Certainty

Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							

	1	2	3	4	5	Don't know the species	Certainty
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							

	1	2	3	4	5	Don't know the species	Certainty
Pin oak (Quercus palustris)							
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

De-icing salts

De-icing salts are used to help melting the snow. The most commonly used de-icing salts are NaCl, $CaCl_2$ and $MgCl_2$. Sometimes we can also find organic compounds. These salts may alter the soil structure, decreasing its permeability and increasing salinity levels, which makes the uptake of nutrients and water by trees more difficult. Following these effects, there is also the hydric stress.

8. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to de-icing salts. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

						Don't	

	1	2	3	4	5	Don't know the species	Certainty
	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer platanoides)							
Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							

	1	2	3	4	5	Don't know the species	Certainty
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							

	1	2	3	4	5	Don't know the species	Certainty

Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Strong winds

Strong winds can also cause damage to urban forest. Hurricane winds and storm surges can severely damage individual trees and landscapes, causing trees to defoliate, partially break, drop branches, topple, or uproot.

9. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to strongs winds. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer							

platanoides)							
	1	**2**	**3**	**4**	**5**	**Don't know the species**	**Certainty**

Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							

Black cherry (Prunus serotina)							
	1	**2**	**3**	**4**	**5**	**specie s**	**Certai nty**

Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Drought

As climate change brings warmer, wetter winters and warmer drier summers, the resistance to drought will become an important requirement for urban trees. In addition, urban trees under stress will be increasingly vulnerable to other disturbances such insects and diseases.

10. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to drought. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer platanoides)							
Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							

Colorado spruce (Picea pungens)							
	1	**2**	**3**	**4**	**5**	**species**	**Certainty**

London plane (Platanus x acerifolia)							
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Extreme temperatures

Extreme temperatures

As climate change brings warmer, wetter winters and warmer drier summers, the resistance to extreme temperatures will become an important requirement for urban trees . In addition, urban trees under stress from future higher temperatures will be increasingly vulnerable to other disturbances.

11. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to extreme temperatures. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer platanoides)							
Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							
Colorado spruce (Picea pungens)							
London plane (Platanus x							

London plane (Platanus x acerifolia)							
	1	2	3	4	5	Don't know the species	Certainty

Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Ice storms

Ice storms can severely damage the urban trees. The most common form of damage is stem breakage, but trees can also be bent or uprooted.

12. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to ice storms. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	**2**	**3**	**4**	**5**	**Don't know the species**	**Certainty**
Norway maple (Acer platanoides)							
Box elder (Acer negundo)							
Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							

White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
	1	2	3	4	5	Don't know the species	Certainty

Pin oak (Quercus palustris)							
Eastern hemlock (Tsuga canadensis)							
American elm (Ulmus americana)							

Snow

The most common form of damage caused by snow in trees is stem breakage, but trees can also be bent or uprooted. Trees suffering snow damage are also more prone to consequential damage through insect or fungal attacks. Snow accumulation on trees is strongly dependent upon weather and climatological conditions.

13. Please rank from 1 (very intolerant) to 5 (very tolerant) the following species with regard to snow. Please specify the level of certainty you have regarding your answer in the far right column (1, not very sure; 2, somewhat sure; 3, very sure). If you don't know the species at all, please select the "Don't know" alternative.

	1	2	3	4	5	Don't know the species	Certainty
Norway maple (Acer platanoides)							

Box elder (Acer negundo)	☐	☐	☐	☐	☐	☐ Don't know the species	
	1	2	3	4	5	Don't know the species	Certainty

Red maple (Acer rubrum)							
Sugar maple (Acer saccharum)							
Silver maple (Acer saccharinum)							
Serviceberry (Amelanchier sp)							
Green ash (Fraxinus pennsylvanica)							
Honey locust (Gleditsia triacanthos)							
Apple tree species (Malus sp)							
Colorado spruce (Picea pungens)							
London plane (Platanus x acerifolia)							
Black cherry (Prunus serotina)							
Callery pear (Pyrus calleryana)							
Red oak (Quercus rubra)							
Buckthorn (Rhamnus cathartica)							
White cedar (Thuja occidentalis)							
Tilia (Tilia cordata)							
Pin oak (Quercus palustris)							

Eastern hemlock (Tsuga canadensis)							
	1	2	3	4	5	species	Certainty

American elm (Ulmus americana)							

✱14. In your opinion, which of the aforementioned disturbances tend to interact which each other the most and increase the negative effect they have on trees?

Disturbances mentioned:

Atmospheric pollution

Soil compaction

Insects and diseases

De-icing salts

Strong winds

Drought tolerance

Extreme temperatures

Ice storms

Snow

✱15. What effects could they cause on trees when interacting (leaf necrosis, root suffocation,etc)?

✱16. Would you add a disturbance that, in your opinion, has an important negative effect on trees and is not on our list? If yes, please explain why.

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