

MANAGING URBAN FOREST PUBLIC VALUES IN A CHANGING CLIMATE

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## Abstract

With more than half of the world's population concentrated in urban areas, urban services are crucial for people's lives. Some of these services are provided by urban trees, which are valued positively by most people. However, urban forest management (UFM) today faces a number of challenges, including accounting for the values of the public and climate change. These two are connected, since climate-driven biophysical changes will affect value provision and people's urban forest values will determine the management direction by which we address the climate challenge. This study aims to understand how to incorporate public values and climate change in UFM by examining how people value the urban forest, how these values are managed, how urban forests are vulnerable to climate change, and how this vulnerability affects value provision. To address these questions, I review the urban forest values literature and reveal opportunities for research. Later I examine the content of 14 Canadian urban forest management plans and reveal that UFM today lacks detail in ecological and social themes. I argue that a management paradigm based on what the citizens consider important about urban forests may help deal with these shortcomings. I present urban forest values research from three Colombian cities (Bogotá, Cali, Pereira) using field tours, personal diaries, and focus groups. I then integrate this research with similar research in Canada to build a values typology that portrays how the public values the urban forest. I then review climate change in UFM and argue that climate change vulnerability assessments (CCVAs) are crucial for embracing climate adaptation in UFM. I present CCVA research in three Canadian urban forests (Halifax, London, Saskatoon) using an exploratory and expert-based method. I demonstrate that the survival of young trees and mal-adapted tree species are important sensitivity factors in urban forests. By mapping how urban forest vulnerability to climate change will affect value provision I argue that climate change is both a threat and an opportunity to bring specificity to ecological and social themes in UFM and to veer towards a UFM style that: plants more trees close to infrastructure and people; ensures tree survival by experimenting with different planting techniques and more-natural arrangements; embraces adaptive management and public engagement; and facilitates ecosystem transition without reducing values satisfaction.

## List of Abbreviations and Symbols Used

AB	Alberta
BMP	Best management practice
C&I	Criteria and indicator
CCFM	Canadian Council of Forest Ministers
CCVA	Climate change vulnerability assessment
CO <sub>2</sub>	Carbon dioxide
DBH	Diameter at breast height
DED	Dutch elm disease
EAB	Emerald ash borer
FGS	Faculty of Graduate Studies
GHG	Greenhouse gas
GIS	Geographical information system
HRM	Halifax Regional Municipality
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
MB	Manitoba
NB	New Brunswick
NEP	New environmental paradigm
NGO	Non-governmental organization
NS	Nova Scotia
SO <sub>x</sub>	Sulphur oxides
NO <sub>x</sub>	Nitrous oxides
O <sub>3</sub>	Ozone
ON	Ontario
SK	Saskatchewan
UFM	Urban forest management
UFMP	Urban forest management plan
UFORE	Urban forest effects model
UN-HABITAT	United Nations Human Settlements Programme
UNDESA	United Nations Department of Economic and Social Affairs
VOC	Volatile organic compound

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# **1 CHAPTER 1: INTRODUCTION**

## **1.1 Urban Forests: Challenges and Opportunities**

The relevance of managing urban services sustainably reflects the dramatic urban transformations of this century. Today, more than half of the world's population lives in urban areas (UN-HABITAT, 2012). A complex set of factors drive people to the city and push them out of the countryside, but most people move to the city seeking to improve their quality of life. Urban services are crucial for the betterment of people's lives and influence this demographic shift. Some of these services are provided by urban nature, in particular a key group of organisms: the trees. Urban trees are the dominant vegetation in many cities (Dorney et al., 1984). They provide a wide range of services, including air filtration and increase in property value, and are valued positively by the community in multiple ways (Nowak et al., 2001).

There is a growing body of literature that sees sustainable management of the urban forest as one of the key features of urban sustainability (e.g. Alberti, 2008). Urban forest management today needs to account for issues that go beyond the technical aspects of tending urban trees. Urban forests face a number of challenges, including increasing or changing urban development patterns and processes, accounting for the desires of an increasing number and diversity of urban dwellers, and long-term environmental threats like climate change. While urban development goes beyond the reach of urban forest management, the last two challenges are accessible, but remain elusive for the most part.

First, considering the public in urban forest management goes beyond informing people about trees and taxing them for tree care (Clark et al., 1997). Many urban forest managers assume that the technical direction that has guided their management approach will automatically provide what people want (Ordóñez & Duinker, 2013). Research is needed to account for citizen opinion and enhance urban forest management.

Second, there is little doubt that the rate of climate change has increased and will continue to do so even faster this century (IPCC, 2013). These changes potentially threaten urban forests, the services they provide, and the values they satisfy. However, there is no clear indication of what the climate threat means for urban forest management beyond carbon capture and greenhouse gas emission reduction (Ordóñez et al., 2010). Research is needed to give meaning to what climate adaptation represents for urban forest management and what, if anything, is supposed to be done differently in the future to plan for this change.

Understanding what the urban public considers important in relation to urban forests, or its values, is important for their management in the context of climate change. Ultimately, biophysical changes in urban forests triggered by climate change will affect the degree to which urban forest management provides values to people. In turn, having a notion of what is important about urban forests will determine the management direction that will address the climate challenge.

The general purpose of my research is to understand how to incorporate public values and climate change in urban forest management. To do this, one must first understand how urban forests are managed today, how people value the urban forest, and how these values are being managed. Then one must understand how climate change may affect the urban forest and its values. Finally, one must learn how to manage urban forest public values in the face of a changing climate.

This chapter introduces my dissertation. It is divided into three sections: the first section presents a research framework, where the definitions of urban forests, socio-ecological model, and sustainable urban forest management are explored; the second section overviews the research questions, objectives, goals, and general approach; the third section introduces the reader to the subsequent chapters of the thesis.

## 1.2 Research Framework

Three important concepts must be defined to provide theory and context to the proposed research on public values and climate vulnerability in urban forest management. These include: the urban forest as an ecosystem; urban forest management as seen through a socio-ecological perspective; and sustainable urban forest management, explored through the concept of urban forest sustainability. This research framework clarifies important conceptual assumptions about this dissertation.

### *1.2.1 The Urban Forest as an Ecosystem*

Defining the urban forest is necessary before this study can proceed, as different definitions of an ecosystem could elicit different discourses on how to manage it. Historically, the term urban forest was first used to distinguish the hinterland, rural forest from the trees in urban areas (Jorgensen, 1970; Jorgensen, 1974). Today there is a widely accepted definition that the urban forest is all the trees in urban areas, whether they are natural or planted (Rowntree, 1984).

From an ecological point of view, this definition is limited and does not reveal the complexity of a forest ecosystem, which may also encompass elements such as animals and the physical environment. However, urban forests have several characteristics that make them different from hinterland forests. Firstly, urban forest structure is differentiated, that is, the arrangement of size, species diversity, and composition is different depending on the site (Dorney et al., 1984). Urban trees can be found in natural forest stands, in managed stands, like in a park, arranged in lines along streets, or as single trees, and be close to infrastructure and/or people. They can be remnants of native forests or be deliberately grown. They vary in composition, diversity, age, health status and ownership patterns (Nowak, 1993; Dwyer & Nowak, 2000). Some urban forest areas do not display the biophysical connectivity of hinterland forests, yet they are connected to the wider physical and social environment (Rowntree, 1986). Due to fragmented habitats (e.g. Matlack, 1997), urban forests processes vary, such as natural regeneration in naturalized areas and artificial plantings in streetscapes (Zipperer, 2008).

Thus, for all practical purposes, the definition of an urban forest as all the trees within an urban area is useful but cannot be interpreted so simply in ecological terms. Rather, the urban forest can be defined in a continuum between a natural forest, where trees are associated with other vegetation, wildlife, and physical entities, such as water bodies, and single, isolated trees in an urban space, where trees are associated with the infrastructure and people within it, and everything in between. This broad definition of urban forests allows management to embrace the ecosystem as a whole, with all the ecological and social considerations this entails, which is a crucial perspective to address values and climate change (Ordóñez & Duinker, 2012).

The definition of an urban area is integral to the definition of an urban forest, particularly to determine its spatial extent. An urban area has many possible definitions and it is still somewhat a matter of debate. Almost every country has its own definition adapted to its own urban characteristics (UN-HABITAT, 2012). However, the main features of an urban area are clear: 1) the urban area is an ecosystem in its own right (McDonnell & Pickett, 1990); 2) the urban area has variable function and structure (McDonnell et al., 1997); and 3) the urban area is defined by parameters of physical geography, land cover type, history, scale, traffic, road type, area, ecological process, and cultural factors (McIntyre et al., 2000). Political boundaries of municipalities are not included, for their spatial extent may be bigger or smaller than these parameters defining urban areas (Grey, 1996).

Thus, as the focus of management, the urban forest can be seen as all the trees within the municipal boundaries (Rowntree, 1998), although this also may vary according to the local community's view.

### *1.2.2 Urban Forest Management: a Socio-Ecological Perspective*

The urban forest is a complex ecosystem with differentiated ecological and social dynamics. The management of the ecosystem mirrors the complex interaction of natural

and cultural issues in urban areas. That is to say, urban forest management can be seen through the socio-ecological perspective some authors use to view urban areas (e.g. Botkin & Beveridge, 1997; McKinney, 2002).

Socio-ecological systems are complex and adaptive aggregations of biophysical units with their social and institutional actors (Grimm et al., 2000; McIntyre et al., 2000; Pickett et al., 2001; Liu et al., 2007; Pickett et al., 2008; Zipperer, 2011). Understanding them implies integrating knowledge from ecological, environmental, political, social, psychological, and economic disciplines. In urban ecosystems, ecological processes, environmental dynamics, information and knowledge, values and perceptions, institutions, demographics patterns, economic systems, power hierarchies, land use and management, and design and architecture, all interact to produce the particularities of such systems (Botkin & Beveridge, 1997; Grimm et al., 2000; Berkes et al., 2003; Berling-Wolff & Wu, 2004). Historical context and land management are also important patterns to understand (Dow, 2000).

The socio-ecological model provides the framework for managing urban areas in general, and urban forests in particular. In an urban forest, a complex ecological dynamic couples natural development processes with human processes, both of which operate at a variety of rates and affect one another in a variety of ways (Nowak, 1993). A socio-ecological perspective provides a way to see urban forest management as a values-based enterprise, one that connects the functions and structures of the physical environment to the desired set of values that people have. An example of this is managing public open spaces for a desired physical activity (e.g. Giles-Corti & Donovan, 2002). However, the purpose of using a socio-ecological perspective in this research is to broaden the set of ideas and goals that guide the management of socio-ecological systems.

A socio-ecological and values-based management style does not necessarily conflict with a technical or professional-centred one, that is, a style that is based on the expertise of technical and professional people. Although the scientific guidance of experts in any field, for example, in the environmental and ecological sciences, is a vital feature for



urban forest management, public values information can complement, enhance, or broaden the scope of management to include a broad range of values. There are three important reasons as to why this is so, and this provides a rationale for studying public values for urban forest management:

First, many urban forest management decisions are done privately by homeowners, given that about half of urban forests are owned privately (Dwyer & Nowak, 2000; Kenney & Idziak, 2000; Nowak et al., 2001; Kuser, 2007; City of Toronto, 2012; HRM, 2012).

Second, citizen priorities on how to manage urban forests may be fully consistent with those suggested by environmental and ecological professionals, assuming that value directions are the same in terms of ecological and environmental desirability. In a sense, when citizens are probed and urban forest manager actors are informed of their views, this can strengthen the message that motivates decision-makers in municipal institutions to adopt a sound management of urban forests, assuming their mandate is to respond to the wishes of their constituents.

Third, and in a broader sense, ecosystem management expresses the way we value nature (Grumbine, 1994), and urban forest values provide a deep driver for management (Dwyer et al., 1991) since they can serve as an expression of what is important about the urban forest (Ordóñez & Duinker, 2010). In a way, everybody is a member of the public at any point in time and when not assuming the role of their profession. The public as a whole has a good grasp of its values. Thus, the management of the desired ecological or social functions and structures of socio-ecological systems depends on an understanding of the public values we set out to manage. The values perspective is crucial to harmonize the social and the ecological aspects of socio-ecological systems, since integrating rather than trading off anthropogenic and intrinsic values of nature is the goal (Moffatt & Kohler, 2008). The perspective also brings a social sciences agenda to ecosystem management that goes beyond giving information to the public about what is being done, but rather bases management on more participatory grounds that complement, enhance, and broaden the management objectives (Endter-Wada et al., 1998). This idea spills over interpretations of sustainable urban forest management, as discussed below.

### *1.2.3 Sustainable Urban Forest Management*

With management as the locus of the research, it is fitting to give meaning to the notion of sustainable urban forest management. Interpreting what managing urban forests sustainably means can only be done through a definition of urban forest sustainability, as sustainability is the goal behind the process of managing ecosystems sustainably (Mebratu, 1998). Many interpretations of this concept exist (e.g. Thomson et al., 1994; Gangloff, 1995; Clark et al., 1997; Clark & Matheny, 1998; McPherson, 1998; Dwyer et al., 2003; Escobedo et al., 2011; Kenney et al., 2011). As noted by some authors, these interpretations of urban forest sustainability are crafted according to a definition of an ideal state of the urban forest resource (Ordóñez & Duinker, 2010). The idea of a sustainable resource is combined with a technical backdrop of tree maintenance, mainly standards such as canopy cover, pruning, and species diversity, which are arbitrarily designed.

Some aspects of this technical perspective are practical for some urban forest stakeholders. Coupling urban-forest sustainability to canopy cover, for example, is practical for urban foresters and tree care-takers because it is easy and has operational meaning: a low canopy cover means that the focus of management should be planting more trees. However, interpreting urban forest sustainability as tree care misses the social aspects of the concept. For instance, some urban forest stakeholders define the concept in terms of the interest and commitment of groups of people who deal with urban trees. In general, urban forest stakeholders, experts and non-experts alike, have widely differing views of sustainability (Elmendorf et al., 2003).

This illustrates that, though not entirely devoid of its technical meaning, urban-forest sustainability is a much more complex concept that requires an inclusive interpretation. A vision of sustainability for urban forests may well be that at any point in the foreseeable future (a viable timeframe of, say, 100 years), the management of urban forests applied today should be able to provide a strong array of values at all times, with acceptable

spatial distribution, except when natural or human catastrophes prevent such (Ordóñez & Duinker, 2010).

This interpretation is useful for three reasons. First, it places urban forest values, or whatever we consider important in relation to urban forests, at the centre of urban-forest sustainability. Leading urban forest scholars remind us that the look, function and management of a sustainable urban forest depend on which ecological and social benefits are desired, who chooses them, and at what space and time scales these elements are to be sustained (Dwyer et al., 2002). Therefore, sustainable urban forest management can be seen as a values-based enterprise.

Second, because sustainability is a vision for the future within a spatial context (Costanza & Patten, 1995; Costanza et al., 2001; Martinez-Alier & Roca, 2001), following short-term or space-limited interpretations of urban forest sustainability could easily end in unsustainability, particularly considering long-term environmental threats such as climate change. The time-frame of 100 years chosen here reflects both the long-term vision that managers should have and the far-reaching implications of deciding how to manage urban forests today with a values-based approach.

Third, it identifies the process of providing and satisfying values as an integral part of managing urban forests. This is crucial for five reasons: 1.) the urban public is the one that benefits the most from urban forests (Dwyer et al., 1991; Dwyer et al., 2003; Lawrence et al., 2013); 2.) understanding what the public wants from urban trees is important to address private urban-forest ownership, since many urban trees are owned privately (e.g. Kuser, 2007); 3.) public values may align with desired environmental and ecological features of urban forests that can help overcome the manicured, ecologically-unsound urban-tree tending tradition in urban forests (McKinney, 2006); and, finally, 4.) a citizen view of urban forests enhances the importance of urban-forest sustainability goals in the wider urban planning and development context.

## **1.3 Research Overview**

### *1.3.1 Research Questions, Objectives, and Goal*

The research is guided by the following research questions:

1. What are the public values of urban forests and how are they managed?
2. How vulnerable are urban forests to climate change and how can they adapt?
3. How is climate change going to affect the provision of urban forest public values?

The research has five objectives:

1. Understand the values people hold in relation to urban forests broadly and deeply
2. Understand how urban forests and their values are being managed
3. Understand how vulnerable urban forests are to climate change
4. Understand how urban forest vulnerability to climate change influences urban forest public value provision
5. Propose the best way to manage urban forests in light of these considerations and thus fulfil public values.

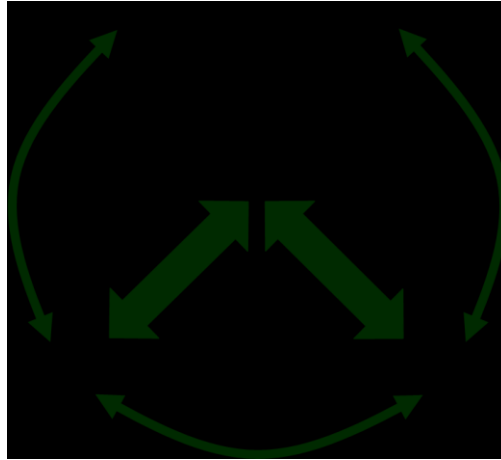
In answering the questions and achieving my objectives, my goal is to understand how urban forest public values can be managed sustainably in a changing climate. The overall result of the study should be a new understanding of urban forest management in consideration of public values and climate change, enhancing current urban forest management practices, and aiding practitioners' decision-making.

### *1.3.2 Research Approach*

The topics of the research questions presented above cover three domains of knowledge: management of natural resources, climate change, and public values, with management taking a central role (Figure 1.1). Within these three domains of knowledge, three themes emerge guided by the first three objectives identified above: 1) public values associated

with the urban forest; 2) the management of these values; and 3) urban forest vulnerability and adaptation to climate change. The interaction of these themes and their respective domains must to be studied under biophysical and social considerations. That is to say that the questions of this research are, in aggregate, interdisciplinary in nature. Thus, interdisciplinarity is one of the paradigms informing my research approach.

The sustainable management of natural resources is inherently interdisciplinary (Lyall et al., 2011). This is also true for urban natural systems (McIntyre et al., 2000). Knowledge integration is key to sustainability, but this knowledge exists within the boundaries of disciplines. An interdisciplinary approach helps cross these boundaries and connects ideas across disciplines. To prevent an interdisciplinary research approach from being superficial, which is a common concern in academic culture that doubts the ability of any one researcher to do quality work beyond the realm of a discipline, one must follow a systematic process that includes: 1) choosing an interdisciplinary research question; 2) identifying relevant disciplines and their own sets of assumptions, theories, and methods; and 3) evaluate, reconcile, integrate, and reflect upon these assumptions, theories, or methods, thus creating a new scientific archetype (Repko, 2008). Integration is at the heart of interdisciplinarity, but it is a complex endeavour. Complexity is a challenge that can be managed by allowing a constant interaction between theory and observation, making use of both reductive and integrative processes of analysis, nurturing creativity while being efficient and systematic, and remaining accessible to a variety of backgrounds and worldviews (Newell et al., 2005).



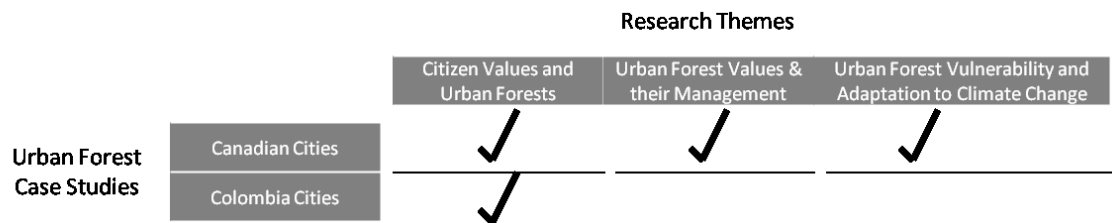
*Figure 1.1: Domains of knowledge of my research with management emphasized as a central domain*

My approach to the research questions uses a novel conceptual platform and a mixed-methods approach that manages their interdisciplinary and complex nature efficiently. Since these questions touch upon the ecological and social sciences, I interpret urban forest management through a socio-ecological model (see previous section). Because such systems must have a local ecological and social context, I focus the answers to my questions and the empirical exploration of the three themes of this research (i.e. 1) public values associated with the urban forest; 2) the management of these values; and 3) urban forest vulnerability and adaptation to climate change) with urban case studies of cities in Canada.

To strengthen the exploration of public values associated with the urban forest, I will have a comparative and contrasting case study by applying the same methods in Colombian cities. These case studies, different in both ecological and social characteristics, enhance the relevance of the study and provide a more comprehensive understanding of what urban citizens value about urban trees, and provide a broader basis to develop a more universal public value typology related to urban forests.

I also explore how values are managed in Canada by analysing urban forest management plans, and I explore the issue of urban forest vulnerability to climate change in Canadian

cities. However, it is not in the interest of this research to explore these issues in Colombia. In so saying, I gain insights on citizen values associated with urban forests cross-nationally, but insights on their management and how climate change vulnerability influences their provision only with Canadian case studies (Figure 1.2). Finally, I use mostly qualitative methods, which are preferred for facilitating integration of ecological and social issues that are impossible or at least difficult to quantify.



*Figure 1.2: How urban forest case studies are used to explore the three research themes in this dissertation*

#### **1.4 Managing Urban Forest Values and Climate Change: An Overview**

This dissertation is divided into the three themes (Figure 1.2) associated with the first three objectives and the first two questions of this research. Objectives four and five, and research question number 3, are explored by joining these three themes together. In so saying, the themes of my research are explored in three topic categories. The first two themes are dealt together under the topic urban forest public values and their management. The third theme is dealt under its own topic, urban forest vulnerability and adaptation to climate change. Finally, the three themes are connected at the end guided by the last two objectives and the third and final question of this research concerning urban forest public values and climate vulnerability. The following text describes the structure and content of this thesis in more detail according to these three topics.

### *1.4.1 Urban Forest Public Values and their Management*

The topic is covered in Chapters 2-5. In these four chapters, I review the urban forest values literature, analyze how they are being managed, present a new typology of urban forest values based on original research, and discuss its implications for management.

In Chapter 2 I review the urban forest values literature and draw conclusions about the gaps and opportunities for urban forest values research and implications for urban forest management. I argue that values are a deeper basis for ecosystem management than any other concept. However, the urban forest literature does not treat urban forest public values in depth. The main limitations of the urban forest literature in capturing values lay, in part, in the inadequate conceptualization of the urban forest as an ecosystem, a geographical bias, and the lack of depth in the methodological approaches to capture public values. I discuss the opportunities for urban forest public values research with new conceptualization and methods.

After clarifying the concept of urban forest values, in Chapter 3 I explore Canadian urban forest management by examining the content of 14 available urban forest management plans (UFMPs) through a content analysis approach. This analysis indicates that urban forest management in Canada would be significantly improved by overcoming the lack of detail in ecological, social, and economic management themes, which refer to components such as nativeness, naturalness, climate change, community stewardship, public participation, and use of economic incentives. I demonstrate how failure to address the themes may be related to the reigning paradigm in urban forest management fixed on enhancing/optimizing urban forest services/benefits, rather than providing a wide array of values. I point to the need for finding a balance between these two paradigms to embrace what sustainable urban forest management really means.

The final chapters in this theme address urban forest public values. In Chapter 4 I present original research on the same theme in Colombia. This research elicits values from the public with the methods developed by Peckham et al. (2013), which are based on Owen et al. (2009) and on a grounded-theory interpretive process of coding and theme



extraction (see Glaser & Strauss, 1967; Strauss & Corbin, 1997). Here I demonstrate that people value the urban forest for a diverse, rich, and interconnected set of reasons related to aesthetic, psychological, socio-cultural, natural/ecological, health, environmental, and economic themes. I bring this information onto Chapter 5, where I combine it with similar urban forest values studies in Canada by Peckham et al. (2013), Sinclair et al. (2014), and Ordóñez et al. (2014), and develop a detailed urban forest public values typology. The typology displays the types of values associated with the urban forest as expressed by the public, collecting urban forest values data from four Canadian cities and three Colombian ones, which display diverse ecological and social characteristics. I discuss how this typology brings us closer to understanding what people really think and feel in relation to the trees in the city and its implications for urban forest management.

#### *1.4.2 Urban Forest Vulnerability and Adaptation to Climate Change*

The second question of this research relates to climate change and urban forests in general, and to urban forest vulnerability and adaptation to climate change in particular. It is addressed in Chapters 6-8.

Chapter 6 discusses the meaning of climate change in urban forests by reviewing general climate change research, the meaning of climate change for forests and urban areas, its impacts on urban forests, and the possible mitigative and adaptive responses. I argue that urban forest responses to this change have been framed mostly by climate mitigation (i.e. reduction of GHG emissions and carbon capture) and by the theme of planting more trees in cities to mitigate environmental impact. I argue how climate adaptation in urban forests is better framed by a clear understanding of urban forest vulnerability to climate change. This chapter sets the stage for all subsequent chapters on the topic of climate change and urban forests.

In Chapter 7 I discuss how to assess the vulnerability of urban forests to climate change. I present a framework where I characterize climate exposure, impact, sensitivity, and adaptive capacity, as well as non-climatic drivers and factors in urban forests. The most

important themes in this discussion include urban tree species selection and diversity, naturalization, resource access, social awareness and engagement, budget and economic valuation, institutional liability, and governance structures. I also present an approach for undertaking climate change vulnerability assessments that can help us understand how and why urban forests are vulnerable to climate change, identify future areas for research, and determine what adaptation measures could be included in urban forest management.

Chapter 8 presents original research on urban forest vulnerability assessment to climate change in three Canadian cities of different ecological and social contexts: Halifax (NS), London (ON), and Saskatoon (SK). The method used is exploratory and expert-based and allows for a qualitative evaluation of vulnerability. The study shows that temperature increases and variability, higher winds, and drought are important climate exposure elements, and young-tree survival and tree species mal-adapted to extreme changes in moisture and extreme heat are important sensitivity elements. Insects and diseases, as well as invasiveness, are important impacts. Climate-proofing through tree species selection, maintenance and plantings, diversification, and naturalization, and better communication and coordination regarding tree protection and urban forest adaptation goals in municipal policy are important adaptive strategies.

### *1.4.3 Urban Forest Public Values & Climate Vulnerability*

In Chapter 9 I undertake a simple conceptual mapping exercise to link urban forest public values to climate change vulnerability. This map provides me with an understanding of how urban forest vulnerability to climate change influences value provisioning and helps me identify promising values-based and climate-sensitive approaches to urban forest management. This chapter also allows me to discuss the two questions of this research together and fulfil the goals and objectives of the research.

Concluding remarks and implications for future research, such as how to advance urban forest values studies and the application of a climate change vulnerability assessment tool, are discussed in a tenth and final chapter.

## **1.5 Summary**

Managing urban forests sustainably requires, among other things, integrating public values and climate change into management. This is not a simple matter of considering what people are saying about urban trees, the possible impacts of climate change, and addressing them through tree selection and maintenance. Advancing the values-based paradigm and adapting to climate change require interdisciplinary research that can supply urban forest management with solid knowledge on the issues of public values and climate vulnerability and a way to advance decision-making in management. This dissertation aims to contribute to this process and, more generally, to a better management of the urban forest, a vital resource for cities to improve urban quality of life, all the while bringing humans into a constructive relationship with their natural surroundings.

## **2 Chapter 2: Urban Forest Values – A Review**

### **2.1 Publication Information**

This chapter is based on the literature reviews included in the following publications. The first one was led by me and co-authored by Peter Duinker:

Ordóñez, C., Duinker, P. (2014) Urban forest values of the citizenry in three Colombian cities. *Society & Natural Resources*. Accepted 24-Jul-2013.

The second one was led by Shawna Peckham and co-authored by Peter Duinker. I was a contributing third author. I contributed a table based on a literature review of urban forest values (Table 1 in the publication):

Peckham, S.C., Duinker, P., and Ordóñez, C. (2013). Urban forest values in Canada: views of citizens in Calgary and Halifax. *Urban Forestry and Urban Greening* 12 (2), 154–162.

The following text expands these two literature reviews.

### **2.2 Introduction**

In a world where the majority of people live in urban areas (UN-HABITAT, 2012), it is increasingly important to understand how people relate to urban nature. Urban trees are the dominant natural element of many cities and contribute to urban quality of life (Nowak & Dwyer, 2007). Although the urban forest is popularly defined as all the trees in the city, trees do not exist in isolation but are a dominant feature of a broader ecosystem, such as important ecological functions and structures, and the distinct socio-cultural dynamics that characterize urban ecosystems (Chapter 1).

Sustaining urban forests is important to sustaining the variety of values, services, and benefits they provide (Dwyer et al., 2003). Exploring how people relate to their urban

forest in a deeper way is crucial for managing it sustainably (Dwyer et al., 1991). The concept of values has proved useful in determining this human-nature relationship at a deeper level (Dietz et al., 2005). Identifying values in ecosystem management is important because of the role they play in defining what is important to sustain about an ecosystem (Chapter 1). Values reveal the psychological underpinnings behind ecosystem management and the values humans put to nature (Kay, 1993; Lockwood, 1999; Miller, 2000; Ghilarov, 2000; Dutcher et al., 2007; Westra, 2008)

In this chapter I set out to review the literature on urban forest values. I present it as a concept that represents the backbone of urban forest management, in contrast to associated concepts such as services, benefits, and attitudes. Values theory is broad and has been approached by many fields, including sociology, psychology, economics, and environmental studies. It is not my intention to review all values theory exhaustively across fields, as our conceptualization of values is constantly evolving and only particular values theories may apply to the environment and ecosystems in general (Dietz et al., 2005), and urban forests in particular.

This review is divided into three sections. I discuss the most relevant social values and environmental and ecosystem values theory in the first two sections. In the third section I present results of my literature review of urban forest services, benefits, and attitudes, as a way to explore urban forest values. I discuss these results as to how they help us understand what people value about urban forests at a deeper level, how they influence urban forest management, and how they reveal gaps and opportunities for public values research. A summary of the chapter is included at the end.

### **2.3 Social Values Theory**

The concept of human values has permeated psycho-social theories for decades, yet it was not until values hierarchy theory was presented that structure and substance were given to the discussion. In this theory, values are seen as constructs that lie at the core of the fundamental belief system behind somebody's opinions and conduct (Rokeach,

1973). These constructs can have a hierarchical nature (Schwartz, 1992) and are abstract representations emerging from social dialogue (Homer & Kahle, 1998). Human values can belong to individual, societal and/or institutional groups (Rokeach, 1979), and to cultures (Schwartz & Bilsky, 1990). They are inherently positive constructs, so the idea of a negative value is the same as not valuing something (Schwartz, 1996).

Values can be divided in two categories: held values, or general ethical dictums, principles, or end states; or assigned values, the relative worth or preference of an object (Rokeach, 1973). Some disagree with these two categorical interpretations and defend the notion that values are abstract, trans-situational guides rather than directed to specific entities (Rohan, 2000). The two interpretations are not necessarily mutually exclusive and can harmonize, as I will discuss below.

In the first interpretation, which can be categorized as fundamental or abstract, values are seen as fundamental beliefs, limited in number, that are engrained in our culture and define the attitudes people hold towards specific things. Under this frame, many authors have identified a list of a few fundamental values that all people hold (Schwartz & Bilsky, 1987; Schwartz, 1996). These fundamental values pervade our attitude towards nature, particularly in the context of environmental or ecological issues (Schultz & Zelezny, 1999). However, this first interpretation of values, prevalent in sociology, does little to capture environmental values in depth. In fact, the theory assumes people consider nature as important due to a preference or attitude process rather than a fundamental value process (Dietz et al., 2005). Thus, the fundamental or abstract value interpretation does not treat values in relation to nature beyond the superficial notion of environmental attitudes.

In the second interpretation, which can be categorized as object- or relationship-directed, values reflect emotional and cognitive dynamics associated with a specific object. Despite the fact that a value is not a quality of an object itself (Schultz, 2002), people can express a rich emotional and cognitive association with a natural element or an ecosystem (e.g. Brown, 1984; Fulton et al., 1996; Schultz et al., 2004; Dutcher et al., 2007), rather

than just valuing things based on an abstract notion of goodness. However, if only explored in an object-directed way, values can be confused sometimes with attitudes or preferences (Rohan, 2002). Attitudes and/or preferences directed to a problem or an object are more variable because certain issues may affect people personally (i.e., they are self-concerned) and not because they are truly altruistic and hold a particular set of values. In such cases, values may be confounded by preferences, which denote orderings and not absolutes (Andrews & Waits, 1980).

Overcoming the shortcomings of the fundamental/abstract and the object/relationship-directed value interpretations means that convergence is necessary for exploring the range of values associated with the environment and ecosystems. This type of value research is not only concerned with whether people value nature or not, as the first interpretation will imply, but also how they value it, which can only be captured through a specific ecosystem or natural object, or an environmental problem, issue, or reality (e.g. Fulton et al., 1996; Owen et al., 2009). Yet, for the general notion of value to hold in its application to a specific object or issue, values must express general value systems that are applicable to elsewhere in people's lives, not only their experience with that object or issue. Indeed, values do not occur in isolation from other values, but as part of an intricate network that many refer to as a value system (Rohan, 2002).

Before discussing how to integrate these two in order to discuss how values research is important in environmental and ecosystem studies, some difficulties in capturing and measuring values must be made clear. First, most values are captured verbally, where value-laden language can be confusing, lack structure, be built as an artefact, or reflect a strategic bias (i.e. a discourse; see Burningham, 1995). When measured non-verbally, values can be dependent on psychological interpretations and behaviour can be too complex to interpret (Andrews & Waits, 1980). Second, it is difficult to differentiate between object- and relationship-directed values. In this case, existence values, or reference to the intrinsic values of the object, are difficult to access, more so than assigned or anthropocentric values, which addresses the importance of something because of its usefulness to a person (Andrews & Waits, 1980). Finally, although some

authors theorize that object-directed values predispose attitudes about objects and thus define behaviour (Tarrant & Cordell, 2002), in practice, values are not the only consideration when people take decisions. In fact, people may take decisions spontaneously for a broad range of conscious and unconscious reasons (Bardi & Schwartz, 2003).

## **2.4 Environmental and Ecosystem Values**

Although several typologies exist, the bulk of values theory has focused on the clusters of self-interest, altruism, traditionalism, and openness to change (Schwartz, 1992). The environmental values field separates altruism in humanistic and biocentric altruism (Dietz et al., 2005). Biocentric altruism is the core concept of the environmental values field, which can also be considered an offshoot of environmental ethics (O'Neill et al., 2008), but as pointed out above, environmental values are not only about whether people are environmentally inclined, but how so.

The early trend of environmental values research was to explore environmentalism according to socio-cultural factors. The new environmental paradigm (NEP) is an example of this (Catton Jr & Dunlap, 1978; Dunlap & van Liere, 1978; Dunlap & Mertig, 1997; Corral-Verdugo & Armendáriz, 2000). Although this research was important to explore the social bases for environmental concern, it does not inform how people value nature or the environment, and the connections between biocentric altruism and the rest of the individual's value system (de Groot & Steg, 2007). Nonetheless, this field informs us that environmental values are associated with socio-cultural identities (Dietz et al., 1998) and are elicited contextually, as they usually have a correlation with identity factors (Chase & Panagopoulos, 1995). Evidence shows that environmental values depend on age (Steel et al., 1994), social class and education (Bright & Manfreda, 1997), urban and rural lifestyles (Freudenburg, 1991), and gender (Liere & Dunlap, 1980). Although some assume that environmental values also vary in relation to culture (Schultz & Zelezny, 1999), the evidence is scant (Dietz et al., 2005).



Advancing the understanding of environmental values meant that values had to be understood in a specific context, particularly within natural objects and/or realities. In this regard, among the many contributions to environmental values theory, values in relation to ecosystems, such as forests, are among the most important ones (e.g. Beckley et al., 1999; CSA, 2003). Forest values research has demonstrated that people value forests due to a rich set of intrinsic (i.e. for themselves) and assigned (for the benefit of people) values (Bengston, 1994). Nevertheless, it is difficult to differentiate some values as strictly intrinsic or assigned. Many forest values studies in North America indicate that people value forest mostly for their contributions to human health and well-being (Patel et al., 1999; Tarrant et al., 2003; Treiman & Gartner, 2005). Some authors argue that this is evidence of a forest values shift as people start moving away from the hinterland land as the basis of their economic activities (e.g. Bengston, 1994; Xu & Bengston, 1997). Although one can argue that human health and well-being are assigned values, for they benefit people, it is important to point out that it would be very difficult to measure these monetarily in contrast to economic values such as timber (Bengston & Xu, 1995; Moyer et al., 2008).

Forest values literature reveals some fundamental characteristics about ecosystem values. First, it is possible to explore values related to nature with the use of an object, in this case an ecosystem, while at the same time capturing human values that have characteristics of being fundamental, abstract, and hierarchical, and reflect general value systems. That is to say that ecosystem values exploration is deep, thus distinguishing itself from a simpler attitude or preference exploration. This echoes the idea that people may have attitudes or preferences in reference to a particular forest issue, problem, or object, but as a whole they also have values related to forests that express what they consider important about that ecosystem at a deeper level. Some authors disagree with this view, as negative concerns or annoyances related to an ecosystem will always come to surface in such explorations, eluding the development of a clear values hierarchy, and thus remaining as simple attitude assessments (Heberlein, 1981). In reality, values trade-off occurs because of the different valued aspects of human life in overlapping systems but not within the ecosystem value typology itself (Dietz et al., 2005). That is to say that

people may display an attitude or a preference in relation to forests if there is a conflict between using the forest for an economic or a leisure activity, but as a whole, the values they assign to the forest denotes a deeper level of importance and is very difficult to change over time (Bengston & Xu, 1995; Beckley et al., 1999; Moyer et al., 2008).

Second, ecosystem values may sometimes be fragmented, that is, the values are not defined by the whole (i.e., a tree is valued, but not the view), but they may also not be defined in isolation of the whole (i.e., a particular tree species in a forest setting) (Schwartz & Bilsky, 1987). This suggests two things. First, ecosystem values, such as forest values, may be expressed via specific descriptors of a natural element, an idea that reflects the notion of valued ecosystem component in the environmental assessment literature (e.g. Beanlands & Duinker, 1984). This has methodological implications, since eliciting values associated with an ecosystem may require converting specific descriptors of values into broader categories. Moreover, this also suggests a connection to place attachment theory, whereby people feel attached to particular elements of a landscape setting due to their frequency of use or relationship with that element (e.g. Moore & Scott, 2003; Lewicka, 2011; Wilkie & Stavridou, 2013).

In short, the concept of value is useful to explore people's perceptions and priorities with nature at a deep level. In the broadest sense, values associated with ecosystems emerge from social dialogue and can be seen as expressions of whatever we think is important about an ecosystem (Moyer et al., 2008). This definition is useful for natural resource and ecosystem management since values can be considered the characteristics or qualities we declare important to sustain and capture the deeper level of people's relationship with nature (Kay, 1993; Noss, 1995; Miller, 2000; Ghilarov, 2000; Turner & Beazley, 2004; Westra, 2008). However, it is recognized that a wide variety of value definitions exist, and that social values theory's search for fundamental abstract values that disregard values in relation to nature may continue to erode the development of a strong ecosystem values theory (Dietz et al., 2005). Nevertheless, this definition is a useful one to understand what people consider important about an ecosystem at a deeper level. Therefore, there is a strong motivation for identifying value in relation to ecosystems in

various cultural contexts in order to advance environmental values research. The urban forest is one of such contexts.

## **2.5 Urban Forest Values**

I bring to this discussion the conceptual framework of ecosystem values discussed above, which includes the following characteristics: 1) ecosystem values in the broadest sense are whatever is important to people in relation to an ecosystem; 2) although broad in scope, ecosystem values reveal the deep meaning nature has for people; 3) ecosystem values emerge from social dialogue and are fundamentally descriptive and qualitative notions of the importance of ecosystems for people; 4) although many typologies exist to categorize ecosystem values, it is useful to classify them as assigned or intrinsic values; and finally 5) values can be considered the characteristics or qualities we declare important to sustain and capture the deeper level of people's relationship with nature.

In this context, the ultimate goal of reviewing the urban forest values literature is to understand what people consider important about urban forests at a deeper level.

However, my review of urban forest values is limited by the fact that urban forest value is a seldom mentioned term in the academic literature (Peckham et al., 2013), excluding the many instances when it is mentioned to mean monetary value (e.g. Nowak et al., 2002).

In general, academics have used the terms values, services, benefits, and attitudes, interchangeably to mean more or less the same thing. Thus, an urban forest values review comprises many concepts and terms, even if they do not capture the full meaning of what I consider to be an urban forest value as defined by the concept of ecosystem value, explained above. The first step is then to clarify what kind of information I expect to obtain by reviewing the literature on urban forest services, benefits, and attitudes by navigating the meaning of these concepts. The second step is to present a comprehensive review of this material and discuss its meaning. The third step is to identify gaps and opportunities in this body of literature and discuss their implications for future research.

### *2.5.1 Navigating Urban Forest Services, Benefits, and Attitudes*

A brief definition of these concepts is important. Firstly, the widest definition of a service is what is provided by society to better people's lives (Brown et al., 2007). Ecological economists use the terms goods and services to convey direct economic and indirect economic values. A more refined definition is encapsulated in the concept of ecosystem services which refer to natural processes that satisfy human and non-human needs (de Groot et al., 2002; Costanza & Farber, 2002; Boyd & Banzhaf, 2007; Wallace, 2007; Fisher et al., 2009). These may include regulatory, habitat, productive, informative, and carrier functions that sustain or enhance human and non-human life.

There is a portion of the ecosystem services literature that sees them as the result of a particular biophysical and measurable function of the ecosystem and thus the assumption that these services must have a quantifiable aspect (de Groot et al., 2002; Farber et al., 2002; Turner et al., 2003). The concept of services allows us to quantify an ecosystem function monetarily even if it is given for free or it is less economically tangible (Costanza & Farber, 2002). However, a portion of the ecosystem services literature disagrees with this quantifiable aspect as it misses many social and cultural values that cannot be easily quantified (e.g. Chan et al., 2012a; 2012b; Ruckelshaus et al., 2013).

The term urban forest service is used by Bolund & Hunhammar (1999), Chen & Jim (2008), Nowak et al. (2008), Young (2010), Dobbs et al. (2011), Escobedo et al. (2011), and Roy et al. (2012), among others, to define what is important about urban forests. An important aspect of this body of literature has been the interest to quantify the provision of services by urban trees in urban areas through monetary valuation methods, which is in agreement with the notion of ecosystem services. For instance, the replacement value (i.e. structural asset) of urban forests in the United States has been estimated to be around 2.4 trillion dollars (Nowak et al., 2002). This number is meant to capture both the direct (e.g. wood products) and indirect (e.g. air pollution control, carbon capture, among others) economic value of urban forests, even though it does not claim to capture their socio-cultural or psychological importance.

Benefit is a concept usually associated with cost (as in the well-known technique called benefit-cost analysis), and an economic overtone is also implicit with this term. However, the ecosystem benefits literature uses the term more broadly. An ecosystem benefit may generally refer to what people receive from an ecosystem not just in terms of life-supporting functions but also in psycho-social and economic terms (e.g. Dwyer et al., 1992; McPherson et al., 1994; McPherson et al., 1997; McPherson & Simpson, 2002; Nowak et al., 2002; Nowak et al., 2003; Tyrväinen et al., 2005; Nowak et al., 2006; Payton et al., 2008; Nowak et al., 2008).

Benefits can be measured directly by the effect of urban forests on people, or indirectly through public opinion about the urban forest. Such opinion can also be conceptualized as an attitude, and in fact some researchers have preferred this term when exploring public opinion (e.g. Kalmbach & Kielbaso, 1979; Schroeder & Ruffolo, 1996; Todorova et al., 2004; Balram & Dragievi, 2005; Schroeder et al., 2006; Zhang et al., 2007; Budruka et al., 2009). An attitude can be defined as a measure of preference, and an environmental attitude is a preference towards natural, environmental, and biocentric issues (Catton Jr & Dunlap, 1978; Dunlap & van Liere, 1978; Heberlein, 1981; Schultz & Zelezny, 1999). However, many of these explorations also end up in a list of negative concerns about urban trees and do not give a clear idea on how people assign importance to the urban forest (e.g. McPherson & Simpson, 2002; Nowak & Dwyer, 2007; Lyytimäki et al., 2008; Roy et al., 2012). Moreover, as with the notion of urban forest service, there has been an interest in the literature to quantify the benefits of urban trees through a monetary valuation method (e.g. Dwyer et al., 1992; Walter, 2000; McPherson & Simpson, 2002; Price, 2003; De Ridder et al., 2004; Tyrväinen et al., 2005; Payton et al., 2008). For instance, a large tree on residential property can contribute almost nine thousand dollars to the price of a house (Donovan & Butry, 2010).

This review makes it clear that despite the confined conceptual boundaries of these concepts, they have been used interchangeably to mean what is important about urban forests. Therefore, a review of the literature regarding what people consider important in relation to the urban forest must encompass all of the concepts above.

### *2.5.2 A Comprehensive Exploration of Urban Forest Values*

The literature on urban forest values, services, benefits, and attitudes is numerous, was reviewed and organized according to value categories and descriptors (Table 2.1). Many comprehensive reviews of these already exist, most importantly: Dwyer et al. (1992); Bolund & Hunhammar (1999); Baines (2000); Walter (2000); McPherson & Simpson (2002); Hastie (2003); Price (2003); De Ridder et al. (2004); Lohr et al. (2004); Tyrväinen et al. (2005); Fuller et al. (2007); Nowak & Dwyer (2007); Chen & Jim (2008); Nowak et al. (2008); Payton et al. (2008); Dwivedi et al. (2009); Young (2010); Dobbs et al. (2011); Escobedo et al. (2011); Seamans (2012); and Roy et al. (2012).

It is Roy et al. (2012) who provide the most recent and systematic review of urban forest services and benefits to date and is of particular importance to my own review (Table 2.1). However, Roy et al. (2012) do not necessarily examine public opinion research. Moreover, many ecosystem services and benefits listed by Roy et al. (2012) have a high level of detail and can be grouped together (e.g. air pollution regulation in terms of particulate matter, SO<sub>x</sub>, NO<sub>x</sub>, O<sub>3</sub>; increase in property values in terms of value of land, house, neighbourhood, and taxes; among others).

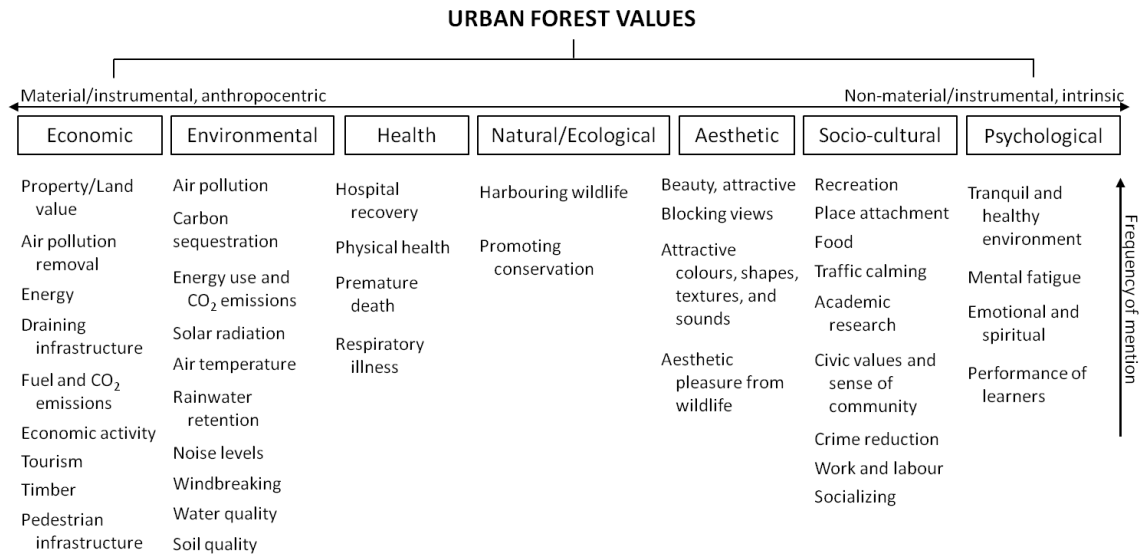
*Table 2.1: A comprehensive listing of urban forest values*

<i>Value category</i>	<i>Value descriptor</i>	<i>Reference</i>	
Environmental	Atmospheric pollution capture through dry deposition	(Nowak et al., 2006)	
	Microclimatic regulation	Regulation of solar radiation	(Armson et al., 2012; Picot, 2004; Streiling & Matzarakis, 2003; Akbari et al., 2001)
		Windbreaking	(Duryea et al., 1996; Heisler et al., 1994)
		Lowering air temperature through evapotranspiration	(Heidt & Neef, 2008; Rosenfeld et al., 1998)
	Carbon Emissions	Direct carbon sequestration	(Nowak & Crane, 2002)
		Controlling carbon dioxide emissions by cooling effect	(Akbari, 2002)
	Hydrological regulation	Increased rainwater retention and flooding	(Xiao et al., 2000; Grimmond et al., 1994)
		Regulation of water quality problems	(Sanders, 1986)
		Improved soil quality	(McKinney, 2006; Zhu & Carreiro, 2004)
		Lowering noise levels	(Islam et al., 2012)
Ecological	Biodiversity	Harbouring wildlife	(Dunster, 1998)
		Promoting conservation	(Adams, 1994)
Health	Fewer complications and faster recovery at hospital having natural views		(Ulrich, 1984)
	Improving physical health (e.g. obesity, immune functions)		(Schipperijn et al., 2013; Li et al., 2011; Li, 2010; Li et al., 2009; Li et al., 2008; Nielsen & Hansen, 2007)
	Decreased child mortality and birth problems		(Donovan et al., 2011)
	Averting premature death		(Takano et al., 2002)
	Averting respiratory-illness-related mortality and hospital admissions		(Donovan et al., 2013; Tiwary et al., 2009)
Psychological	Provision of a tranquil and healthy environment		(Burgess et al., 1988; Mitchell, 2012; Qin et al., 2013)
	Reduction of mental fatigue		(Arnberger & Eder, 2012; Kuo & Sullivan, 2001; Kaplan & Kaplan, 1989; Kaplan, 1995)
	Emotional and spiritual benefits		(Chiesura, 2004)
	Influencing the behaviour and performance of learners		(Taylor et al., 2001)
Aesthetic	Enhancing attractiveness of cities		(Manning, 2008)
	Blocking of undesirable views		(Schroeder, 1991)
	Softening of the urban hardscape (e.g. colours, shapes, textures, sounds and feelings)		(Smardon, 1988)
	Aesthetic pleasure from the thriving of wildlife		(Hunter, 2001; Burgess et al., 1988)

*Table 2.1: A comprehensive listing of urban forest values (cont.)*

<i>Value category</i>	<i>Value descriptor</i>	<i>Reference</i>	
Socio-cultural	Provision of food and increased food security	(Clark & Nicholas, 2013)	
	Traffic calming	(Wolf & Bratton, 2006)	
	Recreational spaces for community	(Gobster & Westphal, 2004; Nowak et al., 2001; Burgess et al., 1988)	
	Research sites for researchers	(McDonnell et al., 1997)	
	Increase in civic values and stronger sense of community	(Kuo, 2003)	
	Reduction of crimes and fear of crime	(Kuo & Sullivan, 2001)	
	Work and labour from tree-caretaking	(SeattleGov, 2007)	
	Socializing and friend-making	(Peschardt et al., 2012; Seeland et al., 2009)	
	Attachment to place through trees	(Hull et al., 1994)	
Economic	Increase economic values (through tree aesthetic)	Private trees (Tyrväinen, 2001) Street trees (Donovan & Butry, 2010)	
	Higher economic activity in tree-covered areas	(Wolf, 2004)	
	Asset for tourism (recreational, aesthetic, cultural)	(McPherson & Simpson, 2002)	
	Provision of timber	(Baines, 2000)	
	Savings on infrastructure	Fuel savings & carbon dioxide sequestration	(Scott et al., 1998)
		Energy savings	(Akbari & Taha, 1992)
		Air pollutant removal	(McPherson et al., 1999; McPherson et al., 1997)
		Draining infrastructure	(Girling & Kellett, 2002)
	Pedestrian infrastructure	(McPherson & Muchnick, 2005)	





*Figure 2.1: Urban forest value in the literature indicating value classification of value descriptors and relative importance according to frequency of mention (categories and themes based on Table 2.1; frequency of mention based on Roy et al., 2012)*

Thus, my review is broader, as it includes public opinion, yet the value typology and classification used is more concise than that of Roy et al. (2012), as many individual urban forest processes or elements are grouped under the same value descriptor. Rather than focusing on specific processes or elements of the urban forest, my review focuses on themes that may be considered important about the urban forest in the literature because people study them. Another way to look at the review is to organize the information according to the general framework presented in section 2.4, which classified values as being material, instrumental, or anthropocentric, and non-material, non-instrumental, or intrinsic. A relative level of relative importance was assigned to the descriptors based on the frequency of mention information provided by Roy et al. (2012) (Figure 2.1).

### *2.5.3 Discussion*

#### *2.5.3.1 Types of urban forest values in the literature*

Exploring urban forest values is a step towards establishing priorities and making management relevant and operational. My review of urban forest values demonstrates that environmental and economic values are the richest in terms of descriptions and, together with aesthetics, are also most frequently mentioned (Table 2.1 and Figure 2.1). Interpreting this for urban forest management means that the priorities of urban forest management are environmental, economic, and aesthetic. It is useful to note that most of the values in the urban forest literature have been captured under the concept of services, benefits, and attitudes, and not under the concept of values. As mentioned earlier, the terms have been used interchangeably to mean the same thing, yet their use is one of the reasons why the typology of urban forest values in the literature is the way it is as demonstrated by this review.

First, services and benefits are concepts that usually capture the quantifiable aspects of what is important about urban forests, and attitudes capture preference of particular aspects of urban forests as expressed by people. These terms focus on the positive environmental effect on people, which can be evaluated monetarily through, for example, the replacement value of air filtration and other functions (e.g. Dwyer et al., 1992; McPherson & Simpson, 2002; De Ridder et al., 2004; Payton et al., 2008; Chen & Jim, 2008; Donovan & Butry, 2009), hedonic pricing methods (Payton et al., 2008; Donovan & Butry, 2010), or their contribution to the price of property (Payton et al., 2008; Donovan & Butry, 2010). This literature suggests an exclusive economically-oriented measure of values, implying that whatever cannot be measured is not important. It seems that conceptualizing what is important about urban forests as a service or benefit makes the issue more technically approachable, but it tends to capture mostly the environmental and economic contributions of urban trees.

Secondly, because attitude (and sometimes benefits) is a concept that refers to preference, research based on this conceptualization has mostly captured aesthetic values. This is the

most commonly mentioned services/benefit/attitude in academic (e.g. Kalmbach & Kielbaso, 1979; Sommer et al., 1990; Schroeder & Ruffolo, 1996; Tyrväinen et al., 2003; Chiesura, 2004; Gorman, 2004; Schroeder et al., 2006) and non-academic (City of Prince George, 2004) public opinion studies. Some important exceptions refer to shade and psychological benefits (Lohr et al., 2004).

In short, the literature on urban forest values, as explored through the terms services, benefits, and attitudes, does not capture ecosystem values broadly or in depth. It is important to point out that there is a strong and emerging academic criticism on how the concept of ecosystem services does not capture many socio-cultural and psychological values people associate with nature and the environment (e.g. Chan et al., 2012a; 2012b). There is also a criticism on how the use of ecosystem services to make ecosystem management decisions sometimes misses many issues associated with ecosystems that have socio-cultural and psychological importance (Ruckelshaus et al., 2013). However, this critical perspective on the way the importance of urban forests is conceptualized in the ecosystem management literature has not yet permeated the urban forest literature. It seems then that any assumption about what is important about urban forests may be premature. This provides the basis of my rationale for using the term values and not services, benefits, or attitudes to capture what is important about urban forests, especially for capturing public opinion. A political ecology perspective on urban forest management is useful to explore the merits of this rationale.

### *2.5.3.2 The values basis of urban forest management*

Urban forest management can be seen as a social enterprise based on values (Chapter 1). Under the perspective of political ecology, that is, the study of the linkages between political, social, and economic issues in resource and environmental sciences (Wolf, 1972; Forsyth, 2013), any resource can be seen a provider of social, political, and economic services/benefits (Robbins, 2011). Political, social, and economic dynamics affect urban resource distribution and allocation; that is to say, urban resources are produced socially (Harvey, 2010). This perspective means that the management of the urban forest resource operates not only on the basis of the professional knowledge of

social actors, but also on the basis of their values. Clearly there are other constraints to urban forest management, including land form and other geographical considerations (Conway & Hackworth, 2007), but the focus here is the priorities of management actors as determinants of the direction of urban forest management.

The perspective of urban forest management allows us to explore who are the actors behind urban forest management. These may include: 1. Municipal technical people, such as arborists, planners, landscape architects, nursery people, professors, who develop management standards and programmes, into which they inject their professional viewpoints; 2. Politicians and administrators, including municipal politicians and officials, and to a lesser extent urban developers, through lobbying, who respond strongly to budgets and profits, and some respond to the political preferences of the electorate; 3. Property owners, including the municipality but also businesses, public institutions, and home owners; and, finally, 4. Citizens, acting as property owners or as renters who do not own land in the city. In contrast to the other actors of the urban forest, citizens are the occupants of the urban ecosystem and are the daily appreciators of its trees. Obviously, actors 1 to 3 also enjoy the urban forest as citizens when not confined to the boundaries of their work. Citizens have the least control of what gets planted and where, and in general how the urban forest is managed and evolves over time.

Another insight gained by interpreting urban forest management as a social enterprise is to realize that urban forest services and benefits are distributed unevenly across the urban realm. Urban forest canopy cover is correlated to higher income neighbourhoods (Talarchek, 1990; Iverson & Cook, 2000; Tooke et al., 2010), demographics with higher levels of education (i.e. college degrees), age of neighbourhood (i.e. older neighbourhoods have more trees; Lawrence, 1995; Heynen & Lindsey, 2003; Landry & Chakraborty, 2009; Pham et al., 2013), and amount of land under municipal control (i.e. public parks; Perkins et al., 2004; Zhou & Kim, 2013). Other demographic characteristics, such as ethnic minorities and ownership (i.e. renters vs. homeowners) are also correlated to canopy cover distribution (Heynen et al., 2006; Landry & Chakraborty, 2009; Pham et al., 2012). Lifestyle seems also to be a main correlative to canopy cover

(e.g. Fraser & Kenney, 2000; Grove et al., 2006a; Grove et al., 2006b). Even when community groups, particularly resident associations, are formed to increase citizen-based and bottom-up resource governance, these social associations are still dependent on property ownership, high income level, and type of housing (Conway et al., 2011; Conway & Bang, 2014). The same characteristics seem to affect vegetation diversity: the so-called “luxury effect”, whereby higher income neighbourhoods are granted higher vegetation diversity (Hope et al., 2006a; Hope et al., 2006b) or are the ones willing to plant more trees (Greene et al., 2011).

A key question that rises in this discussion is whose values dominate when alternative management strategies are evaluated and one is chosen for implementation.

Theoretically, when citizen values are not being probed or are disregarded as being uninformed, then urban forest management is being driven by the values of formal managers, that is, as discussed above, municipal arborists and government officials.

Because these municipal workers see themselves as service providers, it is evident that the services/benefits literature may influence them more. Indeed, many authors point out that service-provision and optimization is the main goal in urban forest management (e.g. Nowak, 2006; Schwab, 2009; Seamans, 2012; Young, 2013). This may imply that managers, unaware of their own values, or assuming that their values are the same as the citizenry, or that they know better, are directing management towards a services-and-benefits-optimization perspective. Under this perspective, according to my review, environmental, economic, and aesthetic values are more prominent. Whether these are the same values of the public is still unclear, as much public values research in urban forests has limitations (see below).

It is obvious then that a services-and-benefits-optimization perspective in urban forest management results in a narrow set of values guiding management. As argued earlier, public values research is crucial for ecosystem management as it may complement, enhance, or broaden what guides the management of socio-ecological systems (Chapter 1). However, and based on this discussion, these values do not dominate in urban forest

management. To be able to adopt these values into management, the gaps in the literature must be overcome, as I discuss below.

### *2.5.3.3 Public values in urban forest management*

Plenty of limitations exist to capture the views the public, or the citizenry, has about urban forests. First, urban forest values explorations have been hindered by the way the urban forest is defined. This applies to academics (e.g. Konijnendijk et al., 2006; see also Chapter 3), people in charge of the urban forest (McLean & Jensen, 2004), and ordinary citizens. Therefore, urban forest values are frequently explored in spaces, conceptually or physically, that do not represent the ecosystem as a whole (Chapter 1). Because people usually experience nature as places, in a conceptual or specific way, and not as abstract objects (Ryan, 2005), it is important that citizen values studies integrate the diversity of urban forest types, from street trees to parks and natural forested areas.

However, studies examining citizen opinion about the urban forest have not explored it in this holistic way. Some relevant studies focus on street trees (Schroeder & Ruffolo, 1996; Coles et al., 2013), on urban woodlands (Tyrväinen et al., 2003; Tyrväinen et al., 2007), on green spaces (Coles & Bussey, 2000; De Ridder et al., 2004; Balram & Dragievi, 2005; Budruka et al., 2009), open spaces (Chiesura, 2004), gardens (Ulrich, 1984; Ulrich, 1999), and even greenways (Gobster & Westphal, 2004), encompassing other natural elements besides trees or not focusing on the urban forest as a whole. In addition, most of the urban forest literature comes from the United States, Europe, and to a lesser extent Australia (Roy et al., 2012). The development of an international perspective has been obviously elusive.

Furthermore, the values held by the citizenry in relation to urban forests have only been explored methodologically via interviews and survey methods. In many of such cases, values are explored with prompted categories (e.g. Schroeder & Ruffolo, 1996; Chiesura, 2004; Johnston & Shimada, 2004; Lohr et al., 2004; Schroeder et al., 2006; Tyrväinen et al., 2007). In others, they are explored in the context of damage events (Hull, 1992), generating interesting results, but overall difficult to replicate. There is a discrepancy

between how people respond to surveys and how they actually think/feel/behave, making it difficult to generalize across studies (Dietz et al., 2005). Ultimately, values are intimate (Hitlin & Piliavin, 2004) and qualitative methods may have the advantage of uncovering how people articulate these thoughts and feelings rather than asking them to react to survey items (Satterfield, 2001). However, qualitative studies rooted in an experience of urban trees, with open value categories, and in a diversity of case studies are a rare find, as my review demonstrates. Much of evidence of the worth of these explorations can be learned from the forest values literature (e.g. Moyer et al., 2008; Owen et al., 2009). A similar public values elicitation is yet to be done in the urban forest realm.

This brief discussion has illustrated the fact that citizen values of urban forests have not been adequately captured in the literature. There is much to gain from studies rooted in an experience of the urban forest, focusing on urban trees in all their possible arrangements. Moreover, the combination of both quantitative and qualitative methods in different geographic contexts could be a valuable contribution to the literature.

#### *2.5.3.4 Advancing public values research in urban forests*

The literature on urban forest services, benefits, and attitudes has contributed immensely to our understanding of what urban trees do to influence the quality of life of urban citizens. It has provided an invaluable measure of the significance of tree functions to meet human needs. It also estimates the value of the ecosystem from an environmental, economic, and aesthetic standpoint. However, by over-relying on the types of values elicited through these concepts, and without an adequate probing of the values of the citizenry, we miss capturing what is important about the urban forest for people at a deeper level and perpetuate biases in urban forest management.

It is useful to note that a values-based management framework for urban forest management (Chapter 1) does not necessarily conflict with the services, benefits, and attitudes literature. Rather, it builds another layer to the ever-growing endeavour of trying to understand what is important about the urban forest to people and trying to guide management according to this. In addition, the values-based management style does not

necessarily conflict with the expert knowledge of environmental and ecological professionals. As argued earlier, public value is an all-encompassing concept, which captures the values of all urban forest management actors, including experts (Chapter 1). In a more practical sense, what the public wants from urban forests can sometimes echo the strategies of management suggested by experts, assuming that value directions are the same in terms of professional, such as ecological and environmental, desirability. This does not necessarily mean that public values are only valid when they reflect the knowledge of experts. Rather, this reminds us that there are always some parallels in what the public and the experts see as important in urban forests.

A successful public values elicitation will result in aligning management priorities better with the values of diverse stakeholders rather than being aligned with the values of a few. How this idea has influenced urban forest management in Canada is an interesting question to answer, and one that I will address in the next section.

## **2.6 Summary**

In this chapter I reviewed the concept of values, the urban forest values literature, and drew conclusions about the gaps and opportunities for urban forest values research and implications for urban forest management.

Values are concepts that can be used to explore the deeper motivations and guiding principles in people's lives. Values can be abstract hierarchical constructs (i.e. I value security), as much as they can be deep emotional and cognitive constructs directed towards objects (i.e. I value that landscape). Values are interrelated to each other. They are difficult to measure, particularly existence, or intrinsic, non-monetary values. They respond to deeper belief systems in people as well as to their socio-cultural and economic conditions. They can be directed to ecosystems and ecosystems can help reveal people's values. Values give a sense of the human priorities in environmental management and as such are a deeper basis for ecosystem management than any other concept.



A broad canvassing of the urban forest literature has yielded a wide array of what people consider important about the urban forest. My review is broader and is reported in a more concise manner than others (e.g. Roy et al., 2012). It captures public opinion research, where most of the psycho-social values are revealed. Analysis of these findings reveals that the urban forest literature is geared towards researching environmental, economic, and aesthetic services, benefits, and attitudes. The typology of urban forest values in the literature does little to capture ecosystem values in depth, particularly those values of the citizenry.

This chapter provided a rationale for using the concept of values for capturing what is important about urban forests for people. So far there are limitations in the urban forest literature for capturing citizen values, including the inadequate conceptualization of the urban forest as an ecosystem, geographical bias, and shallow methodological approaches, premature assumptions have been made about what is important about urban forests. I argued how, because of this, urban forest management may not be addressing management objectives that are important to the public. I also discussed how values-based conceptualization does not necessarily conflict with the services, benefits, and attitudes literature, but rather how these bodies of literature build on one another. Together, they help us understand what people consider important about urban forests.

In the next chapter I set out to understand urban-forest management regimes and find evidence for some of the insights gained here.

## **3 Chapter 3: An Analysis of Urban Forest Management and its Values**

### **3.1 Publication Information**

This chapter is based on the following publication led by me and co-authored by Peter Duinker, with some added content (section 3.7, Implications):

Ordóñez, C., Duinker, P. (2013). An analysis of urban forest management plans in Canada: implications for urban forest management. *Journal of Landscape and Urban Planning* 116, 36–47.

### **3.2 Introduction**

It is important to understand how urban forest values are adopted in urban forest management, particularly the operational processes and actions that exist to transfer this framework into ground work. With an overwhelming urban population (Statistics Canada, 2006), urban trees are an integral part of urban living in Canada, where its population relies on urban forests to improve the quality of urban life (van Wassenauer et al., 2000). Canada provides an ideal context to explore urban forest management. It is of no surprise, then, that there has been a rise in urban forest management programmes in many Canadian cities, with the past decade being particularly busy in this regard. This process is being driven partly by a concomitant rise in the number of urban forest management plans (UFMPs). UFMPs have become the defining documents behind urban forest management. It is timely to use this documentation for evaluating current urban forest management trends in Canada.

This chapter will attempt to answer the first question of the research regarding the application of urban forest values in management. It approaches the question in a novel way by analysing UFMP documentation as means to understand Canadian urban forest management. It is divided into five sections. The first section of the chapter gives a

background to Canadian urban forest management. The second section discusses the materials and methods of the analysis and the third presents the findings. The fourth section discusses these results and extracts best practices. A fifth section evaluates the implications for advancing urban forest management. The chapter is summarized at the end.

### **3.3 Background to Canadian Urban Forest Management**

Several factors may be driving the development of Canadian UFMPs. Administratively, there is a need to justify the existence of an urban forest programme for budgeting and staffing purposes. Yet other issues may be playing a bigger role, as elaborated below.

Research on urban forests has increased in recent decades. This has added to our understanding of urban forests, but also challenged the traditional driving forces behind their management: the aesthetic and environmental benefits of trees, and the problems of growing trees in the city. As for the first driver, studies on public opinion quote aesthetics as people's main concern for planting trees in North America (e.g. Hull, 1992). Urban planners also focus on climate comfort (Lang, 1994; Arnfield, 2003). However, a broader set of urban forest benefits beyond these two is now being considered. Urban trees today are also planted for air pollution regulation, nature conservation, and increased civility, human health, economic development, property values, and sense of well-being (Spirn, 1985; Tyrväinen et al., 2005; Gustavsson et al., 2005; Bell et al., 2005), among other valuable aspects (see Chapter 2). Because ecosystem management expresses the way we value nature (Grumbine, 1994), and urban forest values provide a deep driver for management (Dwyer et al., 1991), the desire to provide a bigger array of urban forest values may justify the development of a UFMP document.

Nonetheless, the problem of growing urban trees may be a more pressing driver. Although the definition of a problem in urban forest management is a matter of location-specific interpretation, and when trying to account for problems in urban forests one cannot be exhaustive, in a historical sense, urban forest problems in North America can

be classified into two main themes: tree loss and tree diversity. Some see tree loss as a result of increased urbanization, which also generates challenging environmental conditions for the surviving trees (Carreiro, 2008). This is compounded with a fragmented ownership pattern that challenges tree control. Also indicative of this is that most tree policies in Canada before the 1990s were directed at the removal of publicly owned trees (Andresen, 1977), thus increasing the share of the resource in private ownership. Approximately half of the urban forests in North America are privately owned (e.g. Dwyer & Nowak, 2000; Kenney & Idziak, 2000; Nowak et al., 2001; Kuser, 2007; City of Toronto, 2012). Tree bylaws have thus become the tool of choice for tree protection in Canada, yet their efficiency and effectiveness is still questionable (Conway & Urbani, 2007). Unequal tree distribution may add to tree loss, as it affects accessibility and, thus, social equity (Perkins et al., 2004; Heynen et al., 2006; Pham et al., 2012; see also Chapter 2).

As for tree diversity, problems with age and species diversity are common. In Canada some cities are composed almost solely of old trees (Town of Banff, 2008), while suburban cities are quite the opposite (Town of Ajax, 2011). Moreover, urban tree selection has depended heavily on a few species. A small number of 4-5 tree species occupy more than half of the canopy cover in most North-American cities (e.g. McPherson et al., 1994; Kenney & Idziak, 2000; Turner et al., 2005). In some cases, most of these species are of European stock (Freedman et al., 1996), although in some cities it is only a few native ones (City of Toronto, 2010). Some of the latter are vulnerable to diseases and pests. The potential impact in Canada of Dutch Elm Disease (DED) and Emerald Ash Borer (EAB), among other diseases and pests, is high (e.g. Poland & McCullough, 2006; Karnosky, 2009). The impact of climate change may exacerbate these via the mal-adaptation of species (Yang, 2009). To solve this, planting of southern species has been suggested (Woodall et al., 2010), as well as striving for long-term climate adaptation strategies that facilitate tree survival (Johnston, 2004; Ligeti, 2007; BC-MCSCD, 2010).

To understand tree-loss and tree-diversity problems, inventories have been conducted to provide better quality data. An urban forest without information about the trees is an urban forest that can be difficult to manage sustainably, one that is prone to reactive management rather than careful planning (Miller, 1997). New inventory standards have also allowed calculation of urban forest environmental services (e.g. Urban Forest Effects Model, UFORE, Nowak & Crane, 2000; today iTree-Eco). Because urban forest structure ultimately determines the services urban forests provide (Nowak & Dwyer, 2007) comprehensive inventories provide a basis for developing actions that may enhance particular urban forest values. However, the comprehensiveness of urban forest inventories depends on whether the urban forest is seen as a continuous or fragmented resource. While some European countries see urban forests as woodlands adjacent to the city (Konijnendijk et al., 2006), in North America these are all the natural and planted trees in urban areas (Rowntree, 1984). Either way, many ecological and social considerations of urban forest management may go beyond either of these common definitions. For instance, due to fragmented habitats, urban forests processes vary, such as natural regeneration in naturalized areas, and artificial plantings in streetscapes (Zipperer, 2008; Nowak, 2012). Some North-American cities respond to this ecological reality by devising different targets for different zones in the city (e.g. SeattleGov, 2007; Steenberg et al., 2013; see also Chapter 1).

With better information about the urban forest and such problems in mind, an urban forest management approach eventually emerged based on three simple goals. Today, urban forest management strives for increasing: 1. canopy cover, or the percentage of leaf cover per unit urban area (AmericanForests, 1991); 2. species diversity, with a standard usually set at a 15% maximum for single-species representation (Miller & Miller, 1991); and 3. tree sizes, as bigger trees provide more ecological services (CUFR, 2004), such as air pollution removal (Nowak et al., 2006) and hydrological regulation (Xiao et al., 1998). These three main goals are common in many North-American urban forest programmes (Schwab, 2009).

This approach provides a much-needed technical focus to solve the problems of tree loss and diversity, as well as provide more environmental services/benefits. It has also advanced treatment approaches by assuming the urban forest as a single ecosystem and setting specific numeric targets of canopy cover, diversity, and tree size across the whole city. Given the right information, it may also allow multi-scale sophistication by setting different targets for different habitat regimes.

However, an over-reliance on this approach and its three main goals may cause unintended value trade-offs. For instance, a one-size-fits-all application of canopy-cover or tree-diversity (at the species level) targets may disregard ecological considerations, such as connectivity and representation of native tree species (see Chapter 2). These are issues ultimately related to broad ecological principles of ecosystem management, such as ecosystem health (Costanza et al., 1992). Moreover, these simple goals imply a reliance on technical steering committees, thus isolating other stakeholders from taking decisions about the urban forest. This may aggravate not only the legitimacy of urban forest programmes (Janse & Konijnendijk, 2007), but also the solutions to problems that require more than a technical approach.

In summary, because of their wide-ranging connections and broad set of values, urban trees relate to everything in the city and are at the forefront of urban planning. Consequently, modern urban forest management must be characterized by: 1. a purpose that goes beyond the circumstantial: ideally, the provision of a broad set of values to the community; 2. broad principles that define the philosophical, administrative, and technical approaches to management (e.g. comprehensive inventories, long time frames, specific goals, etc.); 3. public participation, reflecting that urban forest management does not depend solely on the technical expertise of a few municipal workers, but a varied set of stakeholders; and 4. appropriate documentation, that is, a UFMP. A UFMP is ideally an official municipal document approved by the city council that translates its goals and objectives into action, provides accountability, and has practical meaning.

By translating urban-forest theory into practice, UFMPs help us understand the approaches to urban forest management. So far, there is no literature that analyzes UFMPs. Important studies of urban forest management have centred on budget issues (Kenney & Idziak, 2000), zoning and regulation (Stone, 2004), community programmes (Kuhns et al., 2005; Conway et al., 2011), policies (Ottitsch & Krott, 2005; Conway & Urbani, 2007), urban forest programmes (Clark & Matheny, 1998; Barker & Kenney, 2012; Seamans, 2012), and managers themselves (Young, 2013) but not on documentation. Here I evaluate Canadian urban forest management by using UFMP documentation as a data source. This analysis is empirically-based, guided solely by the information in the plans.

### **3.4 Materials & Methods**

The point of the study was, first, to examine the quality and comprehensiveness of information provided in publicly available UFMP documents in Canada, and second, to get a sense of various urban-forest management programmes across the country, as that sense can be gained from the documentation readily available.

A comprehensive survey of Canadian municipalities with an urban forest programme and publicly available documentation on the world-wide-web was carried out in 2011-2012. The goal was to access an urban forest management or planning document substantial enough to include most of the elements of a UFMP recognized during a review of the literature (Figure 3.1). All documents were retrieved digitally using this method. The urban-forest-related documents of the cities of London (City of London, 2009; City of London, 2012), Montreal (Ville de Montreal, 2005), and Toronto (City of Toronto, 2010) were not used as they were not deemed to be UFMPs. The Québec City UFMP (Ville de Quebec, 2008) was not included due to language constraints (the document is only available in French). The Halifax (HRM, 2012), Kelowna (City of Kelowna, 2012), Thunder Bay (City of Thunder Bay, 2013), and Toronto (City of Toronto, 2012) UFMPs were not used as they were published after the 2011-2012 survey.

Fourteen UFMPs were finally used: City of Kingston (2011), Town of Ajax (2011), City of Burlington (2010), City of Nanaimo (2010), City of St Catharines (2010), District of Saanich (2010), Town of Banff (2008), Town of Oakville (2008), City of Calgary (2007), City of Guelph (2007), City of St John's (2006), City of Prince George (2004), City of Regina (2000), and the City of Victoria (2009). It is important to note that I made no inquiries with any municipal employees to try to fill data gaps.

Textual data from the UFMPs were analyzed using a qualitatively-based content analysis (see Krippendorff, 2004). Content was extracted from the plans either verbatim (relying on the explicit mentioning of a term or concept) or through interpretation, to avoid incompleteness of the database. Content was compiled into a database and organized into themes not based on pre-established categories. The content that referred to the setting and the principles of the plans was organized separately. By the setting I mean the concerns that justified the plan and the process followed (Setting & Considerations in Figure 3.1). By the principles I refer to all guiding statements included the plans (Level 1 of planning process in Figure 3.1). The content that referred to management themes and actions (Levels 2-3 of planning process in Figure 3.1) was organized in a database according to themes of management and approaches for every UFMP. The database was rich in detail and was difficult to use for comparison, since each plan had its own way to refer to particular themes of management and/or had different objectives and targets. The database was processed further to facilitate analysis.

A systematic and qualitative method of comparative analysis was developed. A standard was developed to facilitate comparison (Table 3.1). This standard specified each theme of management into criteria, and each criterion into indicators, each with an assigned objective and target according to the highest level of specificity or ambition achieved in any of the plans. Indicators and targets were assigned either numeric or categorical measurements. Vagueness in the objectives and targets (e.g. defined as “increase” or “enhance”) reflected the vagueness of the plans themselves. More detail was included only when revealed in any of the plans. Plan specificity was compared with this standard. To avoid extensive yes/no or included/not-included tables, indicators under the same



criterion were grouped and colour-coded categories were developed to indicate specificity of each criterion (Figure 3.2). This system allowed for the specificity of a given theme and/or a given plan to depend on two factors: the amount of indicators mentioned; and whether these indicators were associated with specific numerical or categorical objectives/targets, as defined in the standard (Table 3.1).

To illustrate this analysis, rudimentary figures were built indicating levels of specificity for each criterion and UFMP. This illustration proved essential for revealing similarities and differences among the plans according to each theme of management. The information was processed further, and criteria and indicators were lumped into their respective themes to give an overall view of the level of specificity of the themes of management across plans. Rules for amalgamation followed the same colour-coding method used for the more detailed rudimentary figures (Figure 3.2).

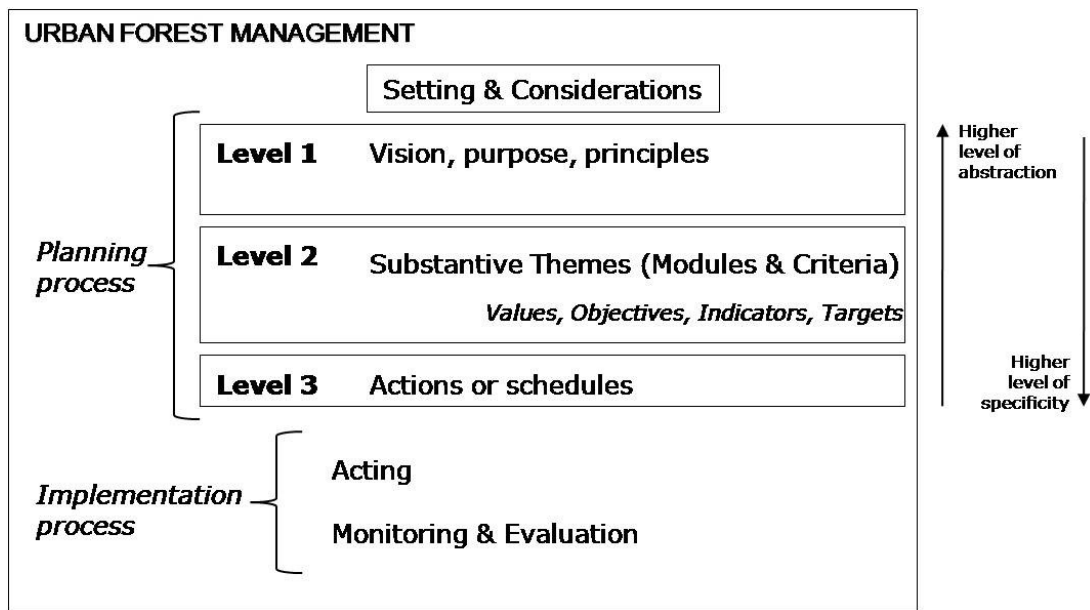


Figure 3.1: A model of urban forest management plan (UFMP) elements.

Table 3.1: Standard for comparison based on the most specific and ambitious example of any UFMP

Cluster	Theme	Criteria	Indicator	Objectives & targets (most specific or ambitious example)	Type of Measurement	Examples
ENVIRONMENTAL-ECOLOGICAL	Maintenance	Pruning	Pruning cycles	Every 2-5 years	Numeric	All UFMPs
			Best Management Practices (BMPs)	Encourage BMPs	Categorical	
		Removal & replacement	Replacement ratio	1:1	Numeric	All UFMPs
			BMPs in removal specifications	Encourage BMPs	Categorical	
		Hazard trees	Response time	Decrease	Categorical	Most UFMPs
			Identification	Enhance database	Categorical	
			BMPs in control specifications	Encourage BMPs	Categorical	
			Response time	Decrease	Categorical	
		Natural disasters	Prevention through tree maintenance	Increase	Categorical	Calgary & Victoria
			Response & recovery time	Increase	Categorical	
		Fires	Fire programme	Existence of Programme	Categorical	Prince George & others
		Insect pest & disease	Integrated Pest Management (IPM) programme	Develop or strengthen IPM	Categorical	Most UFMPs
		Tree inventory	Inventory	Enhance database	Categorical	All UFMPs
			GIS-based inventory	Adapt database to GIS	Categorical	
	Tree damage	Minimum distance from tree	Establish (for operations around trees)	Categorical	Banff	
		De-icing salts & fertilizers	Reduce the use of toxic ones	Categorical		
	Invasives	Identification	Enhance database	Categorical	Ajax & others	
		Control	Removal and discouragement of planting	Categorical		
	Establishment & Enhancement	Canopy cover	Percentage of total urban area	Increase (e.g. 20-40% over 20 years)	Numeric	Oakville & others
		Tree plantings	Number of trees per cycle	Increase (e.g. 2000 /year)	Numeric	Ajax & others
			Quality of tree-stock	Improve	Categorical	Regina & others
		Tree source	Location & ownership of nurseries	Local and municipality-owned	Categorical	
			Size of trees	Large-stature trees	Favour in new plantings	Categorical
		Growing conditions	Soil quantity and quality	Define minimum standards of soil volume, nutrient and fertilizer content	Categorical	Kingston & others
			Structural cells	Use for pavement planting	Categorical	
			Irrigation cycles	Increase	Categorical	
		Targeted Places	Priority zones and plantable spots	Identify	Categorical	Most UFMPs
		Tree Diversity	Species	Family/genus/species percentage representation of total urban forest	Increase (e.g. <10% for Species, <20% for Genus and <30% for Family)	Numeric
Coniferous / non-coniferous	Representation of tree-type		Follow natural patterns (e.g. 50% each)	Numeric	St. John's	
Age-class	Representation of age-classes		Increase (e.g. maximum 10% for any age-class)	Numeric	Oakville & others	
Short & long-lived	Representation of tree-type		Increase	Categorical	Calgary	
Naturalness & Conservation	Native Species	Representation	Increase	Categorical	All UFMPs	
	Forest-like plantings	Natural regeneration	Increase in natural areas	Categorical	Most UFMPs	
		Forest-patch size	Increase (depending on plantable spots)	Categorical		
	Connectivity	Connection of natural areas / significant forest-patches	Increase via canopy-cover targets	Categorical	Guelph & others	
		Habitat provision	Increase via canopy-cover targets	Categorical		
	Wildlife	Wildlife connection species identification	Enhance database	Categorical	Most UFMPs	
		Identification	Enhance database	Categorical		
	Species at risk	Removal protection by-law	Develop	Categorical	Victoria & others	
		Representation	Increase	Categorical		
		Quantity and quality of plantings	Increase	Categorical		
Native species representation		Increase	Categorical			
Plantings of well-adapted species (i.e. southern species)		Increase (i.e. assisted migration)	Categorical			

Table 3.1: Standard for comparison based on the most specific and ambitious example of any UFMP (cont.)

Cluster	Theme	Criteria	Indicator	Objectives & targets (most specific or ambitious example)	Type of Measurement	Examples	
ENVIRONMENTAL- ECOLOGICAL	Climate Change	Carbon sequestration	Percentage offset of municipal emissions	0.5%	Numeric	Calgary, Victoria, & others	
			Total storage by percentage for given time frame (years)	Increase to 2%/year for 10 years	Numeric		
			Credit programme	Create	Categorical		
		Adaptation	Invasives	See "Invasives" category	Categorical		
			Quantity and quality of plantings	Increase	Categorical		
	Education (Information/Awareness)	Communications	Native species representation	Increase	Categorical	Ajax, Victoria, & others	
			Plantings of well-adapted species (i.e. southern species)	Increase (i.e. assisted migration)	Categorical		
			Websites, flyers and brochures	Enhance and maintain	Categorical		
			Public Information Centre (PIC)	Create	Categorical		
			Site interpretation	Create or enhance for natural areas	Categorical		
SOCIAL	Education (Engagement)	Planting	Communications plan	Create	Categorical	Regina & others	
			Communications officer position	Create	Categorical		
			Private stewardship celebrations	Create	Categorical		
			Tree days	Celebrate (e.g. Arbor Day)	Categorical		
			Tree competitions	Create (e.g. Trees for the Millennium)	Categorical		
	Education (Engagement)	Volunteering	Information workshops	Create	Categorical	Victoria & others	
			Urban forest courses	Create at universities and schools	Categorical		
			Arboretum	Undertake feasibility study	Categorical		
			Information workshops	Create	Categorical		
			Seed-giveaway programme	Create	Categorical		
POLITICAL-ADMINISTRATIVE	Recreation	Tours & plantings	Adopt-a-tree/-greenway programme	Create or enhance	Categorical	Most UFMPs	
			Volunteer programme	Create	Categorical		
			Volunteer coordinator position	Create	Categorical		
			Celebration programme	Create	Categorical		
			Community-based tree inventory	Create	Categorical		
	Identity	Historic/heritage trees	Urban forest tour	Create	Categorical	Most UFMPs	
			Plantings along recreation routes	Increase	Categorical		
			Naturalness & nativeness	Natural areas & native species	Enhance (see "Naturalness & Conservation")		Categorical
			Historic/heritage tree programme	Create	Categorical		
			Identification	Identify 5 new trees / year	Numeric		
POLITICAL-ADMINISTRATIVE	Legislation	Municipal documentation	Information flyers	Create	Categorical	Most UFMPs	
			Co-management partnerships	Create with community-based organizations	Categorical		
			Green-infrastructure terminology	Change in all municipal documentation	Categorical		
			Bylaw update or amendment	Create	Categorical		
			New staff openings	Create	Categorical		
		Practitioners	Staff training requirements	Create (including contractors)	Categorical	Ajax & others	
			Tree protection in new development	Agreement requirements	Create		Categorical
			Arborist review requirements	Create	Categorical		
			Private tree protection bylaw	Create & undertake feasibility study	Categorical		
			Permit system	Create for tree-care/removal	Categorical		
Tree protection in private areas	Multi-actor partnerships	Create (e.g. universities, provincial organizations)	Categorical	Most UFMPs			
	Stakeholder steering committees	Create (e.g. city staff, contractors, companies, businesses, local interest groups, NGOs);	Categorical				
	Community-led organizations	Create at neighbor level	Categorical				

Table 3.1: Standard for comparison based on the most specific and ambitious example of any UFMP (cont.)

Cluster	Theme	Criteria	Indicator	Objectives & targets (most specific or ambitious example)	Type of Measurement	Examples
POLITICAL-ADMINISTRATIVE	Policy	Tree protection in new developments	Guidelines or standards	Create	Categorical	Most UFMPs
		Documentation	Inclusion of UFMP goals in municipal documentation	Create	Categorical	Victoria & others
		Coordination	Urban forest working groups	Create as Inter-departmental or multi-actor entity	Categorical	Most UFMPs
		Inclusion, stewardship & empowerment	Public input requirements	Create for important UFMP decisions (e.g. bylaws)	Categorical	
			Multi-actor partnerships	Create (e.g. universities, provincial organizations)	Categorical	Victoria & others
			Stakeholder steering committees	Create (e.g. city staff, contractors, companies, businesses, local interest groups, NGOs);	Categorical	
			Community-led organizations	Create at neighbor level	Categorical	
ECONOMIC	Finances	Budget	Implementation costs	Increase for plantings and volunteer programmes	Categorical	Ajax, Banff, & others
			Further finances	Increase from public and private sources	Categorical	
	Legislation	Financial incentives & penalties	Planting incentives	Create for private areas	Categorical	Calgary & others
			Removal penalties	Create or update for public and private land (e.g. follow International Society of Arboriculture standards)	Categorical	
	Analysis	Valuation techniques	Use of valuation tool	Increase (e.g. iTree, CITYGreen, TreepaQ)	Categorical	Most UFMPs
			Cost-benefit analyses	Create for extra costs (by-law, pruning, incentives)	Categorical	
TEMPORAL-SPATIAL	Temporal	Time-frames	UFMP time horizon	Increase (e.g. 60 years)	Numeric	Victoria & others
			Reporting/monitoring time-frame	Decrease (e.g. every 5 years)	Numeric	
	Spatial	Scales of treatment	Multi-scale specifications	Create targets and objectives per landscape-use	Categorical	Banff & Regina
		Resource continuity	One ecosystem across ownerships	Recognize patterns (private and public)	Categorical	Most UFMPs

Cluster	Theme	Criterion	Indicators	Objectives & targets (most specific or ambitious example)	Specificity levels for analysis (explanation & colour-coding)
ENVIRONMENTAL-ECOLOGICAL	Maintenance	Tree inventory	2 indicators		<ul style="list-style-type: none"> <li>Inventory &amp; GIS mentioned + objectives &amp; targets assigned</li> <li>Only one (1) indicator mentioned + objective &amp; target assigned</li> <li>Both or only one (1) indicator mentioned, but vague</li> <li>None mentioned</li> </ul>
			Inventory	Enhance database	
			GIS-based inventory	Adapt to GIS	
ENVIRONMENTAL-ECOLOGICAL	Tree Diversity	Age-class	1 indicator		<ul style="list-style-type: none"> <li>Age-class mentioned + objectives &amp; targets assigned</li> <li>Indicator mentioned, but vague</li> <li>None mentioned</li> </ul>
			Representation of age-classes	Increase and define maximum/minimum for any age-class (e.g. max. 10%)	

Figure 3.2: Examples of how the specificity analysis was accomplished for criteria based on two (2) and one (1) indicators

### 3.5 Results

To begin, the setting and principles (Tables 3.2 and 4.3) offer us some important insights. It shows that the threat of diseases and pests, lack of diversity, and tree loss due to development patterns were common justifications for developing a UFMP (Table 3.2). The extent of inventories varies across municipalities, with some having UFORE-type inventories, while others do not specify them. In general, most steering committees were composed of city staff, and public input appeared scant. The character of the documentation also varies, with almost half of the plans referring to their UFMP document as a strategy or a framework for a plan. As for the management principles, protection, enhancement, and maintenance of the urban forest resource were common, followed by enhancement of community support (Table 3.3).

The analysis of the management themes included in the plans shows some important patterns. Themes of maintenance and planting/establishment were the most common and specific across all UFMPs, but tree diversity, naturalness/conservation, and climate change were less so (Figure 3.3). Social and political/administrative themes were common but in some cases lacked specificity (Figure 3.4). Most economic themes were not as frequently mentioned or specific (Figure 3.4). Finally, temporal and spatial specifications varied (Figure 3.4). The time horizons of many UFMPs was short (i.e. longest was 60 years; see Table 3.1), and reporting and monitoring time-frames were mentioned vaguely. Multi-scale treatment specifications (e.g. canopy cover or tree diversity targets for each landscape-use category) were almost non-existent. Nonetheless, most UFMPs see the urban forest as a continuous resource across all ownership categories (i.e. both private and public trees). Trends across plans and themes of management are best appreciated by ranking the plans according to their specificity (Figure 3.5).

Table 3.2: The setting of Canadian UFMPs

Municipality	Type of Inventory		UFMP study		Steering committee		Public input		Concerns				Character of documentation		
	UFMP-style <sup>1</sup> (or other)	Unspecified	UFMP study	City staff and consultants (or other)	Unspecified	Specific method	Mentioned but not specified	Tree diseases and pests	Tree loss due to development	Tree diversity	Aging trees	UFMP	Other	Other	
Ajax	■		■	■				■	■	■				Draft	
Banff	(Street trees only)			■				■	■	■	■	■			
Burlington	■				■		■	■	■	■	■				
Calgary	■		■		■					■	■	■			
Guelph	■			■		Workshops		■	■					Frame work	
Kingston	■		■		■	Open house & Survey		■	■	■	■	■			
Nanaimo	■				■		■			■				Strategy	
Oakville	■		■	■		Focus Group		■	■	■	■			Strategy	
Prince George		■		■				■		■				Draft	
Regina	■		■	■				■	■	■				Strategy	
Saanich		■		■		Open house & Survey			■					Strategy	
St Catharines		■		■				■		■				Draft	
St John's	(Street trees only)				■			■	■	■	■	■			
Victoria	■		■	(Stakeholder committee)		Workshops & survey			■	■	■			Draft	

■ = included/mentioned/applies 1 = UFMP style refers to obtaining urban forest information through random plots (see Nowak & Crane, 2000)

Table 3.3: Principles of management in Canadian UFMPs

Municipality	Protection & enhancement of tree resource	Integrity (tree health, diversity & nativeness)	Enhance community support	Ecosystem approach	Trees as infrastructure / utility	Adaptive management	Continuous resource (public and private)	Enhance aesthetic	Enhance accessibility	Enhance identity	Increase economic value	Multiple scales	Long-term vision	Climate change
Ajax	■	■	■			■	■				■			■
Banff	■	■	■	■	■			■		■	■	■		
Burlington	■	■	■	■	■	■	■			■				
Calgary	■	■	■	■	■	■	■				■		■	■
Guelph	■	■	■		■	■	■				■			
Kingston	■	■	■		■		■							■
Nanaimo	■	■	■	■	■	■	■	■	■	■			■	■
Oakville	■	■	■		■	■	■				■	■		
Prince George	■	■		■				■			■			■
Regina	■	■	■			■	■	■		■		■		■
Saanich	■	■	■	■	■		■	■		■		■		
St Catharines	■	■	■	■	■		■							
St John's	■	■	■							■				
Victoria	■	■	■	■	■	■	■	■	■	■	■	■	■	■

■ = included/mentioned/applies

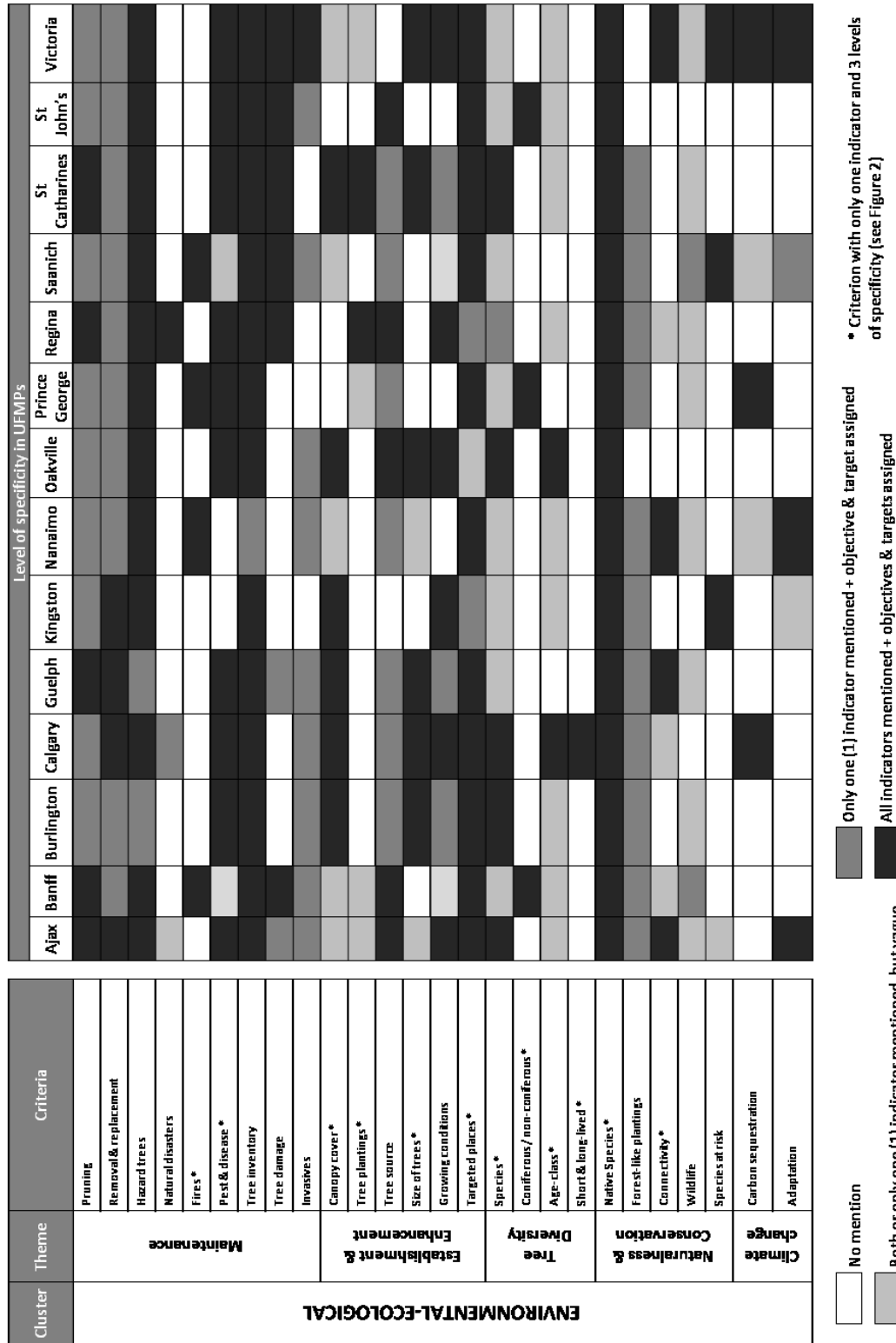


Figure 3.3: Comparison of environmental-ecological themes across Canadian UFMPs, according to level of specificity of criteria



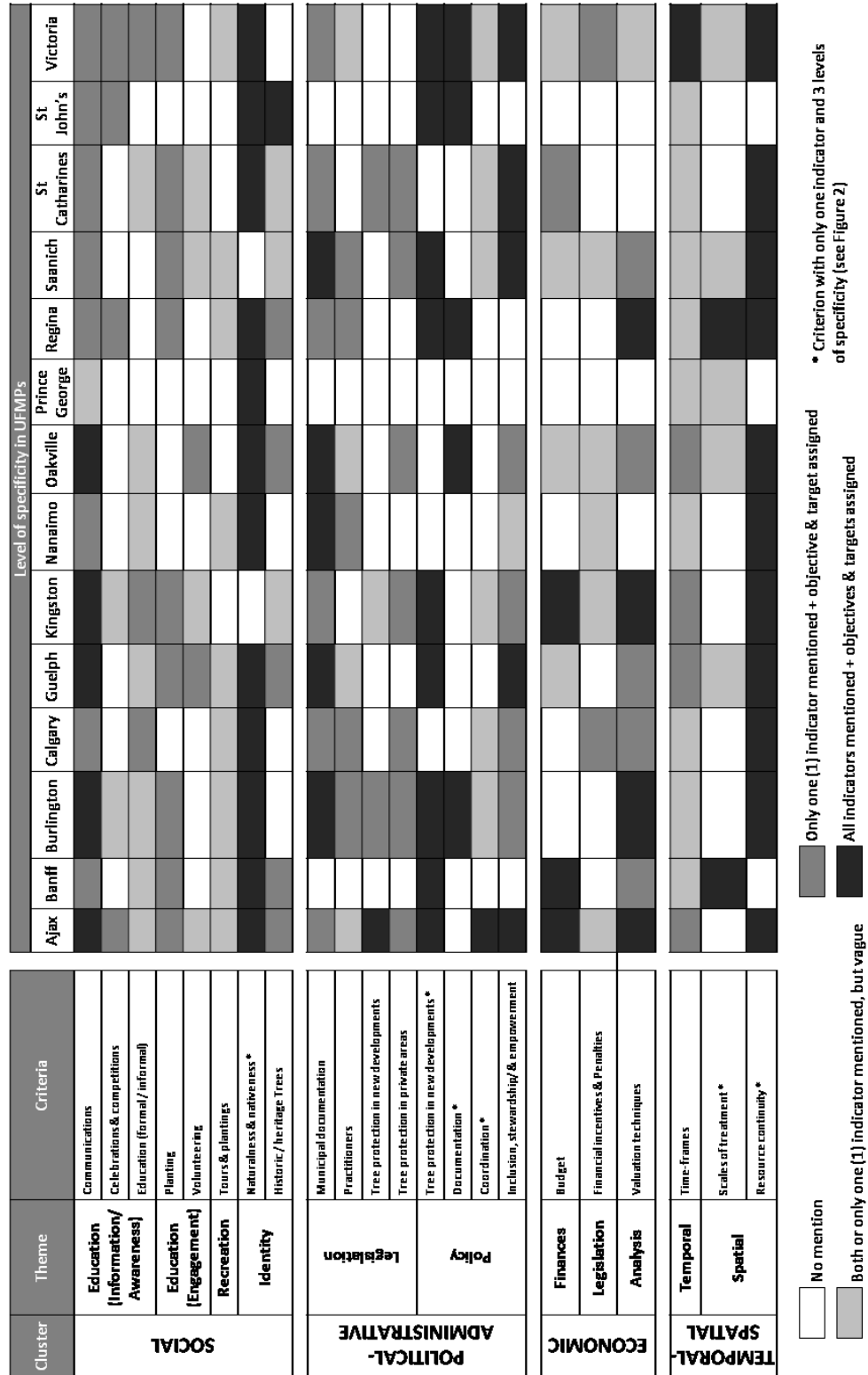


Figure 3.4: Comparison of social, political-administrative, economic, and temporal-spatial themes across Canadian UFMPs, according to level of specificity of criteria

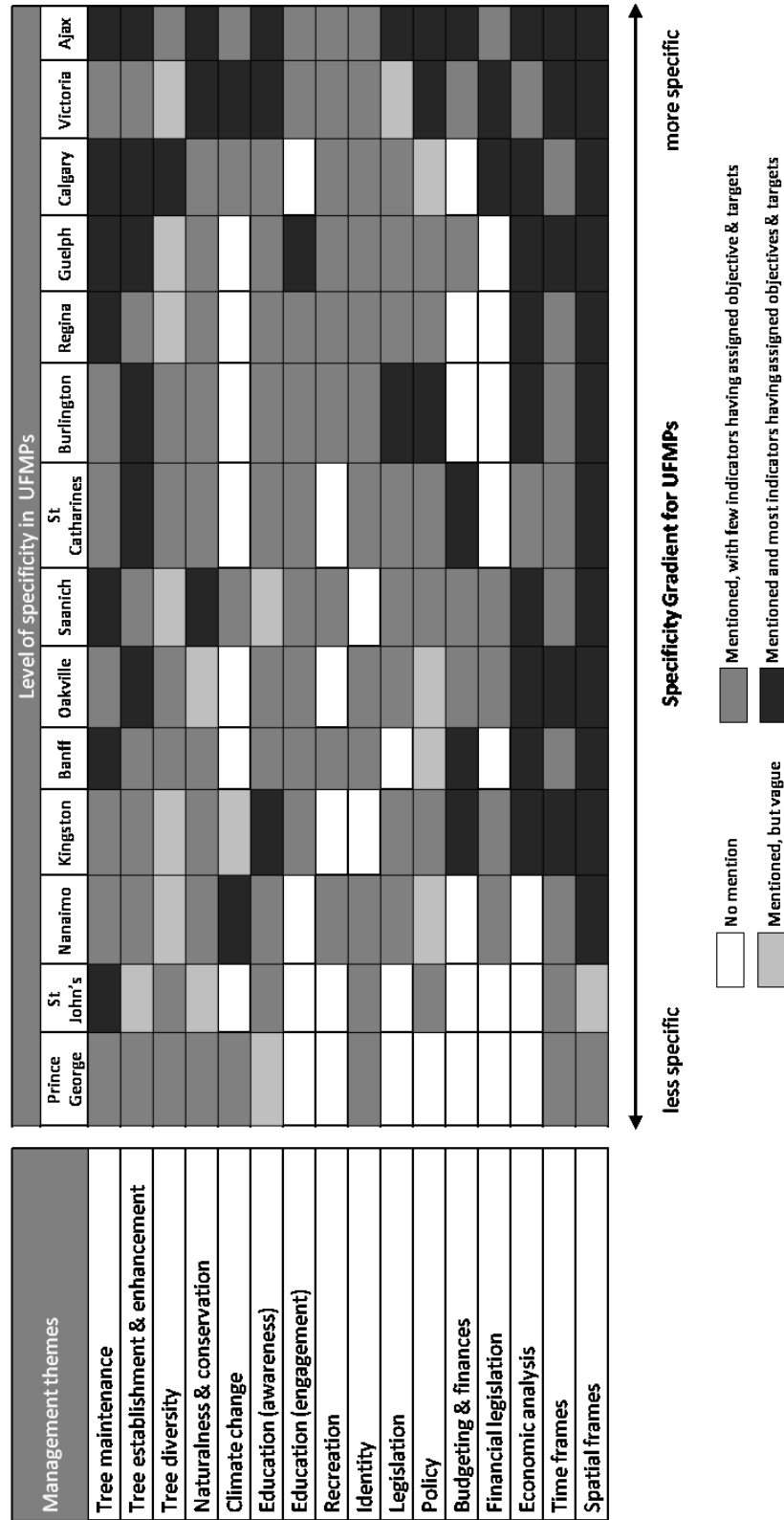


Figure 3.5: Level of specificity of management themes across Canadian UFMPs

## 3.6 Discussion

This analysis has revealed important trends and differences among the plans. A detailed discussion of these in terms of the specific themes and best practices follows a few general observations.

### 3.6.1 *General observations*

This evaluation of Canadian urban forest management is based solely on the information included in the fourteen plans analyzed here. I understand the limitations of extrapolating insights gained here to municipal urban forest programmes, as the specifics of these may or may not be included in the UFMPs. In addition, the character of many plans is not one of a UFMP (Table 3.2). Many plans seem to function more like consultancy documents than municipal ones. This limits how I derive conclusions about Canadian urban forest management from the plans.

The standard I developed was vital for the comparative analysis (Table 3.1). However, it is important to note that the standard itself is rather vague, with most objectives and targets defined generically as “enhance” or “increase”. Because the standard was developed from the most specific examples from the fourteen plans analyzed, its vagueness can only reflect the vagueness of the plans themselves. Specifically, the themes of maintenance, enhancement & establishment, and diversity are well developed, as some of them have numeric indicators. In contrast, the themes of naturalness & conservation and climate change are less precise. Themes in the other clusters are also mostly based on categorical and numerical indicators.

Lack of specificity in the plans may be related to three issues: 1. lack of information; 2. the fact that some indicators may be unquantifiable; and 3. the fact that those who wrote the plans (by default I assume these to be urban forest managers) may not be tuned in to specifying certain criteria. I discuss how these issues interplay in the context of specific themes of management in the next section. Nonetheless, some general observations are useful before I delve into these details.

The first two issues are ultimately related to the quality of inventories. I show how only some plans had comprehensive inventories (i.e. UFORE-type), other have only street tree inventories, and many were not specific (Table 3.2). There is a slight correlation between the most specific plans (Figure 3.5) and those that also had UFORE-type inventories (Table 3.2). A detailed and comprehensive inventory may have allowed some plans to address some management themes more specifically, that is, with numeric indicators. However, this trend does not always hold. According to this qualitative analysis, some municipalities with an UFORE-type inventory rate low in specificity, while others without a specified inventory rate high (Table 3.2; Figure 3.5). Nonetheless, the desire expressed in many plans to develop stricter and more comprehensive inventories (Figure 3.3) may mean that not a lot is formally known and documented about their urban trees, thus restricting the development of more-specific targets.

Lack of tune-in may be related to two factors: the management approach and public input. As for the former, in the introduction to this chapter a common approach to urban forest management was presented based on goals for canopy cover, tree diversity, and tree size. These goals address the most pressing issues about urban forests, such as tree loss and lack of tree diversity, thus increasing their environmental benefits for humans. Tune-in may thus be affected by how urban foresters focus their attention on specific benefits while disregarding others. I will explore the full implications of this observation when I discuss specific themes in the next section.

As for public input, this may create a greater awareness about some issues, particularly social ones, by the professionals who developed the plan. However, many of the plans document low levels of public input (Table 3.2). I do recognize that public input may still be present even if it goes undocumented in the plans, but this is beyond the reach of this study. Regardless, there seems to be no correlation between significant public input (Table 3.2) and a stronger social programme (Figure 3.4). This will also be discussed in the next section.

### 3.6.2 *Specific themes*

The content of the UFMPs reflects the richness of themes and considerations behind urban forest management (Table 3.1). Space dictates that I can discuss here only what I deem the most important themes of management and their trends across the plans (Figures 3.3-3.5).

The environmental/ecological themes of maintenance, enhancement-establishment, and diversity are the most frequently mentioned and specific of all, many containing numeric targets (Table 3.1; Figure 3.3). Therefore, they dominate the content of the plans. It is important to note that numeric targets are ultimately arbitrarily set, as there is no standard as to what, for instance, canopy cover should be for all cities. Regardless, the plans analyzed here have ambitious numeric targets for pruning cycles, tree replacement ratios, canopy cover, tree size (i.e. favouring big trees), and tree diversity at the species level. This reflects that most municipalities have a lower-than-desired level of maintenance, canopy cover, and diversity. It also demonstrates how tree loss and dominance of a few tree species characterizes most urban forests in Canada (Kenney & Idziak, 2000; Millward & Sabir, 2010). However, tree diversity only achieves a level of specificity at the species level. There are no numeric targets assigned for nativeness or age-classes, among other diversity criteria (Table 3.1; Figure 3.3).

As mentioned above, vagueness may be due to a lack of information, unquantifiable indicators, or lack of tune-in on the part of managers. A lack of information may not be the reason, since UFORE-type inventories may have provided enough information for at least some plans to add more numeric-based indicators (Table 3.1). In addition, while some indicators may be deemed unquantifiable (e.g. encouraging BMPs), others may very easily become numeric (e.g. define minimum soil volume and nutrient content). Therefore, lack of tune-in may be a more indicative factor. I elaborate on this idea below with examples from criteria from the naturalness & conservation and climate change themes.

The themes of naturalness & conservation and climate change receive less attention in the plans, in that they are not assigned specific objectives and numeric targets and are not frequently discussed (Table 3.1; Figure 3.3). This vagueness contradicts the importance of upholding ecological principles (Zipperer, 2008), fulfilling the urban forest values of wildlife habitat and nature conservation (Dunster, 1998), and addressing climate change (Yang, 2009; Johnston, 2004). Evidence suggests that vagueness may not be related to lack of information. For example, those municipalities with UFORE-type inventories also undertook UFORE studies, which assess carbon sequestration. This assessment may inform the development of specific climate mitigation targets. They also may provide information for developing multi-scale treatment and addressing naturalness. Multi-scale treatment is intuitively related to naturalness, since the principle recognizes the fragmented character of urban forest habitats and the need to devise differentiated targets for each, such as natural regeneration targets for naturalized areas (Millward et al., 2011). Regardless, few plans address naturalness or climate change in any significant way (Table 3.1; Figure 3.3). This contrasts with the fact that many municipalities pay homage to climate change and multi-scale treatment as management principles (Table 3.3).

This leaves me with lack of tune-in to explain such vagueness. Tune-in may be related to the fundamental issue of the management approach, as discussed in an earlier section. Since the themes of naturalness and climate change have less-tangible human benefits, and if the plans have an approach focused on increasing these, then this may explain why they have stronger specification in areas of maintenance, enhancement, and diversity at the species level, but less in areas of naturalness, climate change, and other tree-diversity criteria. In fact, many North-American municipalities have streamlined the argument of improving environmental benefits through urban forest management in order to address issues of urban living and human health (Seamans, 2012). In this approach to urban forest management, many ecological and climate issues remain fringe arguments. However, it is important to note that, as the UFMP analysis shows, most Canadian municipalities are concerned about naturalness and climate change as they apply to urban forests, but they have not found ways to be specific about these issues.

Additionally, I have argued how lack of tune-in may also be related to public input. It would be intuitive to think that municipalities that had initial public input are also those with a broader set of public values and stronger community programmes. However, there is no correlation in the data to demonstrate that. Many plans that mention public input have weak education components, while others that do not mention such input have strong ones (Table 3.2; Figure 3.4). Few, like Victoria, have both. As with the environmental/ecological themes, tune-in may be more influenced by the management approach than by public input. This becomes evident when discussing education, the dominant theme in the social cluster.

The division of education into two themes, awareness and engagement, implies that an education programme can have two streams: seeking the legitimacy of the urban forest programme, and motivating the community to get involved. While communication issues are the most commonly-shared and specific across plans, neither criterion under engagement is specific about targets (Table 3.1; Figure 3.4). Since these criteria serve to complete ambitious tree-planting schemes, specific targets could easily be achieved here by, for example, specifying the number of trees to be planted by these programmes. This is crucial, since enhancing the urban forest means addressing its problems and greater quantities of tree-related benefits. However, there is no indication here about tree distribution. Tree distribution is a complementary issue, as it expresses accessibility and equity (Pham et al., 2013; Heynen et al., 2006; see also Chapter 2). Yet, accessibility is only recognized by two plans as a management principle (Table 3.3). This is unfortunate, as increasing plantings does not necessarily mean that those trees will be planted where they are needed the most. It could be said that many plans wish to fulfill social values serendipitously by focusing on a planting approach to management. Even then, the idea of engaging the public still lacks specificity in many cases. In fact, the only social criterion that is assigned a numeric-based indicator is historic/heritage trees (Table 3.1), but it is not a common theme across plans (Figure 3.4).

Lack of specificity is also a characteristic of the political-administrative and economic clusters. The first cluster is dominated by the themes of adopting green infrastructure

terminology and creating private-tree protection bylaws and policies (Figure 3.4). These themes point to command-and-control type of regulations. This is because considering trees as infrastructure implies they are urban necessities, for which the municipality should be responsible (Nowak, 2006), and adopting bylaws and policies for private lands is an obvious way to regulate tree loss directly (Troy et al., 2007). However, some are skeptical about the efficiency and effectiveness of tree bylaws, since much effort is directed towards protecting trees and results can be mixed (Conway & Urbani, 2007).

For many municipalities, it seems better to regulate negative behaviours than to motivate positive ones; that is, cutting a tree is prohibited and penalized, but planting or protecting one is not tangibly encouraged. Yet the more positive approach of fostering stewardship through incentives, which falls under the economic cluster, is only advocated by a few plans and has no numeric indicators. In fact, all economic criteria remain unspecified, despite the fact that economic components are theoretically more tangible, as they are measured in dollar values, and that all UFMPs recognize that urban forests contribute to economic development (Table 3.3). Lack of information may explain this vagueness for some plans, since the only economic valuation tool that is prominently mentioned by some UFMPs is the UFORE study, and most plans are only at the stage where they wish to undertake more economic analysis. Nevertheless, lack of tune-in for integrating economic issues into urban forest management may also explain this vagueness. This is supported by the fact that urban forest values such as timber, food, and tourism (McPherson & Simpson, 2002; Clark & Nicholas, 2013) are not mentioned in any of the plans (Table 3.1).

Finally, vagueness in the plans can be approached by a strong adaptive management scheme, which is in fact frequently mentioned as a principle (Table 3.3). Although adaptive management can be simply seen as management that adapts to new circumstances, some see this as a shallow interpretation (Duinker & Trevisan, 2003). Rather, the concept refers to the integration of uncertainty and change into management by devising learning processes based on monitoring activities that in turn feedback not just into the management actions but also into the basic assumptions and values of the



management model (Holling, 1978). Adaptive management is then crucial for experimenting with uncertain components, such as nativeness, naturalness, climate change, community stewardship, public input, tree incentives, and use of economic instruments. However, no plan applies adaptive management to address the vagueness of these themes.

### *3.6.3 Best practices*

This analytical exercise leaves open the question of what is the best way to manage the urban forest. However, the standard developed with the information from the UFMPs (Table 3.1) gives us a starting ground to answer this. I draw out a suite of urban-forest best management practices (BMPs) based on UFMP information (Table 3.4).

The BMPs list by no means represents an intention to advocate for particular practices, but rather to filter out the most useful information from this analysis. I recognize that some BMPs will not apply to some municipalities (e.g. fire programmes). Other disagreements on the list may be based on arbitrariness, cost-efficiency, or value trade-off. Suggested canopy-cover, tree-diversity, replacement, nativeness, and climate adaptation targets may be contended. For instance, canopy-cover and tree-diversity targets depend on the current urban forest structure and plantable spots available. Nativeness varies geographically, and genetic specificities may be different even within the same species. Planting southern tree species as an adaptation measure for climate change may lead to phenological complications that must be considered (Park & Talbot, 2012). Targets are arbitrarily set by a municipality, and it is up to it to determine which one fits best to its reality. What is given here is merely what is found to be most common, specific, and ambitious in the 14 UFMPs analysed.

I believe that developing a BMP list is useful in several ways. It builds upon existing criteria-and-indicator frameworks of urban forest management found in the literature (e.g. Clark et al., 1997; Kenney et al., 2011). It also draws attention to elusive areas of urban forest management (e.g. climate change) by pointing out how other municipalities are

addressing them. It is clear that some management themes, such as tree maintenance, or green infrastructure terminology, are concrete and have practical applications. Because of this, they are also shared by many UFMPs and leave little space for improvement. In contrast, nativeness, forest-like planting, climate adaptation, multi-scale treatment, and using economic themes as management indicators, among other issues, need more attention and specificity in the future. Most of these are not new ideas, but urban forest management could benefit from their further exploration and implementation

*Table 3.4: Urban forest best management practices (BMPs) as based on content of Canadian UFMPs*

<i>Management theme</i>	<i>Criteria</i>	<i>Objectives &amp; targets (most specific or ambitious example)</i>
Tree Maintenance	Pruning, removal & monitoring	2-5 year pruning cycles, 1:1 tree replacement ratio; tree removal specifications and monitoring; integrated pest management
	Databases	Stricter, more comprehensive, and GIS-based tree inventories
	Tree damage	Use of less-toxic de-icing salt; define maximum-distance-from-tree for near-tree operations
	Natural disasters	Increase maintenance; increase response and recovery time
	Fires	Implement a fire programme based on: vulnerability assessment, fire-proofing, response time, and monitoring
Planting & Ecological	Canopy-cover	Increase canopy cover to 20-40% of urban area over 20 years
	Species diversity	Maximum representation of 15% per species
	Nativeness & naturalness	Increase natives, species-at-risk, and forest-like plantings
Climate Change	Carbon sequestration	Offset 0.5% of city emissions, increase carbon storage by 2% over 10 years; create a carbon credit system
	Climate adaptation	Increase native species, invasives control, plantings, and southern species
Social and Educational	Engagement	Enhance volunteer planting, planting workshops, and seed-giveaways, create volunteer and communications-officer positions
	Awareness	Seek partnerships to create formal or informal courses/workshops
	Identity	Identify, maintain and monitor heritage trees
Policy, Legislation and Administration	Terminology	Refer to trees in public documentation as green infrastructure
	Coordination & cooperation	Identify common goals with stakeholders, create tree-protection policies (private & developments)
	Public participation	Enhance public input; establish broad stakeholder steering committees
Economics	Finances & Analysis	Identify implementation costs; seek further financial support; create planting incentives
	Analysis	Undertake UFORE/iTree analysis
Temporal-Spatial	Time frames	Set UFMP time frame to 60 years; define reporting/monitoring time frames
	Spatial frames	Assume continuity of resource (private & public trees); define multi-scale treatments

### 3.7 Implications

The sound management of Canadian urban forests is determined by how we conceive their respective futures. The analysis above reveals that UFMPs in Canada are concerned with managing the services/benefits of the urban forest and regulating through the de-incentivizing negative practices rather than incentivizing positive practices. This connects to the set of values that so far defines urban forest values literature (Chapter 2) and urban forest management, which in turn relies on six main goals: 1.) technical maintenance of trees; 2.) enhancement of canopy cover (or leaf area; see (Kenney, 2008); 3.) information-based communication programmes; 4.) municipally-organized planting schemes; 5.) private tree bylaw development; and 6.) seeking adequate funding.

These set of goals and the set of values on which they are based can be seen as the reigning management paradigm. Most urban forest management frameworks are influenced by this paradigm (see Clark et al., 1997; Dwyer et al., 2003; Nowak, 2006; Kenney et al., 2011; Dobbs et al., 2011; Escobedo et al., 2011; Seamans, 2012; Jim, 2013; Young, 2013). Undeniably, the paradigm helps us advance our understanding of urban forest services, but on its own it does not provide a comprehensive direction for urban forest management. The paradigm has a simplified notion of urban forest ecology, a limited understanding of the priorities of the citizenry (Chapter 2), short-term planning horizons, and lacks operational detail to bring many social and ecological management themes into practice. The paradigm also seems to centre urban forest management on formal institutions, conceived as a set of formal entities and rules (Mincey et al., 2013), hindering governance structures that can promote local community stewardship (e.g. Lawrence et al., 2013; Molin & Konijnendijk, 2014). This is crucial given that half of the urban forest is, at least in North America, in private hands (see Background section in this chapter).

The analysis of UFMPs points out to how some municipalities are adopting a values-based paradigm (e.g. Nanaimo, Calgary, and Victoria) and consequently have stronger ecological and social considerations and longer planning horizons. Other Canadian

UFMPs not included in this analysis have recently shown some adherence to this notion (e.g. HRM, 2012)). However, a persistent shortcoming is the lack of systematic probing of the citizenry (e.g. Table 3.2). Private stewardship is also vague, with municipalities (e.g. Nanaimo, Regina, Saanich, and Victoria) only suggesting the possibility of preserving and planting trees through incentives, while specific actions remain unspecified. Certainly, this move will depend on the development of a strong community framework that includes fostering stewardship in the community (Wolf & Kruger, 2012; Molin & Konijnendijk, 2014) and new governance structures (Lawrence et al., 2013). Working out the specifics of this new paradigm is crucial to help manage urban forests better.

The idea of referring to the reigning direction and the values-based direction of urban forest management as paradigms helps us interpret what managers are considering important about urban forests. The idea is not to invalidate the services perspective and impose a values one, but rather to demonstrate that different paradigms address different urban forest values. Ultimately, both the services and values perspectives are useful in different ways, and combining them is necessary to direct management in multi-directional ways and achieve sustainability of the resource.

In light of this exploration of Canadian urban forest management, the question remains of how urban forests are being managed elsewhere. Of course, this goes beyond the scope of this dissertation given the choice of case studies (Chapter 1). However, a few ideas can merge with a brief exploration of the literature. Firstly, most urban forest literature comes from Europe and North America (Chapter 2; see also Roy et al., 2012). In general, European urban forest management is not geared towards canopy cover and tree diversity as the North American one, probably because it is so close to the rural forestry tradition, where human uses such as recreation, aesthetics, and timber harvest seem more important (e.g. Rydberg & Falck, 2000). Nevertheless, European urban forest management has been evolving and many cities go beyond these narrow set of values (e.g. Ottitsch & Krott, 2005; Lawrence et al., 2013). Whether this is indicative of a merging of European and North-American styles is still unclear. A systematic comparison of urban forest

programmes in Europe and North-America will be an interesting research direction for future studies.

The development of an international perspective, one that spans the rest of the world, is an even more interesting venture. Increase in the urban demographic in the developing world is recent (UN-HABITAT, 2012) and urban forest management there has probably not reached the level of maturity as elsewhere. Nevertheless, some authors point out how urban forest values in these environments differ. For instance, food security (Kuchelmeister, 2000; Cilliers et al., 2013), soil erosion (Uribe-Botero, 1998), and biodiversity conservation (Andrade et al., 2013), may all be more important concerns in the cities of the global south than in Europe or North America. Nevertheless, empirical evidence is needed to understand the basis of these views and if such services are desired by the citizenry and whether they are being provided. Moreover, many assume that the difference in urban forest structure among cities is what ultimately determines different paths of management, but in reality there are more similarities than differences in urban forests worldwide. Similar problems, such as tree loss, changing development patterns, invasive species, insects and diseases, lack of diversity, loss of nativeness, and lack of community engagement affect all urban forests. A broad but limited review of the literature demonstrates that this is the case in African (Seburanga et al., 2013), Asian, including Chinese (Jim & Liu, 2001; Yang et al., 2005; Chen & Wang, 2013) and Indian (Prasad & Badarinath, 2004; Dwivedi et al., 2009; Muthulingam & Thangavel, 2012), and Latin-American (Molina-Prieto, 2007; Molina-Prieto & Vargas-Gómez, 2012; Andrade et al., 2013) cities.

All in all, an international perspective on urban forest management is crucial for developing customized solutions while learning from each other. One of the first steps is to develop a cross-national and cultural understanding of how urban forests are valued by the public at a deeper level. I will address this issue in the next two chapters by presenting original research in Colombia and relating it to similar studies done in Canada.

### **3.8 Summary**

I have explored Canadian urban forest management in this chapter by analyzing the content of the 14 available urban forest management plans (UFMPs). Analysis of this documentation indicates that management would be significantly improved by overcoming the lack of detail in ecological, social, and economic management themes, which refer to components such as nativeness, naturalness, climate change, community stewardship, public participation, and use of economic incentives. I demonstrated how failure to address the themes may be related to the reigning paradigm in urban forest management fixed on enhancing/optimizing urban forest services/benefits, rather than satisfying a broad set of values, and regulating and penalizing negative behaviour, rather than incentivizing positive stewardship. I have pointed to the need of a paradigms interpretation to understand how a values-based framework embraces a broader set of values than the one currently directing urban forest management. In addition, a deeper understanding of urban forest management as a learning process may compensate for vagueness, thus calling for strong implementation of adaptive management. While the specifics of these issues remain to be worked out for each urban forest, there is considerable interest in addressing these issues as my analysis demonstrates. There is indication that some municipalities in Canada are starting to direct urban forest management under a values framework, yet there is still some progress to be made to advance this idea. This study sets a benchmark for future explorations into urban forest management such as comparing approaches across North-American cities and the world. An international perspective on urban forest management ultimately depends in understanding urban forest values in their broader context by probing the citizenry with adequate methods and across national boundaries. This is the topic of the next two chapters.

## **4 Chapter 4: Urban Forest Values in Colombia – A Case Study**

### **4.1 Publication Information**

This chapter is based in the following publication led by me and co-authored by Peter Duinker, with some added content (section 4.2, Introduction)

Ordóñez, C., Duinker, P. (2014) Urban forest values of the citizenry in three Colombian cities. *Society & Natural Resources*. Accepted 24-Jul-2013.

### **4.2 Introduction**

In an urban world, people's relationship with urban nature is important. In Chapter 2 I discussed how exploring the way people relate to their urban forest through the concept of values helps us to understand this relationship in a deeper way. This requires an exploration unconstrained by traditional methods. Among the most common methods to elicit urban forest values we find phone or mail surveys and questionnaires delivered at home (e.g. Schroeder & Ruffolo, 1996; Chiesura, 2004; Johnston & Shimada, 2004; Lohr et al., 2004; Schroeder et al., 2006; Tyrväinen et al., 2007; Coles et al., 2013; see also Chapter 2). These methods depend heavily on people's availability and willingness to respond, capture little depth about people's connection with the urban forest, and may be susceptible to producing inadequate socio-demographic profiles (Chapter 2). Although visual elicitation (e.g. Tyrväinen et al., 2003) addresses some of these shortcomings, such studies do not embrace the urban forest as all the trees in the city. Public interception surveys have also been used effectively in the evaluation of green spaces (e.g. Chiesura, 2004; Coles et al., 2013), but there is not a focus on trees or other urban forests spaces besides parks or street trees. Thus, the urban forest values of the citizenry have not been adequately elicited with these research methods. Innovative methods rooted in an experience of urban trees in a diversity of sites and with open questions are rare in urban forest values research (Chapter 2).



Although this dissertation focuses on urban forest values and their management in Canada and the influence that climate vulnerability has on the provision of these values (Chapter 1), using an alternative case study to compare and contrast research undertaken on public values associated with urban forests is crucial to strengthen any insights to be gained in this field. The urban forest reality in Colombia, although determined by different socio-economic and cultural dynamics, is not that different if seen from urban demographic and urban forest management perspectives.

First, the demographic profile of Canada and Colombia is overwhelmingly urban, with more than 80% of the Canadian population concentrated in cities (Statistics Canada, 2006) and almost 75% of the Colombian one (DANE, 2009). Moreover, as with Canadian cities (Chapter 3), Colombian urban forest management had a long tradition of responding to the aesthetic and environmental benefits of trees and the problems of growing trees in the city. However, in contrast to Canada, food provision for the poor was an important consideration in urban tree planting in many Colombian cities, as has been exemplified for many developing countries (e.g. Kuchelmeister, 2000), and an example of this is the predominance of mango trees in many such cities (Molina-Prieto, 2007). Other management strategies have recently included soil erosion (Uribe-Botero, 1998) and biodiversity conservation (Andrade et al., 2013) as important considerations.

In general, there are more similarities than differences in urban forest issues between Canadian and Colombian cities. Similar urban forest problems affect these cities, such as tree loss, changing development patterns, invasive species, insects and diseases, lack of diversity, loss of nativeness, and lack of community engagement in their management. For instance, urban encroachment is affecting urban nature biodiversity in Bogotá (Andrade et al., 2013). Emerging diseases have the potential to destroy many of the trees of the dominant species in some cities (e.g. Urapán trees in Bogotá; Filgueira et al., 2004). Almost 50% of the tree species in many cities are non-native (e.g. Bogotá; JBB-SDA, 2010). Lack of public participation in urban forest management decisions in Colombia affects environmental justice in many cities (Cobo, 1998). Finally, many cities

in Colombia lack a strategic vision for the management of their urban forests (Molina-Prieto & Vargas-Gómez, 2012).

All in all, the Colombian context provides an excellent case study to explore public values associated with the urban forest, and it serves as a comparative and contrasting case study to explorations that have been already undertaken in Canada and that inform this dissertation (see Chapter 5). These case studies, both different in ecological and social characteristics, enhance the relevance of the study and provide a more comprehensive understanding of what urban citizens value about urban trees, and provide a broader basis to develop a more universal public value typology related to urban forests (see Chapter 5).

This chapter presents original research for understanding urban forest values in three Colombian cities. The following sections detail the methods used and the results obtained. A final section discusses the results in the context of the literature and draws insights about how the Colombian citizenry values urban forests.

### **4.3 Methods**

Urban forest values were explored in the Colombian cities of Bogotá, Cali, and Pereira. All cities have different demographic and ecological qualities (Table 4.1). The data collection was done through field tours, diaries, and focus groups over a period of six months starting in November 2011 and ending in May 2012.

The method imitates that presented by Peckham et al. (2013) which is based on Owen et al. (2009). Both this and the earlier studies are interested in developing a value typology based on a deep understanding of how people value the urban forest, not on making statistical inferences about how the Colombian population values the urban forest. As such, it was open to all adults and geared towards people who have an interest in the urban forest. However, some demographic data were collected in order to put the information into the context of participant characteristics.

As with Peckham et al. (2013), participant selection was based on willingness to participate and open to any adult. Recruitment was done through posters and flyers in public spaces (e.g. markets, parks, libraries, universities, cultural centres, and government buildings), radio announcements, and direct email invitations to organizations and institutions. The tour involved visiting five urban forest types (Table 4.1). During the tour, participants filled out a diary divided in two sections. The first section was filled at the beginning of the day, before any visit to the sites, and included a short survey to capture more information about the participants' recruitment, interest in ecology and formal ecological knowledge, as well as an initial set of questions about what participants considered important about the urban forest in their city. The second section was filled during the visits to the sites and worked as a semi-structured interview with questions about what the place made participants feel and think. As the researcher, I did not interfere with participants during the tour. At the end, participants took part in an audio-recorded, one-hour-long focus group. I moderated the event by facilitating discussion and asking questions from a set of questions based on the diary, allowing participants to explore their meaning collaboratively. Lunch was provided as an incentive in participant recruitment.

Diaries and focus-group recordings were transcribed and analyzed through codification and theme extraction using qualitative software N-Vivo (10). The analysis was all undertaken in Spanish. Interpretative analysis was grounded-theory-based. This method allowed extracting values in a systematic way by discovering concepts and themes with the use of constant comparative analysis until saturation was reached (Glaser & Strauss, 1967), taking into consideration the frequency of ideas (Corbin & Strauss, 1990; Strauss & Corbin, 1997; Corbin & Strauss, 2007) but not of terms, as in content analysis. Final results were then translated to English.

*Table 4.1: Selected urban forest sites*

<i>Urban forest type</i>	<i>Brief description</i> <sup>1</sup>	<i>Bogotá</i>	<i>Cali</i>	<i>Pereira</i>
Urban park	Historic (>30 years), downtown park for recreational use, with concrete paths, and few young and old trees	Nacional Park	Perro Park	Olaya Park
Commercial street	Scattered old or young trees on a busy street	Séptima street	Quinta street	Circunvarar street
Tree-lined residential street	Scattered old trees in a quiet, old (>50 years), neighbourhood street	Teusaquillo	El Peñón	Álamos
Recreational sport park	Park for sport use, with open spaces, some concrete/gravel paths, and few young and old trees	El Salitre Park (+wetland) <sup>2</sup>	Río Cali	El Vergel Park
Densely forested park	Densely forested, naturalized park or conservation area dominated by diverse and native trees of many ages	Botanical Gardens	Botanical Gardens	Botanical Gardens

<sup>1</sup> Except for the botanical gardens, there is a high representation of non-native species in these three urban forests (>50%, e.g. Bogotá, JBB-SDA 2010).

<sup>2</sup> El Salitre park in Bogotá included all the features described for the recreational sport park but it also included a wetland conservation area.

#### **4.4 Results**

Twelve, one-day field trips of 3-11 people were undertaken in Bogotá, Pereira, and Cali with a total of 72 participants. Demographic trends were similar for each city and amalgamated. The sample was dominated by young (80% are < 39 years), student or professional (40% and 30%, respectively), urban residents (90%), with a slight tendency for participants to be women (60%).

Additional information about the participants and the recruitment process was obtained with the initial survey. More than half of the participants had or were pursuing a university degree. 50% of all participants declared knowledge of the activity through friends (i.e. snowballing), 20% through posters and flyers, and 15% through email invitations. Less than 20% declared belonging to an NGO. In contrast, the vast majority (>80%) demonstrated an interest in ecological issues, spending time in nature, and feeling

connected with nature. However, this same amount declared a low level of formal ecological knowledge.

The combination of methods (diary and focus group) allowed me to capture a wealth of data from personal and collaborative reflections. The first priority of the analysis was to extract the essence of this information through coding and clustering. These allowed me to identify a comprehensive array of urban forest value descriptors (Table 4.2). To facilitate analysis, frequency-of-mention and cluster categories were built. Approximately 150 codes and eight clusters were identified (Figure 4.1). Codes of only one mention were eliminated. In terms of individual codes, the four most frequent codes by far (>200 mentions) were “tranquility-calmness”, “air quality”, “habitat (animals)”, and “education-learning”. The psychological, aesthetic, socio-cultural, and natural/ecological value clusters are the strongest in terms of richness (Figure 4.1) and frequency-of-mention (Figure 4.2).

The second priority of the analysis was to explore the patterns between methods (Figure 4.2). The data analysis discriminated according to pre-tour/post-tour (i.e. the initial set of questions vs. the diary questions for the site visits and the focus group) and diary/focus group coding. Differentiating the results between individual participant and individual city group was not the goal, so no effort was taken to discriminate codes according to participant and/or city. Pre-tour coding was dominated by environmental and psychological themes, while post-tour coding had no clear dominance, although psychological, aesthetic, natural/ecological, and socio-cultural themes are more frequently mentioned (Figure 4.2). Descriptors seem to have been more frequently elicited through the diary than with the focus group (Figure 4.2), although two extreme cases exist: most psychological descriptors were elicited through the diary method and socio-cultural ones are almost evenly split (Figure 4.2).

Table 4.2: Coding and clustering examples

Example	Quote <sup>1</sup>	Codes	Cluster(s)
1	<i>“Oxygen and breathing”</i>	Oxygen Air quality	Environmental
2	<i>“Sense of well-being, shade, less noise, enjoyment of colours and smells.”</i>	Well-being	Psychological
		Shade Sound barrier/blockage	Environmental
		Colours Smells	Aesthetic
3	<i>“Here I feel calm, tranquil, unstressed, I forget my problems, I feel comfortable with the sound of the birds, with the wind on my face, and the relaxing view of the trees. I feel happy!”</i>	Tranquility/calmness Forget worries Relaxation Happiness	Psychological
		Sounds (birds) Natural/pleasant views	Aesthetic
		Less stress / nervousness	Health
		Harmony, equilibrium Sounds Big and old tree Natural forms (trunks) Connection of tree with urban space (fountain)	Aesthetic
4	<i>“It is a small place, with few trees surrounded by buildings that conserve big and beautiful trunks of what seemed to have been very big trees, which are now covered by very different vegetation. There’s a tall and straight one, there’s another broad and dense one, and both fit very well with the palm trees for their height and straightness. The fountain creates the sound of water that drowns the noise from cars. It is a very pleasant place, despite its size.”</i>	Diversity of species Connection with natural elements (water)	Natural/ecological
		Sound barrier/blockage	Environmental
5	<i>“I prefer to pay the entrance to the Garden<sup>2</sup> because it is in a better condition and I can see a bigger diversity of plants and animals, so I can feel better, I don’t know. At the other public parks one doesn’t feel so well.”</i>	Well-being	Psychological
		Biodiversity Habitat for fauna (general)	Natural/ecological

<sup>1</sup> Original in Spanish, translation by the first author. Some alterations to the text are included to correct grammatical errors. Ellipses (e.g. ...) are added to indicate deleted text, so focus is given to the essence of the idea.

<sup>2</sup> The participant here refers to the Botanical Garden of Bogotá.

Table 4.2: Coding and clustering examples (continued)

Example	Quote <sup>1</sup>	Codes	Cluster(s)
6	<p><i>“But obviously, if you plant natives, that tree, that individual, is going to fulfill more ecosystem functions: insects are going to go for it, birds will eat form it, etc. If it’s an exotic no, it’s just there. Obviously, it fixes CO<sub>2</sub>, but that’s it, it loses some attributes.”</i></p>	<p>Native trees Habitat fauna (insects, birds)</p>	Natural/ecological
		<p>CO<sub>2</sub> capture</p>	Environmental
7	<p><i>“(…) This city has few places to meet, like the Nacional and the Simón Bolívar park, and there are always more and more people who need a place to play. The dominant social classes have their private clubs and they go play golf on Sundays. But other people need the parks.”</i></p>	<p>Contact with people Spaces for recreation &amp; play Accessibility (public) Equity (for all)</p>	Socio-cultural

<sup>1</sup> Original in Spanish, translation by the first author. Some alterations to the text are included to correct grammatical errors. Ellipses (e.g. …) are added to indicate deleted text, so focus is given to the essence of the idea.

<sup>2</sup> The participant here refers to the Botanical Garden of Bogotá.

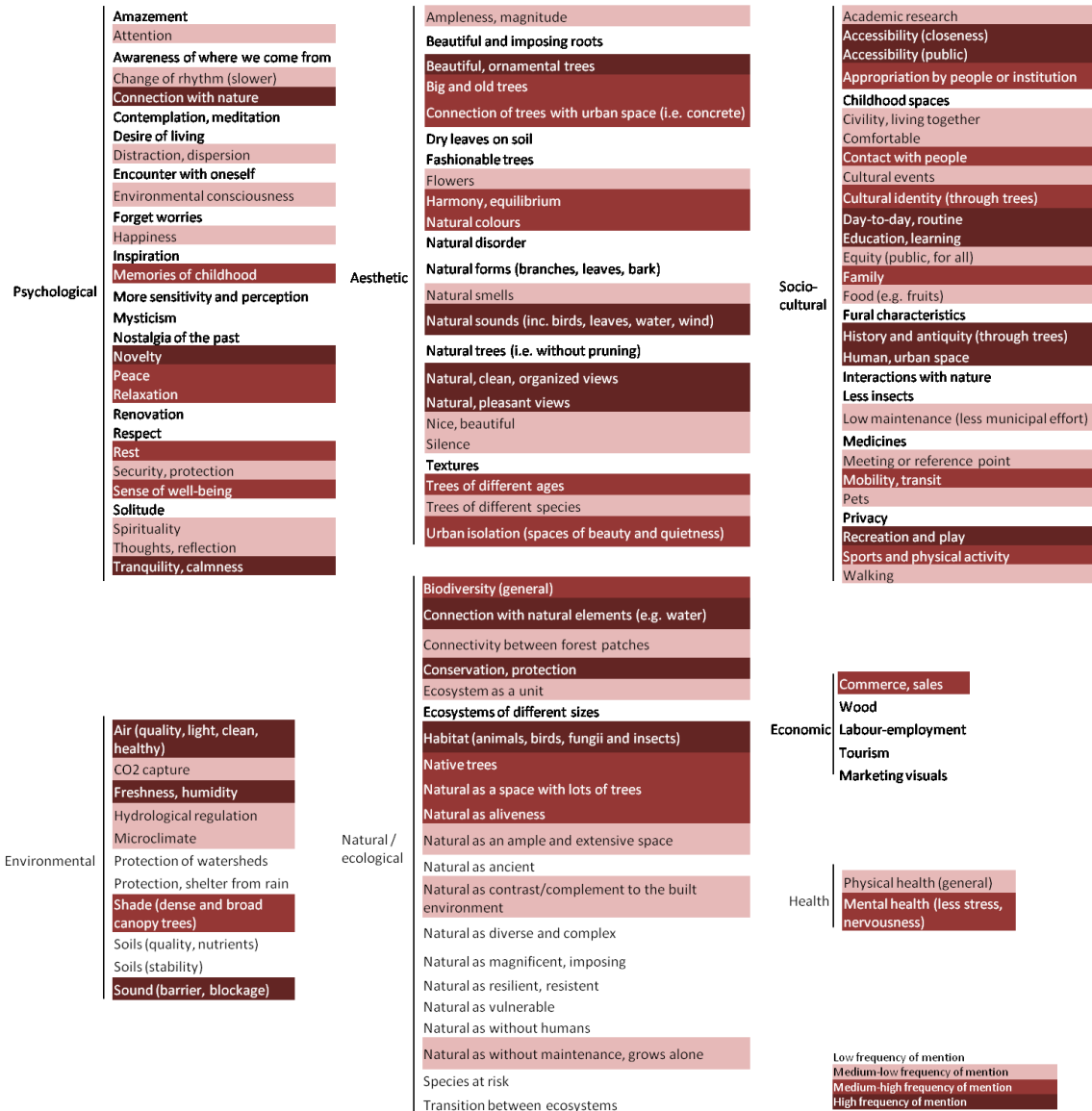


Figure 4.1: Urban forest value themes for Bogotá, Cali, and Pereira by cluster and codes and indicating frequency of mention



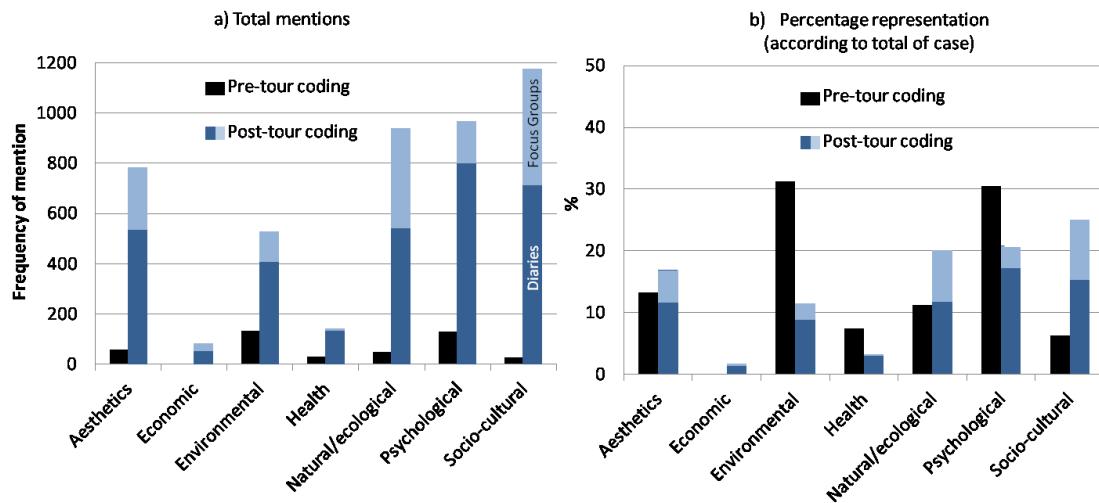


Figure 4.2: Coding clusters results for Bogotá, Cali, and Pereira by (a) frequency of mention and (b) percentage representation. Results are categorized by case (pre and post-tour coding). Post-tour coding results also indicate contribution of method of capture.

## 4.5 Discussion

### 4.5.1 Participants

The participant demographics deserve to be discussed. The sample of participants shows a distinct pattern: young, student or professional, urban residents, with a slight tendency to be women. This bias may be related to the recruitment process. Although the study was open to all adults, and the places selected for posters were diverse, the recruitment method was geared towards people who have an interest in the urban forest. Bias may have been compounded by the fact that snowballing was the most important factor for subsequent recruitment. The self-selection recruitment mechanism seems to favour these demographic patterns. The authors assume that these are also the types of participants who would provide substantial data on these issues. However, different methods could be developed in future studies to obtain different perspectives on the value of urban forests from other urban residents.

Although the sample may seem narrow, it is important to note two things. First, this sample is representative of these kinds of studies (Owen et al., 2009; Sinclair et al., 2014; Peckham et al., 2013), reinforcing the internal validity of the method. Whether this is connected to the notion that young people and women tend to have a more positive attitude towards the environment (Dietz et al., 1998) is a matter of future, complementary, and statistically-significant exploration. Second, some features of this sample represent the wider Colombian context, while others are divergent. As with the sample, the Colombian population is overwhelmingly urban (75.9%) and young (63.9% are <35 years), with more women than men (51.2%) (DANE, 2005). In contrast, where only 10% of the Colombian population has a professional degree and the majority of people are occupied in commerce and services areas (DANE, 2005), my sample is dominated by students or professionals. Again, I do not to assume representativeness based on this sample set.

#### *4.5.2 Urban forest values in general*

Richness, frequency, and interconnectedness are three features of the data that help us understand the results (Figures 4.1 and 4.2). While frequency of mention is straight forward, richness in description reflects the depth and diversity of ideas participants have. Another feature of the data, not evident in my illustrations, is the interconnection of ideas. When expressing a value, participants referred to many descriptors at the same time and intertwined clusters. For instance, in mentioning tranquility/calmness, a participant also refers to happiness, relaxation, visually pleasing view, and pleasant, natural sounds (Table 4.2, example 3), thus encompassing three values clusters at once.

Because of the richness and interconnectedness of the data, discussing each descriptor and each cluster in isolation from the others are both difficult tasks. To facilitate analysis I discuss each cluster category. In so doing, I will discuss both frequent descriptors and

related ones from other clusters in order to make adequate inferences about what the participants were trying to communicate about their urban forest values.

### *4.5.3 Aesthetic values*

The aesthetics cluster is rich in descriptions of the beauty of trees, natural sounds (particularly birds), natural views, trees of large stature, sense of harmony/equilibrium, and urban isolation, among others (Figure 4.1). This richness of aesthetic descriptors has not been found elsewhere in studies about urban forest aesthetics (e.g. Sommer et al., 1990; Chiesura, 2004; Gorman, 2004; Lohr et al., 2004; Schroeder et al., 2006), particularly those about preference of urban tree form that focus strictly on individual trees (e.g. Sommer & Summit, 1995; Sommer, 1997). More importantly, aesthetic descriptors in this study are usually mentioned in reference to the ecological structure of the sites such as species richness and diversity, connections with natural elements, and a sense of unity and complexity, among others (Table 4.2, example 4). Further exploration is needed in urban forest values research regarding the recurrent associations of aesthetics and their natural/ecological connection, since past studies do not refer to the urban forest in the same comprehensive way as I do in this dissertation (Chapter 1). Finally, some aesthetic descriptors suggest that participants' aesthetic sensitivity depends on the contrasting greyscale of the city. This notion of valuing-through-contrast is pointed out by the descriptors of "urban isolation", "connection with urban elements", "natural as complement for the city", among others, which are frequent in the data (Figure 4.1).

### *4.5.4 Psychological values*

Psychological values are expressed mainly through positive feelings (Figure 4.1), ideas that have a strong hedonic meaning. Positive feelings can be classified as self-interest values, as they exist only for the pleasure of the individual (Dietz et al., 2005). The fact that most of the psychological descriptors were elicited through the diary method (Figure 4.2) corroborates this observation.

Hedonic values do not occur alone. These ideas are expressed through aesthetic descriptors, discussed above, and through the participants' positive interpretation of nature. Well-being, for example, is described in the context of biodiversity (i.e. species richness) and habitat quality (Table 4.2, example 5). This corroborates how people's interpretation of biodiversity is usually related to species richness and the connection to other elements of nature, such as water or wildlife (Gyllin & Grahn, 2005).

Moreover, hedonic values may also play a part in health values. According to one example (Table 4.2, example 3), the positive psychological effects of trees, such as feeling less stressed, more rested, and happier, also influence health. The literature recognizes how urban natural environments enhance mental health (e.g. Tzoulas et al., 2007; Mitchell, 2012). In contrast to these studies, these results speak to trees specifically and demonstrate how participants connect health and psychological benefits of the urban forest in their own words.

Positive feelings evoked by the urban forest also draw out spiritual connection. It has been recognized that people give a spiritual meaning to their forest experiences through descriptions of novelty, compatibility, fascination, timelessness, and union (Williams & Harvey, 2001). Although "spiritual" itself is an infrequent code, novelty, amazement, connection with nature, and slowed rhythms are conspicuous (Figure 4.1) and may be used to express these elevated sensations.

Novelty is another prominent psychological descriptor. Novelty may express the human value cluster of openness to change (e.g. Schwartz, 1992) in terms of the positive aspect of seeing new images and landscapes. Participants may be valuing the novelty of the natural experience in contrast to their daily routine. This may imply that the more you do something (i.e. visit natural spaces), the less you may value it, and vice versa. This seems to contradict the basis of place attachment theory (e.g. Ryan, 2005; Budruka et al., 2009), and it is suggested as a matter of future exploration in urban forest values research.

Other positive psychological feelings may be expressing biocentric values. The frequency of descriptors of feeling of belonging and respect may be interplaying with those that describe what natural means to the participants. Nature for them means a place where there is interconnection, life, antiquity, and magnificence (Figure 4.1). Some claim that citizen's descriptions of ecologically sensitive concepts in the urban context are meager (Gyllin and Grahn 2005). It is curious then that this study elicits such rich descriptions of what natural means to the public

#### *4.5.5 Natural/ecological values*

The most-frequent natural/ecological descriptors point to the connection of trees to natural elements and habitat, and to definitions of what natural is: nature as diverse, vulnerable, complete, magnificent, and without humans (Figure 4.1). This seems to corroborate the literature about public opinion of urban natural spaces, whereby people seem to preferred a diversity of natural elements (Nordh & Østby, 2013) although with some management for access (Hofmann et al., 2012).

A significant portion of these descriptors was elicited through the focus groups, more so than other clusters (Figure 4.2). This feature can have two alternative explanations: 1. participants have, collectively, strong ecological concerns; or 2. individuals who are knowledgeable about ecological matters dominated the group discussions. The first alternative cannot be explained based on their education or environmental engagement. Most participants disclosed a low level of formal ecological knowledge or affiliation with environmental NGOs (see section 4.4). Thus, if true, participants were bringing these themes forward collectively. As this is the original purpose of this method, it demonstrates its strength in eliciting urban forest values. Otherwise, attention to natural/ecological themes in focus groups may be related to individual dominance. If true, this is one of the tacit limitations of using focus groups as a way to capture values, as individual narratives may dominate some themes. However, because the analysis does not discriminate according to individual contributions, this may be a conjecture and further research is needed to understand the strengths and weaknesses of focus groups.

#### 4.5.6 *Socio-cultural values*

Socio-cultural themes allow us to explore altruistic values closer. The two main themes here are how higher tree density is related to a higher quality of life, and how equal access to trees implies an equitable society. Participants have the opinion that public forested spaces are popular alternatives for people with less economic solvency to have access to physical and social activities (Figure 4.1). These results agree with the notion that urban green spaces are places of social encounter (Seeland et al., 2009; Peschardt et al., 2012), and recreation and play (Gobster & Westphal, 2004), issues that contribute to quality of life (Sheets & Manzer, 1991). Descriptors such as civility and security reinforce the idea that trees reduce mental fatigue (Kuo, 2003). It is interesting to note that public accessibility and equity are often described in tandem (Table 4.2, example 7), demonstrating, as have others (e.g. Satterfield, 2001; Heynen et al., 2006; Pham et al., 2012), how important it is to achieve equal access to trees in a disparate social context. Quality of life and equity are ethical issues that are ultimately grounded in a strong sense of human altruism.

As with the earlier cluster, the fact that a significant portion of the socio-cultural descriptors was elicited through the focus groups (Figure 4.2) may point to either collective thinking processes or individual dominance. If collective thinking explains this, it demonstrates the strength of this method for allowing participants to express socially sensitive values, although this is only the case in this study. Again, because the data are not discriminated by individual contributions, these ideas require further exploration.

Participants also described how urban forest places generate a sense of identity and reinforce traditionalistic human values. It was not a coincidence that many of the places chosen by the researchers have a historical association. The biggest trees in Bogotá, Cali, and Pereira can be found in old, historic neighbourhoods (Table 4.1). Themes of identity and history suggest a sense of place. Most contributions on place attachment and urban nature have attached it to green spaces (e.g. Budruka et al. 2009; Ryan 2005) but not to

trees, with some exceptions (e.g. Hull et al., 1994; Coles et al., 2013). This study is evidence that trees provide a sense of place as long as they are also embedded in a historical context of the city. In this regard, trees evoke ideas of old age and associate themselves with historic architecture.

Finally, it is curious that provision of basic necessities by the urban forest, such as food (e.g. Kuchelmeister, 2000), are not mentioned so frequently in this study, although urban forest management in Colombia was geared towards food provision for the poor in its early stages (e.g. Uribe-Botero, 1998), evidenced by the dominance of mature mango trees in Colombia's warmer cities (Molina-Prieto, 2007). However, I do recognize the demographic limitations of this study as ways to capture urban forest public values of the urban poor in Colombia.

#### *4.5.7 Environmental values*

Most environmental benefits of the urban forest recognized in the literature were also mentioned by the participants, in particular, air quality regulation (Nowak et al., 2006), microclimate regulation (Rosenfeld et al., 1998), carbon capture (Nowak & Crane, 2002), soil quality regulation (McKinney, 2006), and noise blockage (Islam et al., 2012). Air quality is one of the most-mentioned codes. Participants also mention freshness and shade, which are in turn related to microclimatic regulation. Noise blockage is quite frequently recognized as influencing positive feelings (Table 4.2, examples 2 & 4). These three themes are not unrelated to the particularities of Colombian cities, which are usually affected by high temperatures, solar radiation, levels of air pollution, and noise, mostly due to chaotic motor traffic. However, the participants may have been especially sensitive to these, given that the field tours happened at a time of day when it was particularly sunny and hot.

The discrimination of the data in pre-tour and post-tour coding gives interesting insights about this cluster. The environmental and psychological clusters dominate the initial, or pre-tour, questions (Figure 4.2). While these descriptors are still frequent in the coding of

the second section of the diary and in the focus groups (post-tour coding), the environmental cluster does not dominate so clearly, while the psychological cluster remains as important. This discrepancy between pre- and post-tour dominance of the environmental cluster may be caused by the characteristics of the method. Pre-tour coding captured the thoughts of participants at the start of the day. Here they may have initially assumed that the activity intends to measure their environmental attitude or knowledge. As the tour happens, and participants have a direct experience with the trees, they express themselves in more intimate ways, with deeper thoughts and feelings, rather than just reacting to open questions about what they consider important about urban trees. Therefore, they can express a broader set of values, reducing the relative importance of the environmental ones. This contrast demonstrates the strengths of combining methods to capture a diverse range of urban forest values.

#### *4.5.8 Economic values*

Finally, although economic values are quite frequently studied in the urban forest literature, these are not one of the top concerns for the participants. Most of the literature on economic valuation of urban forests focuses on how trees contribute to increased property values (e.g. Donovan & Butry, 2010) and the valuation of environmental services (e.g. Tyrväinen, 2001). However, here participants describe the economic value of trees mostly in terms of commerce and sales, as street vendors are a common characteristic of public parks in Colombia. Although the link between urban forests and commercial activities exists (e.g. Wolf, 2003), many of these studies occur in places where informal economic activity is uncommon. Informal economic activity in forested areas is typical of Colombia and many Latin-American cities. The results here suggest that these may be a particularity of Latin-American urban forest values. However, further evidence is needed to develop a hypothesis in this regard.

## **4.6 Summary**

In this chapter I have presented my own work on Colombian urban forest values. The results demonstrate that people value the urban forest because of a diverse, rich, and



interconnected set of reasons related to psychological, socio-cultural, aesthetic, natural/ecological, health, environmental, and economic themes. The Colombian public gives more weight to psychological, socio-cultural, aesthetic, and natural/ecological descriptors than to the economic and environmental ones. However, discrete environmental descriptors such as air quality and shade are high in people's minds.

Here I discussed how the application of new methods is necessary to understand why people value trees at a deeper level. However, these results are not without limitations, and further research is still needed to complete the understanding of urban forest values initiated here. In the next chapter I combine the information from studies related to mine and develop a typology for public values in urban forests.

## **5 Chapter 5: Public Values in Urban Forests and their Management: A Typology of Values Integrating of Values Elicited in Canada and Colombia and its Implication for Urban Forest Management**

### **5.1 Introduction**

This chapter presents a typology of urban forest values of the public based on an integration of my own study in Colombia (Chapter 4) and related studies carried out in Canadian cities, chiefly Sinclair et al. (2014) (based on Diduck, 2012), Peckham et al. (2013), and Ordóñez et al. (2014). These studies are used for they are based on the same conceptual platform of ecosystem values as this thesis and use similar or complementary methodologies. The typology identifies the types of urban forest values that belong to the public or citizenry and their relative importance. The typology is useful for future theory development regarding public values in relation to urban forests in particular and urban nature in general.

The chapter is divided in three sections. The first section presents the methods and results of the related studies in Canada. A second section draws comparisons and differences between the Canadian and Colombian studies and presents and integrated and consistent urban forest values typology. Limitations in terms of demographics, sample space, and language are discussed. Implications for urban forest management are evaluated in a third section.

### **5.2 Urban Forest Public Values in Canada – Methods and Results**

#### *5.2.1 Qualitative Studies*

The relevant pieces for discussion in this section are Peckham et al. (2013) and Sinclair et al. (2014). The methods used in these two studies are the same as those in my own Colombian study. These are explained in detail in section 4.3.

The results of the two studies were similar to mine (Chapter 4). The participants in Pechkam et al. (2013), a total of 89, were characterized by being young (39% are < 31 years, and 28% more are <45 years), educated (63% held at least one university degree), with a slight tendency to be women (53%). The participants in Sinclair et al. (2014), a total of 24, were also young (>50% are 25-35years), educated (approx. 60% held at least one university degree), with a slight tendency to be women (58%). All of the participants in these two studies were urban residents. Most respondents in both studies (68%) heard about the project through a friend.

The values information from both studies were extracted and presented in a similar way as the Colombian results in the previous chapter (Figures 4.1 & 4.2). It is useful to note that the frequency-of-mention categories for both studies were built under a different criterion from those in my own study. For instance, in terms of individual codes, a high frequency of mention in Pechkam et al. (2013) is based on >100 mentions, a category which includes descriptors such as “naturalness”, “recreation”, “variety of form”, “tranquility”, and codes associated with sounds (Figure 5.1). In Sinclair et al. (2014), a high frequency of mention is based on >35 mentions, a category which includes descriptors such as “aesthetics”, “natural”, “recreation”, “shade”, and “beauty” (Figure 5.2). Despite these differences, and assuming internal validity of the studies, the relative importance of value descriptors is still expressed consistently for each study. The descriptors and relative importance obtained by these studies is useful information that can be integrated with my own information presented in Chapter 4.

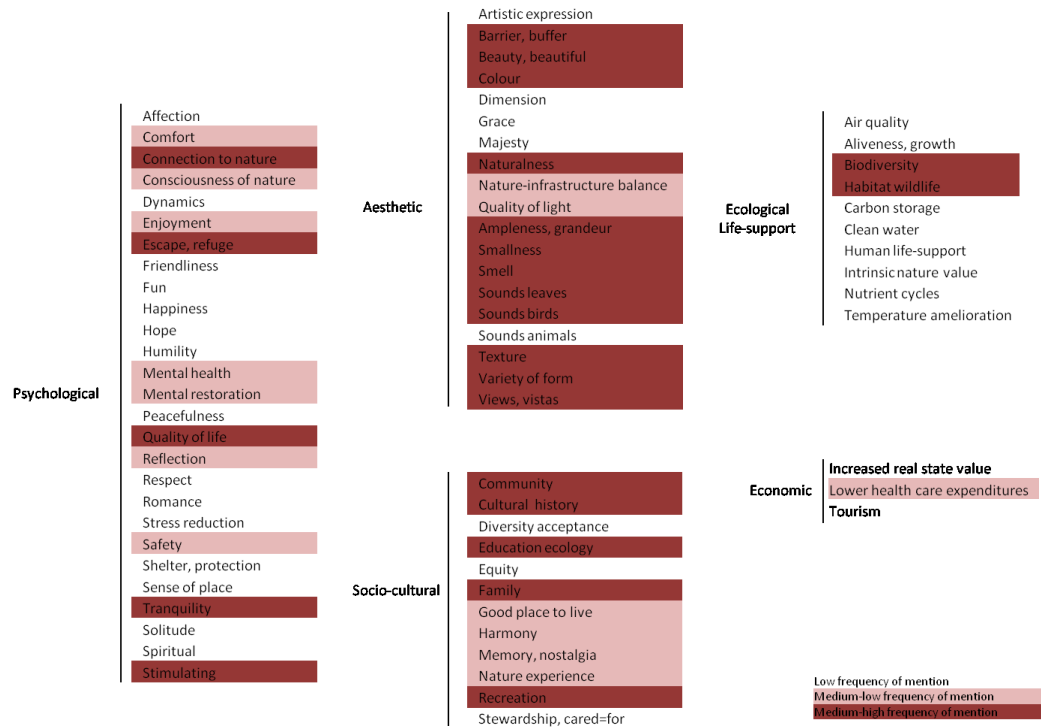


Figure 5.1: Urban forest value descriptors for Halifax and Calgary by cluster and codes and indicating frequency of mention (based on Peckham et al., 2013)

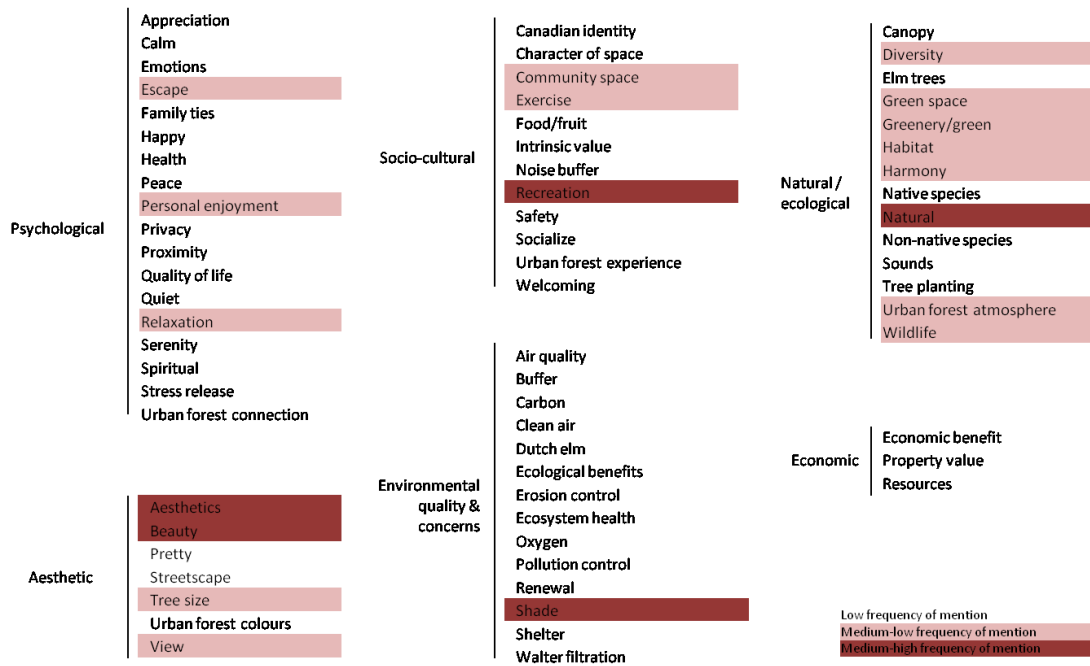


Figure 5.2: Urban forest value descriptors for Winnipeg by cluster and codes and indicating frequency of mention (based on Sinclair et al., 2014)

### 5.2.2 *Quantitative Studies*

The relevant piece of work is the sidewalk interception surveys carried out by Ordóñez et al. (2014). The survey was used to elicit urban forest values in the Canadian cities of Fredericton, Halifax, and Winnipeg in a more quantitative way than that of the qualitative studies (above and Chapter 4) in order to validate claims statistically. It differs from past studies on public opinion on urban forests, as it captures value descriptors in the respondent's own words, does not depend as heavily on people's availability and willingness to respond, allows for an experience of the urban forest whilst the survey is delivered, and may capture adequate socio-demographic profiles (see discussion in Chapter 2).

The results of Ordóñez et al. (2014) show that the sampling conditions, defined as the conditions under which the survey took place, differed mostly in terms of time of year and weather. The demographics of the respondents (n=1077) differed mostly in terms of student and non-student characteristics. The rating of importance of the urban forest (measured between 1 and 5, 5 being highest level of importance) across all three cities was high (M=4.64, SE=0.04 at 95% confidence level). There is only a small difference in ratings among cities (or province of origin), weather conditions, gender, age, and student/non-student, suggesting that respondents in Winnipeg (or originating in MB), respondents under hotter conditions, female, older (born on or before the 60s), and non-student respondents were more likely to rate the trees in the city at a slightly higher level of importance than others (Ordóñez et al., 2014). The fact that female and older respondents give more importance to urban forests reflects the results of the literature (e.g. Lohr et al., 2004).

When asked what they considered important about the trees in the city, respondents in the referred to (in order of frequency of mention) aesthetics, air quality, shade, naturalness, environmental quality, sense of place, personal well-being, biodiversity, recreation, spiritual, and carbon (Figure 5.3). These themes were extracted after coding respondents'

original answers, in a very similar way to the coding and categorization method used in the qualitative studies (see section 4.3). There is a difference in the proportions of these answers among cities and weather conditions suggesting a possible influence of weather in the selection of values, particularly for the selection of shade in Winnipeg (Figure 5.3; (Ordóñez et al., 2014). When compared with other public opinion studies (e.g. Hunter, 2001; Lohr et al., 2004; Chiesura, 2004; Schroeder et al., 2006; Tyrväinen et al., 2007) the results seem to reinforce the common notion that aesthetics, environmental, psychological, and ecological, in that order, are the most important public values associated with the urban forest.

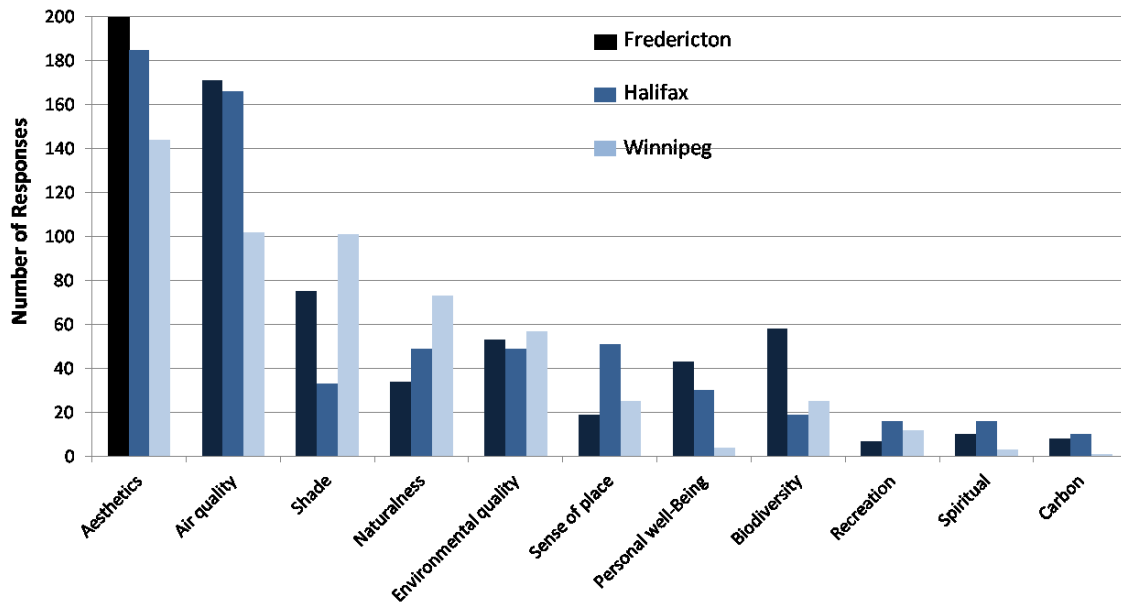


Figure 5.3: Frequency of coded themes of what respondents considered important about the urban forests per city in Fredericton, Halifax, and Winnipeg (after Ordóñez et al., 2014)

## **5.3 A Typology of Public Values in Urban Forests**

### *5.3.1 Types of Public Values and their Relative Importance*

With the consistent results of the studies in Canada (above) and Colombia (Chapter 4), I have some confidence in developing a preliminary typology of public values in urban forests. This typology is a set of descriptors about what people consider important about urban forests that may be common across local contexts. I do this by integrating the information from Figures 4.1 and 5.1-5.3. I assign each value descriptor a relative level of importance based on the level of importance suggested by the results (Figure 5.4).

Comparing this typology of public/citizen values of urban forests to that of the literature (Figure 2.1, Chapter 2), I see an agreement of some common ideas, in terms of value descriptors and relative importance based on frequency of mention, particularly items such as air quality, beautiful/ornamental, calmness and tranquility, and recreation, as expressions of environmental, aesthetic, psychological, and socio-cultural values, respectively (Figures 2.1 and 5.4). However, there are some differences in the way health, natural/ecological, and economic values are being expressed. In these cases some descriptors in the public values set take prominence over those in the literature, chiefly mental health over physiological health descriptors, connection to nature over wildlife habitat, and commerce activities over increase in property values (Figures 2.1 and 5.4).

However, the most important difference in the way values are expressed in the literature and by the public, based on my own contributions and the studies reviewed here, is that they strengthen the notion that people value trees because of non-material, psycho-social reasons. In fact, some of the elements or relationships that people value the most have no direct use or monetary value and are difficult, if not impossible, to quantify. The richness and relative importance of value descriptors under the psycho-social categories is indicative of this (Figure 5.4). The typology also contributes to the field of urban forest values in two important ways: 1.) it introduces the values of non-American or European urban citizens; and 2.) it introduces themes and descriptors that have not been captured

before, adding richness to the way the importance of urban forests was described in the past (see Figure 2.1).

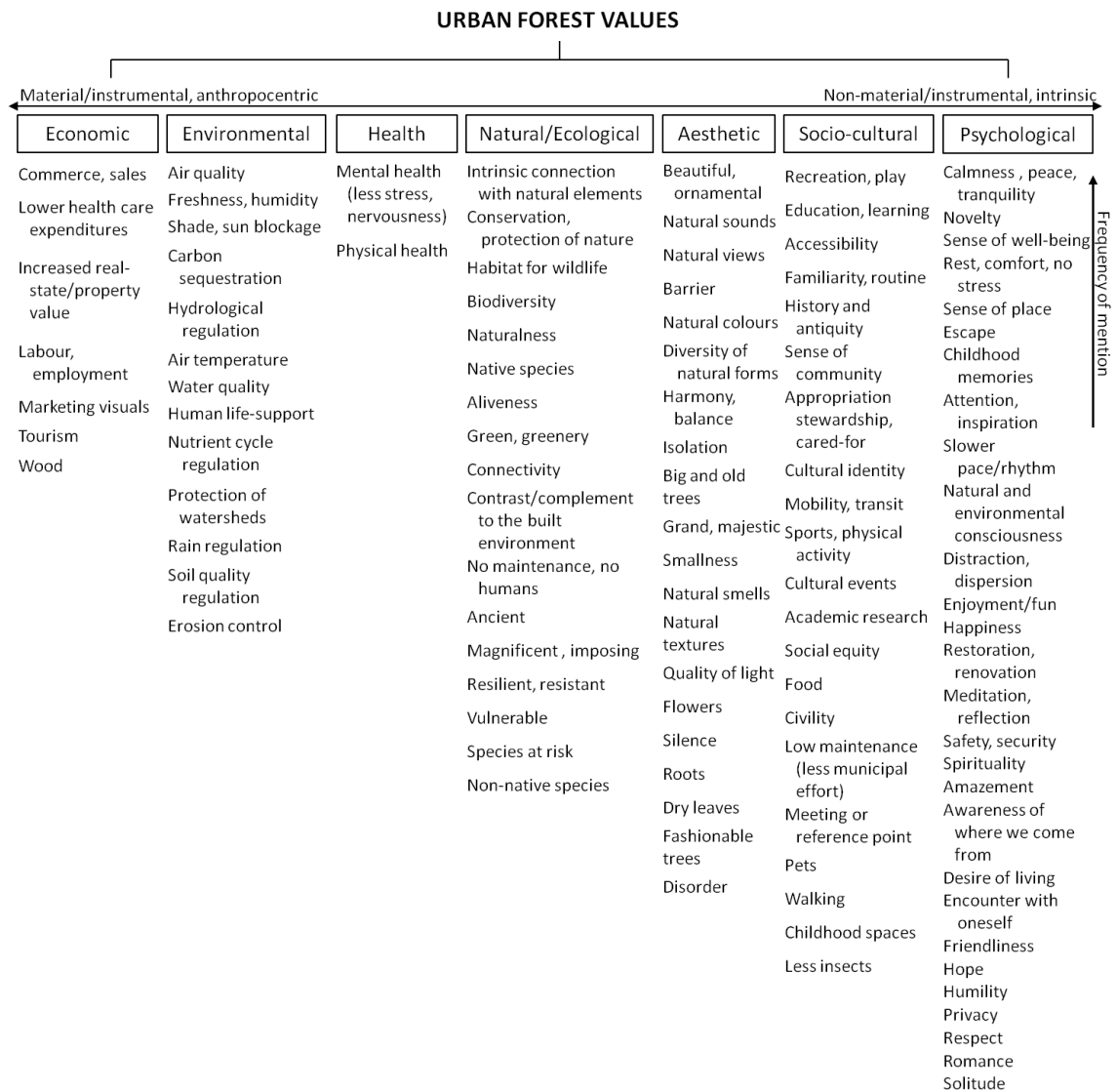


Figure 5.4: Value categories and descriptors of the public as integrated from Peckham et al. (2013), Sinclair et al. (2014), Ordóñez et al. (2014), and Chapter 4, indicating frequency of mention



It is important to point out that because this work operates under the concept of values and not attitudes or preferences, some may deem it incomparable to earlier results. Past studies have referred to the idea of what people consider important about urban forests as discrete constructs that express attitudes or preferences, but not values (Chapter 2). For instance, some academics may still prefer to refer to aesthetic value as a discrete construct that amalgamates all possible descriptions of aesthetic pleasure. However, changing the use of language is not the aim of presenting this typology. Rather, the end goal is to bring complexity to the general perception of how people value urban trees. For instance, the sidewalk survey data reflect the trends in the literature of public opinion about urban forests, suggesting that urban forests are important to the public because they are pretty. The qualitative data demonstrates that, although this is true by itself, it is also only part of the story. Aesthetics are more than visual appeal. What are important are the complex emotional reactions and psychological effects. People's aesthetic preference of forms and shapes are easily elicited and may come out as discrete constructs, but at a deeper level, they also speak to people's ideas of harmony and space, to people's mental state, and to people's feelings about nature. Ultimately, the point is to demonstrate that the urban forest values system is complex and interconnected, with each theme existing within a network of reactions, effects, priorities, and guiding principles, rather than discrete constructs.

This typology also relates in some ways to the literature of urban forests services, benefits, and attitudes reviewed in Chapter 2. As discussed in that chapter, this body of literature allows us to measure the importance of urban forests in monetary terms (e.g. Dwyer et al., 1992; McPherson et al., 1994; McPherson et al., 1997; McPherson & Simpson, 2002; Nowak et al., 2002; Nowak et al., 2003; Tyrväinen et al., 2005; Nowak et al., 2006; Payton et al., 2008; Nowak et al., 2008). As pointed out in Chapter 2, this body of literature tends to dominate the debate about what is important about urban forests, indicated by the richness of descriptions and frequency of mention of economic and environmental values (Figure 2.1). It also tends to influence how these values find expression in urban forest management (Chapter 3). The contrast between this typology and that in Chapter 2 in no way invalidates the claims of the literature on urban forest

services, benefits, and attitudes. In fact, it echoes some of these ideas. The richness and relative importance of themes related to environmental issues, particularly air quality and microclimatic benefits, indicates that these services are important to people. However, the contribution here is that I am accounting for public/citizen values and not for those of academics, municipal managers and planners, and technical people, which, as discussed in Chapter 3, reflect the types of values found in the literature.

Finally, there is a method-relative aspect of public values in urban forests. The values in the qualitative data were more or less the same, both in the way they were expressed through descriptors, and in their relative importance (Figures 4.1, 5.1, & 5.2). This strengthens the internal validity of this method as ways to capture the deeper meaning of urban forests for the general public. However, the values in the sidewalk survey, although slightly affected by weather, indicate a preference for aesthetics, air quality, and shade. These results are echoed in the literature (e.g. Hull, 1992; Schroeder & Ruffolo, 1996; Hunter, 2001; Tyrväinen et al., 2003; Lohr et al., 2004; Schroeder et al., 2006). Because both methods required a mechanism of interpretation of the verbatim data, it is safe to note that there is the possibility that variations in interpretive analysis may have resulted in different values taking more or less prominence. However, taking into consideration the urban forest values literature (Table 2.1 and Figure 2.1), the most important difference between these methods may be related to experience of the urban forest and depth of the data capture. The surveys demonstrate that aesthetic and environmental values are readily elicited through survey methods, while psycho-social and natural/ecological values can be captured through a deep, personal or collective experience of urban trees. As the urban forest values literature continues to grow and the combination of methods becomes the norm for exploring public values in urban forests, we would be able to see if the insights gained through this typology hold true.

### *5.3.2 Limitations and Further Research*

A number of limitations are unavoidable when making inferences about how the general public values the urban forest based on the data of my study and associated studies.

Foremost, because qualitative explorations are not interested in making statistical inferences about the population they sample, the values elicited by these methods may not be representative of the wider population of the locale. As the three qualitative studies demonstrate, opportunistic, or snowball, recruitment is most important for drawing people to the study. The participants of these studies tend to be urban, educated people with a slight tendency to be women. As discussed in Chapter 4, this profile conforms with the profile of people who value the environment in general (Dietz et al., 1998) and the urban forest in particular (Lohr et al., 2004). However, there is some disagreement with the young profile of the participants of this study, as previous urban forest studies (e.g. Lohr et al., 2004) demonstrated that older people value urban forests more. More application of this method in other case studies is needed to validate some of these insights.

The sidewalk survey method was designed to overcome the limitations of the qualitative studies, as well as the limitations of phone and post surveys, which are by far the most common methods to capture public opinion about urban forests. However, the method also suffers from a subtle demographic bias obtained from a restricted spatial scale (Ordóñez et al., 2014). The study suggests that female, older, and non-student individuals were more likely to rate the urban forest at a slightly higher level of importance. This profile is in agreement with some of the literature (e.g. Lohr et al., 2004), but it is in disagreement with the qualitative studies, where it is younger students who tend to participate. More application of this method in other case studies is needed to validate some of these insights. Overcoming the demographic biases may also require the development of other methods.

As discussed briefly in the previous subsection, there is a method- and context-specific quality for urban-forest public values, as the differences among the surveys and the qualitative studies, and among the qualitative studies themselves, reveal. First, aesthetic and environmental values are elicited easily with the use of survey methods, while richer psycho-social and natural/ecological values are elicited with the more elaborate method

of diaries, focus groups, and field trips. The experience of the urban forest was enhanced in these two methods in ways that have not been discussed in the literature before, where people only manifested their opinion about trees in the city abstractly in their house or by looking at images. However, the depth of the experience and the amount of data collected in both are very different. As suggested in the last section, these differences may account for the relative importance of values in both studies, in terms of richness and frequency of mention. More research is needed to see how experiential and data-complexity differences account for elicited urban forest values.

Secondly, and not surprisingly, socio-cultural issues related to accessibility and equity were richer and more prominent in Colombia than in Canada (Figures 4.1, 5.1, & 5.2). It was argued that in a social context with a more fragmented socioeconomic structure, Colombian people value the urban forest in ways that speak to the social issues affecting them (Chapter 4). Although the same can be said in Canada, the frequency, richness, and inter-relation of socio-cultural themes are less significant. Although in both studies economic values are not salient, in the Colombia study there is a new association about the economic value of urban forests, specifically, fostering informal economic activity. This theme tends to dominate in the typology developed in this chapter (Figure 5.4). Undeniably, other specificities may emerge as the urban forest values literature continues to grow, and more research is necessary to validate this typology.

Finally, the use of language in this typology is tied to the language that emerged from the data themselves, particularly from the qualitative studies. The data from the survey are now inaccessible to corroborate the subtleties in languages use. Needless to say, previous studies on public opinion may have condensed the richness of language obtained into a few discrete categories in a similar way. However, as mentioned in the earlier section, the point of the typology is not to change language uses. Rather, its contribution is to reveal the richness in psycho-social themes to serve as a contrast to the richness in environmental and economic themes in the literature, to offer a set of public values data elicited through a conceptualization of the urban forest as a broader ecosystem (Chapters 1 and 2), and to offer another view on the matter besides the dominant U.S. and European

one. Undeniably, other specificities may emerge as the urban forest values literature continues to grow, and more research is necessary to validate some of the uses of language presented here.

A point worth mentioning is that a clear understanding of urban forest values is only possible using a combination of many methodological approaches. In some ways, it is preferable that every town and nation figures out its own urban forest values and that cross-municipal and cross-national comparisons can be facilitated to strengthen the typology initiated here.

#### **5.4 Implications for Urban Forest Management**

The results presented here give me an idea of what people consider important with respect to urban forests but not how these priorities can be adopted into urban forest management. Discussing this is important to offer guidance for aligning the interests of different urban forest management actors (Chapter 2). It is important to remember that values research has limitations to inform ecosystem management. Not everybody makes thoughtful decisions guided solely by values (Bardi & Schwartz, 2003); thus, public values are not necessarily a measure of public behaviour. However, at a theoretical level, the contribution of the values concept to ecosystem management is to give a notion of what is important to manage in ecosystems (Chapter 1). Thus, being aware of these values, as managers, academics, planners, technicians, or citizens, is crucial for a deeper understanding how and why we manage urban forests (Chapter 2).

The typology developed here indicates that people value nature deeply and for a variety of reasons, reasons that inform urban forest managers of the priorities of the citizenry, and reasons that strengthen the message of making operational some of the vague social and ecological themes identified in Canadian UFMPs (Chapter 3). I derive from these results the ideas that, just because some issues are less “obvious” from a technical standpoint, it does not mean they are less valuable. The results also demonstrate the value of formal, context-specific research, rather than extrapolating results from other areas.

Although increasing canopy cover will probably aid in satisfying more public values of urban forest, a very different picture of urban forest management can be visualized if based on what people think, feel, and want, rather than just those things we can calculate. Managers can respond to public urban forest values not only through technical fixes, like planting more trees or increasing tree diversity, two prominent goals of urban forest management today (Chapter 3), but also by enhancing the natural experience in the city through the provision of high quality, diverse, and accessible urban forest spaces. This may require redesigning some of the usual urban forest planting paradigms, such as species selections in the city, tree spacing in streets, the representation of large parks, pocket parks, and more natural areas rather than just street trees. Indeed, the results here suggest that the lack of social and ecological specificity found in the way urban forest management programmes are designed (Chapter 3) can be overcome if the public values principle is adopted at a deeper level.

Adopting the values of the public into urban forest management also implies democratizing the management process. Consulting the public with the methods presented here provides benefit for managers, but also for the people, as they have a say in how trees are being managed in the places they live. Ultimately, it is up to every urban forest programme to align itself with what is important to its public.

## **5.5 Threats to the Provision of Urban Forest Public Values: The Case of Climate Change**

The sustainable management of urban forests can be seen as a way to provide a strong array of values at all times with acceptable spatial distribution (Chapter 1). Undeniably, the provision of urban forest values through management is threatened today by urban forest stressors that make it hard to ascertain either the survival or adequate functioning of urban trees. There are also issues that will threaten the provision of urban forest values in the future. Ideally, the management of urban forests applied today must be able to account for these future threats whenever possible. Obviously, natural or human

catastrophes are considered as future threats and can prevent sustainable urban forest management to provide urban forest values to its citizens in the future, but these may be unforeseen and unexpected, and little can be done to prepare for them. However, there are some future stressors that can be mitigated or to which urban forests can start to become more resilient today.

Of the many stressors affecting urban forests, including tree loss due to increased urbanization and changing urban development patterns, adequate growing conditions in the urban environment, insects and diseases, among others, climate change is one that has not been substantially addressed. There is some indication that few municipalities in Canada have identified effective mitigative and adaptive strategies to account for climate change in urban forest management (Chapter 3). This may be either because it is not a prominent or immediate urban forest stressor, because its effects are confounded, not well understood, or uncertain, or because urban forest managers are not tuned-in to these considerations. Undeniably, climate change effects on ecosystems will remain uncertain in the immediate future (IPCC, 2007b). However, uncertainty, or the expression of the degree to which a value is unknown because of disagreements of what is known or even knowable, should not limit any management regime to address climate change and the development of mitigative or adaptive options (Morgan et al., 2009; IPCC 2007b). And doing so is important since climate change and its wide-ranging effects on urban forests may enhance the effects of stressors already affecting them, thus making it more difficult to address them and for urban forest management to provide the desired values.

Little information exists today about what climate change means for urban forest management and the threat it poses to providing for urban forest values. However, there is some indication that its effects may be grim. For instance, the big size of many urban trees may make them more prone to windthrow in the future considering that climate change projections indicate more frequent and intense storms (Yang, 2009). Given the importance that large, mature trees have in providing urban forest values (this Chapter), this is a potential threat to urban forest value provision. Moreover, some urban tree species may not be adapted to the future climate (Yang, 2009), which, considering the

long lifespan of some urban trees, may have detrimental effects on urban tree health in the future. As trees become more stressed from new environmental conditions brought on by climate change, they are prone to be affected by insects and diseases, an already detrimental stressor for many urban trees in North America (e.g. Karnosky, 2009; Donovan et al., 2013).

These and other biophysical changes in urban forests triggered by climate change will affect the degree to which urban forest management provides values to people.

Complementarily, and as discussed in Chapter 3, the set of values that influence urban forest management determines the management direction. If the set of values is too narrow, this direction may not be aligned with providing a strong array of urban forest values to urban citizens. In tandem, it may also not be aligned with the environmental and ecological considerations that are required to address the climate challenge. Although the environmental and ecological knowledge exists and is guided by experts in the field, urban forest management actors may not be tuned-in to them. Understanding how public values and climate change considerations are compatible is then important to set a solid basis for urban forest management in consideration of the values of the urban forest and the changing climate to come.

In the coming chapters I will address the topic of climate change in urban forests. I will review the literature of climate change and urban forests, and I will explore the issue of urban forest vulnerability to climate change. These explorations will give me some theoretical and empirical basis to understand how this vulnerability poses a threat to urban forest value provision. I will discuss what directions of management are necessary to address climate change in urban forests so as not to sacrifice the provision of a strong array of urban forest values in the future.

## **5.6 Summary**

In this chapter I developed a typology of urban forest values of the public based on an integration of my own study in Colombia (Chapter 4) and related studies carried out in



Canadian cities (Sinclair et al., 2014; Peckham et al., 2013; Ordóñez et al., 2014). The typology demonstrates that people value the urban forest because of a diverse, rich, and interconnected set of reasons related to aesthetic, psychological, socio-cultural, natural/ecological, health, environmental, and economic themes. The public gives more weight to psychological, environmental, aesthetic, natural/ecological, and socio-cultural descriptors than to economic ones. The novel methods used for eliciting these values were necessary to understand why people value trees at a deeper level. The urban-forest public values typology is richer than the urban-forest values ones from the literature, reviewed in Chapter 2. However, these results are not without their limitations, and further research is still needed to complete the values typology initiated here. I later discussed how a public values-based urban forest management has implications in the operational features of urban forest management, such as canopy cover and tree diversity targets, the distribution of new tree plantings, and the provision of more natural spaces. It may also help overcome lack of specificity in many themes of management, as demonstrated in Chapter 3. As urban forest management looks into the future, it is clear that future threats such as climate change may reduce public value provision. This is an issue that I will address in the upcoming chapters.

## **6 Chapter 6: Urban Forests and Climate Change – A Review**

### **6.1 Introduction**

Climate change is a concern for all ecosystems on Earth. It is unequivocal that temperature has increased since preindustrial times more rapidly than earlier and extremely likely that the dominant driver is anthropogenic greenhouse gas emissions (GHG) (IPCC, 2013). Such temperature changes have a direct influence on the processes that determine local weather, chiefly precipitation, wind and the frequency and/or intensity of extreme weather events (IPCC, 2007a). These changes threaten urban areas. Not only do cities contain the majority of the world's population (UN-HABITAT, 2012) but their microclimatic envelope may enhance future temperature increases (e.g. McCarthy et al., 2010). Besides temperature changes, cities will also be affected by extreme events such as droughts, floods, storms and heat waves, and long-term resource issues such as water scarcity and increased in air pollution (Wilby, 2007).

Climate-driven changes will affect the provision of urban services, particularly the services provided by urban nature. The urban forest is one of such services. Urban trees provide a wide range of environmental and economic services including climate amelioration (McPherson et al., 1997; Shashua-Bar & Hoffman, 2000; Wong & Yu, 2005; Gill et al., 2007; Bowler et al., 2010). In fact, urban forest enhancement figures prominently as an urban adaptation strategy to climate change - that is, the adjustment of natural or human systems to cope with its consequences (Smit & Pilifosova, 2001) - in North –American cities (e.g. planting 1million trees, City of New York, 2011; doubling tree canopy, City of Toronto, 2008). However, the fact that climate change also threatens them has been largely overlooked. There is evidence that municipalities are starting to address this. For instance, the threat of climate change is a prevailing theme in urban forest research agendas (James et al., 2009; Wolf & Kruger, 2012), and the possible impacts that climate change will have on urban forests have been explored (e.g. Ligeti, 2007; Yang, 2009; BC-MCSCD, 2010). However, it is yet unclear what climate change means for urban forest management. For instance, urban forest management plans in

Canada do not embed climate change in any significant way (Chapter 3). The climate threat on urban areas and its trees may also reduce public value provision of urban forests.

This chapter will review the literature on what climate change means for urban forest management, in terms of its impacts and responses. It brings together literature from four domains of knowledge, including climate change in ecosystems and human systems; climate change and forests (hinterland); climate change and urban areas; and climate change and urban forests. The purpose of this chapter is not to provide an exhaustive review of the literature in these four domains, but rather to explore the key ideas behind managing climate change in the context of these ecosystems. The goal is to develop framework for understanding what climate change means for urban forest management. I consider climate change as an added stressor to the urban forest ecosystem that may exacerbate other stressors already affecting it. It uses the language of climate change science and assigns a precise meaning to it in the context of urban forests, instead of extrapolating insights from the interaction between climate change and hinterland forests. The framework focuses on climate adaptation, thus filling significant gaps in the urban-forest climate change literature and developing an agenda for research opportunities.

This chapter is divided into five sections. The first three sections discuss climate change in ecosystems and human systems, climate change and forests, and climate change and urban areas, respectively. This is followed by a section on urban forests and climate change, including contributions, impacts, and responses, with this last part of this section elaborating extensively on the meaning of climate adaptation in urban forests. A final section evaluates the way climate adaptation could be included in urban forest management and the opportunities for research in the field of urban forest vulnerability to climate change. The discussion is illustrated by a conceptual map. A summary is given at the end of the chapter.

## 6.2 Climate Change, Ecosystems, and Human Systems

The planet has experienced many climatic changes throughout its history, altering the distribution and quality of ecosystems. Ecosystems influence global climate by altering GHG and aerosol concentrations in the atmosphere. Accelerated by anthropogenic GHG emissions, climate is expected to change and affect most natural and societal ecosystems on the Earth surface. Though climate change effects vary across the globe, even our modest projections suggest a considerable global mean increase of 1.3-1.9°C by mid-century, depending on the GHG emission scenario (Meehl et al., 2007). The farther into the future, the greater the discrepancies among scenarios, but increase of average annual temperature by the end of the century could be as high as 1.7-4.4°C if GHG concentrations reach beyond twice the amount today (Meehl et al., 2007). Even so, temperature responses to emission projections are averaged across all models, so it is safe to say that many regions of the world will experience the extreme temperatures along both sides of the range of this increase in the coming 50 to 100 years (IPCC, 2007a).

Temperature changes have a direct influence in the processes that determine local weather, chiefly precipitation, wind and the frequency and/or intensity of extreme weather events (IPCC, 2007a). Even a modest 2°C departure from mean temperature would imply different climate conditions from those under which most ecosystems have evolved in recent centuries. This will cause changes in precipitation, evapo-transpiration, extreme weather events and sea-level rise (IPCC, 2007a), changes that will present a challenge to most ecosystems around the world (Scholze et al., 2006).

As the climate continues to change, some ecosystems will thrive while others will go extinct, in particular those ecosystems that have small ranges and a limit to their distribution, for example, high-mountain ecosystems (Schwartz et al., 2006). Endemic species are of particular concern, and some may irreversibly disappear with climate change. Studies of warming in the past 50 years demonstrate that climate change effects on world ecosystems and species are differentiated, although vegetation shows a higher level of response, chiefly because of the dependence of global plant distribution on temperature (Parmesan & Yohe, 2003). It is theorized that fauna-flora dynamics will

follow plant responses (Parmesan, 2006). This is of particular concern, as forests are a significant portion of the world ecosystems and where most of the terrestrial biodiversity is concentrated (MEA, 2005).

It is important to note that although temperature is an important driver behind the changes expected in ecosystems, climate change will manifest itself through different means. Changes in precipitation patterns, changes in evapo-transpiration regimes, and the joint effects of temperature and precipitation extremes such as heat waves, droughts, floods, and storms, together with sea-level rise, which will incur in flooding and changes in salinity, are also important drivers (Figure 6.1). In general, there is more energy in the climate system today, and given its non-linearity, manifestation of climatic changes as extreme weather patterns is in some instances more concerning than the slow increases in temperature and changes in precipitation (IPCC, 2007b). In general, the impacts of climate change on ecosystems will depend on their vulnerability to these factors of exposure, and will alter ecosystem quality and integrity (Figure 6.1).

Human systems will also be affected by climate change. Direct impacts of climate change on human populations is expected (Patz et al., 2005; Haines et al., 2006), given the importance of air pollution and heat waves on public health (Luber & McGeehin, 2008). As with ecosystems, the impacts of climate change on human systems will depend on their vulnerability to these factors of exposure, and will influence the development and socioeconomic drivers of society (Figure 6.1). The cost of climate change impacts in the world's economy is expected to be significant (Stern et al., 2006).

The link between ecosystems and human systems is crucial in understanding climate change since ecosystems affect societal functions and vice versa (Eakin & Luers, 2006). Ecosystems provide immense amounts of services to human societies and are in turn valued greatly by people. Ecosystems influence people's health and are where people settle and extract their resources. However, the relationship between political, socioeconomic, and cultural factors with ecosystem functioning are complex, particularly under the scope of climate change (IPCC, 2007c). How society understands ecosystems

and the decisions it takes regarding their management and regulation are important aspects of this relationship, and this is determined by the knowledge, education, and monitoring of the ecosystem (Freedman et al., 1995; Freedman, 1998). Social attitudes, values, and preferences, which are affected by political and socioeconomic factors as well as by development drivers, influence this interpretation. Eventually, decisions about management and regulation of the ecosystem are taken, thus determining the management institutions, budgets, the quantity and level of skills of the staff employed, the ownership regime, governance and policy, social awareness and engagement, and economic valuation. All of these factors are important when understanding a social system response to and preparedness for climate effects (Kelly & Adger, 2000; Yohe & Tol, 2002; Adger et al., 2004; Adger et al., 2007).

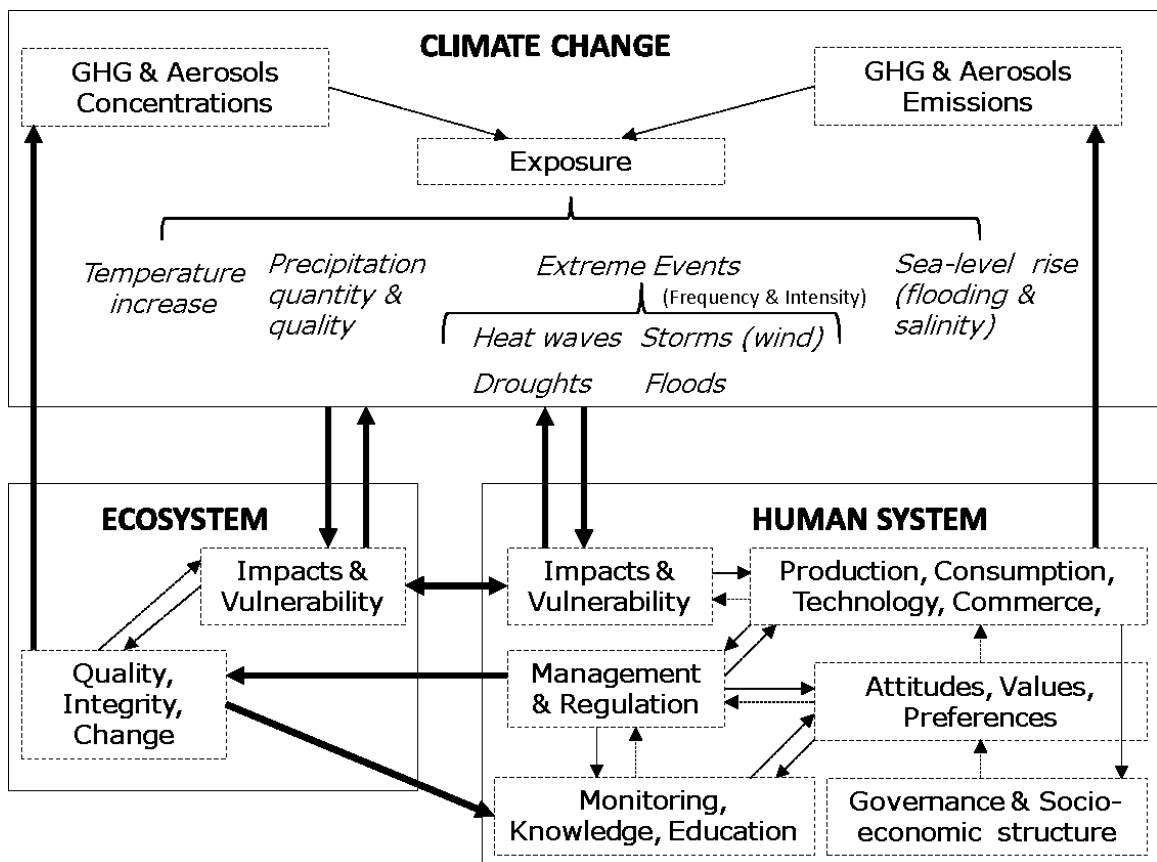


Figure 6.1: A conceptual map of climate change interactions with ecosystems and human systems

What this discussion portrays in the context of climate change is that not only ecosystem responses influence communities, but that communities also influence them. Ultimately, understanding how ecosystems, human systems, and climate change interact is an important step to give meaning to climate change to particular ecosystems and societies (Figure 6.1). Understanding the specific social and ecological dynamics that influence and are influenced by climate change are of course particular to an ecosystem and a locale (Schneider et al., 2007).

### **6.3 Climate Change and Forests**

The impact of climate change on the world's forests is of particular concern (Parmesan & Yohe, 2003). Forests comprise about 30% of the Earth's land area (FAO, 2012) and are a key natural resource that is highly valued by most people. They also contribute to the regulation of climate by providing a carbon sequestration mechanism and sink, and their net loss is one of the contributing factors to anthropogenic GHG emissions (IPCC, 2007a).

Temperature increases due to climate change may initially drive forest productivity (Boisvenue & Running, 2006), but the farther the projections go, productivity can fall (Fischlin et al., 2007). In that regard, gains in CO<sub>2</sub>-induced growth may be downplayed by air pollution (acid deposition, nitrogen and sulphur oxides depositions, and ozone), which is exacerbated by warmer weather, slowing tree growth and causing stress (Mohan et al., 2009). Moreover, while these projections consider only annual averages, seasonal climate variability may have a bigger influence on forest productivity in the long term (Bugmann & Pfister, 2000). In fact, some studies show northern forests cease to be carbon sinks after a 3°C departure from average temperatures at particular times of the year (Scholze et al., 2006).

Forest range shifts in the past 20 years in some areas of the world (e.g. Canada, Lescop-Sinclair & Payette, 1995) have given us an understanding of how temperature changes will affect forest ranges in the future (e.g. Iverson & Prasad, 2002; Bourque et al., 2010)

and tree-species adaptations to the new climate. Studies in Canada, a country with such a considerable forest resource, confirm that shift (McKenney et al., 2007). These shifts restrict certain tree species to a smaller or bigger area, changing the forest structure. Range shift may be fast or slow depending on the species, but in general it is slow (Kirilenko et al., 2000). This shift may be also impacted to a lesser extent by sea-level rise, which could reach, on the low end of most projections, 0.59-1.0m globally by the end of the century (Meehl et al., 2007).

The disturbance regime of forests will change with climate change, in particular, storms, hurricanes, wind events, pathogens, fire, drought, flooding, landslides, and their interactions (Dale et al., 2001). The spread of insect pests and disease, like the recent outbreaks of mountain pinebettle in BC due to lack of low-temperature winters (Carroll et al., 2004), are of particular concern. Invasive species and insect pests cause biotic disturbance that may be enhanced by climate change by becoming more widespread and abundant (Logan et al., 2003; Dukes et al., 2009; Smith et al., 2012). Wind is a major concern in wind-prone areas, as some of the most devastating forest-loss events are caused by wind damage (e.g. Peterson, 2000).

The single or combined result of these changes will have consequences in forest ecosystem resources, such as soil nutrients (Pastor & Post, 1988), site conditions, disturbances (as above), and individual tree variables (Williamson et al., 2009). Changes in forest ecosystem dynamics will affect forest productivity in the long term (Boisvenue & Running, 2006; Kirilenko & Sedjo, 2007) and impact forest diversity (Steenberg et al., 2011). For detailed information on climate change variables and forest characteristic interactions specific for Northern forests see (Williamson et al., 2009; Johnston et al., 2009; Duinker & Ordóñez, 2010).

As forests are affected by climate change, human societies that are intrinsically connected to the forest resource will also be affected. As noted in the previous section, ecosystems and human systems interact in many ways in relation with climate change, and the climate impacts and vulnerabilities of each system are affected by the other. Ultimately,



climate management in ecosystems is a social enterprise (Eakin & Luers, 2006). This has meaning in forest management, as management decisions that alter forest composition, structure, and disturbance regime due to social or economic drivers may enhance the impact of climate change (Seppälä et al., 2009). In turn, biophysical changes in forests will influence how people obtain their services and fulfill their values from them. In Canada, where forests are important for people and the economy, governance and economic structures influence adaptation of the forest sector to climate change (Gibson et al., 2000; Johnston & Williamson, 2007). Other factors, beyond the realm of direct forest management practices, may also affect forests and the people depending on them. For instance, landscape development patterns in many regions of world, together with forest management practices, will determine the way some forests react to climate change (Hansen et al., 2001). Although climate change is a driver in respect of forest fires, people may still influence the occurrence of fires in the future (Wotton et al., 2003). Finally, forest conservation issues are intrinsically related to climate management strategies, determining not just the survival but also the adaptive capacity of many forest ecosystems (Noss, 2001).

#### **6.4 Climate Change and Urban Areas**

With most of the population concentrated in cities, urban ecosystems are particularly vulnerable to climate change, not only because of their high human density, which is a determinant factor behind urban human mortality due to extreme weather events, but also because of their particular microclimate (e.g. McCarthy et al., 2010).

With human population expected to reach 9 billion people by 2050 (UN-HABITAT, 2012) even with a slower rate of growth, the population will be more urban (Cohen, 2003). Demographic pressures mean that any catastrophe in a city will cause many human and economic losses, as in the case of storm surges (e.g. Hallegatte et al., 2011). Moreover, demographic drifts towards the city will continue to transform the landscape. Landscape transformation may augment climate change as the urban heat island increases (Pataki et al., 2006).

Furthermore, cities have their own climate generated by a localized and differentiated albedo, which is in turn caused by the urban concrete cover, the heat distribution across the built infrastructure, and the immense amount of heat generated by combustion processes for electricity and cars (Oke, 1987). However, because of high resolution and the changing nature of local weather, good approximations of future urban climate are hard to obtain. In fact, global temperature projections due to climate change are averaged near the surface. Thus, current climate projections do not account for urban areas due to the small climate potential (about  $+0.05^{\circ}\text{C}$  today), although this may become more significant in the future (Stone, 2007). However, certain inferences can be made from regional approximations by taking into consideration the particularities of the urban climate, such as the effect of enhanced temperature, or urban heat island (Souch & Grimmond, 2006), averaged at  $+2-3^{\circ}\text{C}$  for most cities (Arnfield, 2003). There is great seasonal temperature variability in urban microclimate with some cities experiencing urban heat islands of almost  $+12^{\circ}\text{C}$  in some periods (Blake et al., 2011).

Thus, it is known that cities were affected more by heat stress during summertime than the surrounding rural areas in the past 50 years (Gaffen & Ross, 1998). Some studies suggest that climate change will modify the potential of climate forcing of urban areas by about 30% (McCarthy et al., 2012). Moreover, temperature is intrinsically related to humidity changes in the city, which tend to be extreme. For instance, urban precipitation regimes over the long-term mimic drought conditions (Roloff et al., 2009), while urban flooding may be sudden and devastating (Schreider et al., 2000). Indeed, extreme events such as droughts, floods, storms and heat waves, and long-term resource issues such as water scarcity are issues of concern (Wilby, 2007). Air quality problems are also expected to increase even within moderate climate scenarios (Wilby, 2008).

The human dimension of climate change effects in urban areas can be explored in several ways. First of all, by some accounts, cities emit a considerable amount of the GHGs that are contributing to climate change (Stern et al., 2006; UN-HABITAT, 2010). Moreover, there is a probability of human life loss in cities due to extreme weather conditions and

weather-related disasters (Patz et al., 2005; Huq et al., 2007; Romero-Lankao, 2010; Hanson et al., 2011). Extreme weather events can have extreme social responses, such as the transformation of labour (Alam & Rabbani, 2007). It is then obvious that awareness of the local causes and consequences of climate change in urban areas facilitates the interest of local authorities to address climate change with fitting measures (Solecki & Oliveri, 2004; Demeritt & Landon, 2006).

However, in many cases, awareness of contributions and impacts is not enough. Some suggest that the downscaling of climate management in urban areas is affected by discordant climate information and analysis (Cash & Moser, 2000). Moreover, addressing a global problem such as climate change is difficult to do for local actors since many of the policies and regulations are built at the national level and some may hinder municipal leadership (Ivey et al., 2004; Schreurs, 2008). This fosters an atmosphere of mistrust of local authorities towards national intentions (Shackley & Deanwood, 2002). It is evident that simple awareness or technical information about climate contributions and impacts is not enough to bring attention to climate issues in urban areas.

Differentiating urban responses to climate change in terms of mitigation and adaptation is another useful way to explore this topic. There is a general understanding that a multi-level approach to climate change mitigation is the only one that will work (Ostrom et al., 1999). Some advocate for scaling down climate management as the only effective way to address the climate challenge (Adger, 2001; Slocum, 2004a; Bai, 2007). Others simply argue that local climate responses are becoming important in climate change mitigation efforts (Kuik et al., 2008). Indeed, there is a focus on climate mitigation, or reduction of GHG emissions, as a way of addressing climate change at the urban level (Wilbanks & Kates, 1999). This results in already-existing environmental policies getting dressed as climate policies (Collier & Löfstedt, 1997; Betsill, 2001; Shackley & Deanwood, 2002; Kousky & Schneider, 2003; Fleming & Webber, 2004). For example, the transnational network Local Governments for Sustainability (former International Council for Local Environmental Initiatives, ICLEI) manages information about climate protection for cities, but many of these refer to already-existing policies for improving infrastructure,

transportation, and environmental quality (DeAngelo & Harvey, 1998; Kousky & Schneider, 2003; Bulkeley & Betsill, 2004; Slocum, 2004b). Some climate mitigation policies in cities have been designed to obtain political benefits for cities at the national level (Lindseth, 2004).

Urban climate management also addresses climate adaptation, as it has been argued that adaptation is more relevant at the local level (Tompkins & Adger, 2005; Adger et al., 2005; Schneider et al., 2007). However, there is still not a good understanding of urban vulnerability to climate change, which is crucial for developing effective adaptation strategies (Schneider et al., 2007). While urban vulnerability research is growing in areas like water resources (Hunt & Watkiss, 2011), energy systems (Kirshen et al., 2008), and coastal hazards (De Sherbinin et al., 2007), many other relevant areas remain unexplored. A focus on particular areas of urban vulnerability is driven by the desire to mitigate the environmental impacts of climate change, using the infrastructure of the city to build resistance around possible weather events instead of re-designing the city and addressing urban adaptation to climate change at a deeper level (Dawson, 2007; Bulkeley & Betsill, 2013; Bulkeley, 2013; Jabareen, 2013). Such is the case of urban forest enhancement, which has been identified by many as a key element of urban climate adaptation. Authors have referred to using urban trees as means to ameliorate climate-driven changes in urban areas (Lindley et al., 2006; Rosenzweig et al., 2007; Romero-Lankao, 2007; Hamin & Gurrán, 2009; Zimmerman & Faris, 2010; Romero-Lankao & Qin, 2011; Stone, 2012). However, urban forest management deals with more than planting trees, and it is still unclear what climate mitigation and adaptation mean for it. I explore this topic in the next section.

This brief discussion illustrates how climate management in urban areas has a focus on dressing already-established environmental goals as climate policies, and on using the infrastructure of the city, including its trees, as means to mitigate climate impacts. These ideas are relevant to how climate change is being managed in the urban forest context, as discussed below.

## 6.5 Climate Change and Urban Forests

Urban trees are often the dominant vegetation in many cities and urban forest management is important for the sustainability of a city (Chapters 1 and 3). Since the above review suggested that climate change is an important consideration in forest and urban ecosystems, understanding the interactions between urban forests and climate change is important. Here I review the relevant literature on urban forests and climate change by focusing on three themes: urban forest contributions, the impacts of climate change on urban forests in the context of other urban forest stressors, and the responses of urban forests to climate change. Although much of the discussion about climate change and urban forests is determined by the effects of climate change on forests and urban areas, as exposed above, there are some significant differences.

### 6.5.1 *Urban Forest Contributions*

Urban forests contribute to climate change by modifying and controlling GHG emissions through carbon capture and release, shading buildings and regulating microclimate either through albedo or the hydrological regime. In the US, for example, urban forests capture about 23 million tonnes of carbon every year (Nowak & Crane, 2002). The shading effect of trees on buildings helps reduce energy use and thus carbon emissions (Akbari, 2002). Furthermore, urban trees help regulate the urban microclimate, augmenting or minimizing climatic change. This occurs either by reducing albedo and providing shade and cover (Heisler, 1986; Scott et al., 1999; Streiling & Matzarakis, 2003; Jonsson, 2004; Armson et al., 2012) or by regulating the hydrological regime of cities (Sanders, 1986; Rosenfeld et al., 1998; Heidt & Neef, 2008) that affects the urban microclimate (Souch & Grimmond, 2006). Urban forests also contribute to GHG emissions with the loss of canopy cover and trees and the release of volatile organic compounds (VOCs). The maintenance of urban forests may also contribute depending on its carbon intensity and related emissions (Nowak, 2000). However, carbon accounting is not a prominent theme in urban forest management, particularly in Canada (Chapter 3). More research is needed to quantify urban forest management contributions to climate change beyond carbon storage.

### *6.5.2 Climate Impacts on Urban Forests*

Climate change is an added stressor to the set of ecological and environmental stressors already affecting urban forests. The urban forest is subject to a number of natural and, mainly, anthropogenic stressors that reduce the lifespan of many trees (Nowak et al. 2004). These may include unnatural hydrological cycling (Quigley 2004), low quality of soil (Zhu and Carreiro 2004), destructive building activities (Florgård, 2000), wind events (Kontogianni et al., 2011), high salinity (Florgård, 2000), bad tree pruning, small root space and soil compaction, and poor provision of water (Sieghardt et al., 2005; Roloff et al. 2009), and insect and diseases effects (Poland & McCullough, 2006), among others. Other stresses include the urban heat island, which causes some tree species to be mal-adapted (Roetzer et al. 2000; Sukopp & Wurzel, 2003). Together, stressors lead to artificially shortened life spans for street trees, in comparison to their expected life-spans, which is species-specific (Nowak et al. 2004). Beyond individual trees and highly urbanized environments, and at the ecosystem level, urban trees in more naturalized environments are affected by fragmentation, caused mostly by urbanization, which influences many ecosystem processes, such as seed dispersal, negatively (McDonnell et al., 1997; Matlack, 1997; Kostel-Hughes et al., 1998; Heckmann et al., 2008).

The direct impact of climate change on urban trees may either increase the stress variables affecting the urban forests or enhance existing ones. These stresses may comprise higher temperatures and species mal-adaptation to the new climate, temperature extremes, precipitation changes (in both quantity and quality; i.e. snow to rain), and extreme weather events. These stresses may enhance species mal-adaptation to urban environmental conditions, air pollution increases, soil habitat alterations, and insects and diseases (Johnston, 2004). Mal-adaptation to temperature, increased mortality due to changes in ecosystem quality, extreme events, and insects and diseases have been the impacts of interest in Canadian urban forests (e.g. Ligeti, 2007; BC-MCSCD, 2010), and a detailed discussion of these is given below.

Mal-adaptation of tree species to the new climate would generate a significant loss or gain of urban forest habitat depending on the species, particularly considering the microclimatic effect of urban habitat conditions on certain urban tree species.

Phenological responses, such as shortening of the growing season and prolongation of the end season (White et al., 2002) and changes in spring phenophases (Roetzer et al., 2000) are common in urban forests. As forest ranges shift (section 6.3) certain urban tree species will lose their ability to thrive in the new urban microclimatic conditions. Some authors have argued that the effect of this in urban forests will probably be lessened because many trees in the city are alien species whose forest ranges do not correspond to natural patterns (Yang, 2009). However, it is yet unclear how alien and native species differ in their mal-adaptation to urban microclimatic conditions, and less to the added impact of climate change. Nonetheless, tree species mal-adaptation will be a significant issue in natural and unmanaged areas, as these may play a role in hinterland forest range shifts in the future (Woodall et al., 2010). So, all in all, it is logical to assume that climate change may exacerbate the stress that urban environmental conditions cause on urban tree species and causes them to be mal-adapted.

Two impacts of great concern are extreme weather and insects and diseases. An increase in intensity and frequency of storms, such as hurricanes or droughts, would mean more damage to urban forest stands and individual trees and also make them more susceptible to insects and diseases. An expected increase of frequency and intensity of wind events may exacerbate the significant loss of urban forest already caused by wind damage (e.g. Duryea et al., 1996; Thompson et al., 2011), specially in North America (e.g. Halifax, Burley et al., 2008; and Vancouver, Lawson, 2010). Beyond direct urban tree loss, reduced urban tree health, insects and diseases may have an intense effect on individual species, thus affecting the species diversity of the urban forest (e.g. Poland & McCullough, 2006; Karnosky, 2009), and this may be exacerbated with a change in temperature (e.g. Carroll et al., 2004). Emerald Ash Borer (EAB), for example is already one of the main causes in the reduction of urban forest services (Poland & McCullough, 2006; Donovan et al., 2013). However, it is yet unclear whether some of these insects and

diseases and driven by temperature. The concern so far is how reduced urban tree health due to climate stressors may exacerbate already-established insects and diseases threats.

Although the above effects have been garnered most of the attention, climate change will also have impacts of significance in urban tree habitat conditions at the ecosystem level. This is of particular concern in more naturalized urban forest stands. Here, and as with hinterland forests, climate change may affect tree regeneration rates, their representativeness in the forest, their age diversity, and their general health and aesthetics (Johnston et al., 2009). For example, tree species more suitable to the new conditions may invade a site that had before not been suitable. Moreover, more frequent and intense fires, particularly in peri-urban areas (Ligeti, 2007; Whitman, 2013) may influence invasiveness (Smith et al. 2012). Most of the concern is focused on invasive alien species, which would affect mostly unmanaged areas, like naturalized parks or abundant tree stands. Seed recruitment in the urban environment may change considerably due to climate change, especially considering that urban areas have a high content of exotic species (Kostel-Hughes et al., 1998). Moreover, already-established, middle-aged, healthy trees may be more capable to endure climate change, while younger trees, such as seedlings, and old trees, will probably not (O'Brien et al., 2012).

The impacts of climate change on urban forests will affect the provision of values to humans, and in turn, human influences in the urban forest may downplay many of these impacts. At the ecosystem scale factors that contribute more to the thriving of a particular tree species may include habitat microclimate, seed dispersal, biotic interactions, genetic adaptations, and human decisions including land development and tree protection, among others. However, the long-term significance of climate change impacts can never be underestimated. Climate-driven ecosystem changes ultimately affect the way the urban forest functions and the values it provides. A way to explore management responses is by discussing the precise meaning of mitigation and adaptation in urban forest management.



### *6.5.3 Urban Forest Responses to Climate Change*

#### *6.5.3.1 Mitigation*

Climate mitigation refers to the reduction of GHG emissions. As discussed above, urban forests reduce net GHG emissions by capturing carbon from the air and reducing energy use. Although carbon storage by urban trees is not a significant contribution to reduce global, national or even local emissions, it is not a trivial contribution (Nowak & Crane, 2002). Urban forest management can increase carbon capture by increasing the urban canopy cover and by planting trees that grow to a larger stature and can eventually capture more carbon. The urban forest could be optimized to follow such a growth and age structure. Moreover, carbon capture can be increased by species selection. The development of a carbon-species-selection matrix is crucial for this approach (Nowak et al., 2002). The arrangement of trees in relation to buildings could also be optimized to contribute to energy efficiency. Finally, urban forest maintenance also creates GHG emissions, and reduction in this area would involve tackling the technological, social and economic factors involved. However, as mentioned above, much uncertainty exists in this area given that carbon accounting has not been embraced fully in urban forest management.

Climate mitigation considerations have been well characterized before (e.g. Abdollahi et al., 2000; McPherson et al., 2008). In fact, some urban forest management plans developed in North America refer to such management practices (e.g. SeattleGov, 2007; City of Calgary, 2007), although much detail on carbon accounting is still needed (Chapter 3). Nonetheless, operationalizing this response in management is difficult without a coupled mitigation-adaptation approach, as the impacts of climate change may downplay many of the GHG emission reduction effects given the vulnerability of urban forests to the coming changes in climate. Thus, a discussion of adaptation is important to see urban forest management responses to climate change in a more comprehensive way.

### 6.5.3.2 *Adaptation*

Adaptation is the adjustment of a system in response or in anticipation to changing environmental conditions that depends on the system's vulnerability, degree of impact, level of risk, and adaptive capacity (Brooks, 2003). There are two facets of an adaptation response in an urban forest setting: using urban forests to help cities adapt to change, and adjusting the urban forest to climate change.

The effects of climate change in the urban environment can be mitigated by vegetation, as was mentioned in the earlier discussion of climate change and urban areas (section 6.4). Studies that demonstrate the amelioration of the heat island effect in cities point to the reduction of temperature by vegetation (Rosenfeld et al., 1998; Simpson, 1998; Shashua-Bar & Hoffman, 2000; Gill et al., 2007; Bowler et al., 2010). Trees also have an effect on air quality, a relevant topic as climate change is expected to decrease air quality in the urban environment due to higher temperatures and changing precipitation patterns (Akbari et al., 2001; Nowak et al., 2006; Manning, 2008; Zimmerman & Faris, 2010). Urban trees are being referred as an important element in an urban adaptation strategy for mitigating climate impacts on urban areas (section 6.4).

Consequently, the focus of helping cities adapt by managing urban forests is to simply plant more trees (Lindley et al., 2006; Rosenzweig et al., 2007; Romero-Lankao, 2007; Hamin & Gurrán, 2009; Zimmerman & Faris, 2010; Romero-Lankao & Qin, 2011; Stone, 2012). It is known that this is an already-existing environmental strategy in urban forest management, at least in Canada (Chapter 3). Although planting trees is an important climate adaptation measure for cities, climate impacts on them may surpass their ability to help the city adapt, and more so in the urban environment where particular conditions already enhance stress (section 6.5.2). The microclimatic conditions of urban environments already trigger phenological changes in urban trees (Roetzer et al., 2000; White et al., 2002). The growing conditions in some urban environments already mimic drought conditions (Roloff et al., 2009). These effects can be compounded with other non-climate-related factors of stress, such as soil conditions (e.g. Lundholm & Marlin,

2006). Large trees in urban areas may be more prone to wind-throw (Yang, 2009). These issues point to the importance of climate adaptation in urban forest management.

Adaptation may be a more important consideration for urban forest management if a climate response is to be sustained in the long term, since mitigation response may be downplayed by a mal-adapted system. An example of this for urban forests is given by Ordóñez et al. (2010) using the four-option palette by Bizikova et al. (2007) including doing adaptation and not mitigation, or mitigation and not adaptation, or neither. On one end there is a no-action plan that has a net effect of increasing both emissions and vulnerability. A mitigation-only approach would concentrate on planting more trees in better locations, but with no consideration of species climate mal-adaptation or any other element of an adaptive response, the net effect would be decreased emissions combined with increased vulnerability. An adaptation-only approach would concentrate on planting trees that are, for example, better adapted to future climatic conditions, but one which may not consider planting more or planting them close to infrastructure, thus decreasing vulnerability but increasing emissions.

Adaptation can be achieved through a climate management strategy focused on reducing the system's climate vulnerability and increasing its adaptive capacity (Adger et al., 2007). It is important to note, though, that adaptation of an ecosystem does not necessarily mean a return to a past natural state (Spittlehouse & Stewart, 2003), even though natural restoration can increase resilience (Holling, 1996). Rather, it implies taking management decisions with a predicted climate scenario in mind and adjusting to uncertainty. Preliminary discussions about urban forest adaptation to climate change have addressed important issues such as planting more trees to help regulate urban microclimate (Gill et al., 2007), assisted migration of southern species (Yang, 2009; Woodall et al., 2010), and optimizing species mix (Rostami, 2012). While assisted migration is useful, drought and frost resilience must inform the adequate species selection (Roloff et al., 2009). Other criteria may be important. For example, the increase in frequency and intensity of windstorm events may require the selection of species with deep root systems (City of Calgary, 2007). Rapid regeneration may also be required to

counteract variability in climate, so fast growing species may be an asset (City of Victoria, 2009).

So far, many of the suggested adaptation strategies in the urban forest management literature are biophysical in nature, although there are suggestions for addressing issues related to the adjustment of institutional budget, development of new technologies, improving cost-efficiency, public consultation, inclusion and empowerment of private land owners, and raising the level of importance of the urban forest within public administration and community (BC-MCSCD, 2010; Ligeti, 2007). However, these are still vaguely stated, with no clear objectives. Climate adaptation in urban forests will be incomplete without full consideration of its human dimension. For instance, different permutations of urban tree species selection depend on the scenario under consideration and the intended characteristic of urban trees we want to sustain or enhance. An example will be to add detail to the way age structure and nativeness criteria are integrated in urban tree species selection. These have not been well studied in the context of climate change or in Canadian urban forest management in general (Chapter 3). I speculate that these criteria will be useful as climate management is adopted in urban forests.

As with climate management in urban areas, climate management in urban forests is being linked to already-existing environmental strategies. The focus, especially in Canada, is on planting more trees, optimizing species diversity, and planting southern species, with some vague ideas around social, economic, institutional, and policy issues. This reflects an interpretation of climate adaptation as that of mitigating climate impacts on urban forests rather than developing a systematic way to adapt urban forests to the climatic changes to come. The lack of an understanding of urban forest vulnerability to climate change, at both an ecological and social level, may be the main reason for these shortcomings. Indeed, adaptation in urban forests may involve reducing vulnerability in an ecological sense, but also in a social sense, particularly in areas of management such as awareness, access, institutions, ownership, governance, and knowledge (section 6.2). However, how these issues are specified at the local level depends on the vulnerability of the urban forests in question, and this is still a matter of future research and case studies.

## **6.6 Advancing the Climate Adaptation Agenda for Urban Forests**

It is evident from this discussion that climate management must be accommodated in urban forest management. Climate change is an added stressor to the already-established set of urban forest stressors. However, its wide-ranging effects may exacerbate many of the existing stressors. Understanding how mitigating these impacts or how to adapt to the effects is important in urban forest management. Urban forest adaptation to climate change is a promising area of future research in urban forest management, since most of the climate change and urban forest literature has focused on climate mitigation (McPherson et al., 2008; Nowak et al., 2002; Abdollahi et al., 2000) and the literature on climate change and urban forests is rather vague on how to address urban forest vulnerability to climate change (see discussion above).

A point of departure is to understand how climate change and urban forests interact. A conceptual map that illustrates how to adopt climate management in urban forest management can be built using the insights gained in this review (Figure 6.2). As climate management is downscaled to the level of urban forests, many of the overarching societal activities, such as economic production, are not directly applicable, and the urban forest management activities and framework takes a central role. In this map, climate impacts and vulnerabilities of urban forests span across the ecological and human dimension of the ecosystem. Ecosystem quality and integrity are influenced by and influence climate impacts and vulnerabilities, and are central, but by no means the only, foci of management. In turn, management activities exist in the human dimension of the system, and they respond to attitudes, values, and preferences, are determined by the knowledge of the ecosystem, and influence and are influenced by climate impacts and vulnerabilities (Figure 6.2).

By adopting climate management in urban forest systems, urban forest management is able to sustain the strongest array of values and maintain the quality and integrity of the ecosystem, with objectives, targets and indicators in mind. The integration of both

mitigative and adaptive responses is crucial to addressing climate change in urban forest management strategies, as they are closely interconnected and contribute to each other's goals (Pielke, 1998; Wilbanks et al., 2003; Klein et al., 2007).

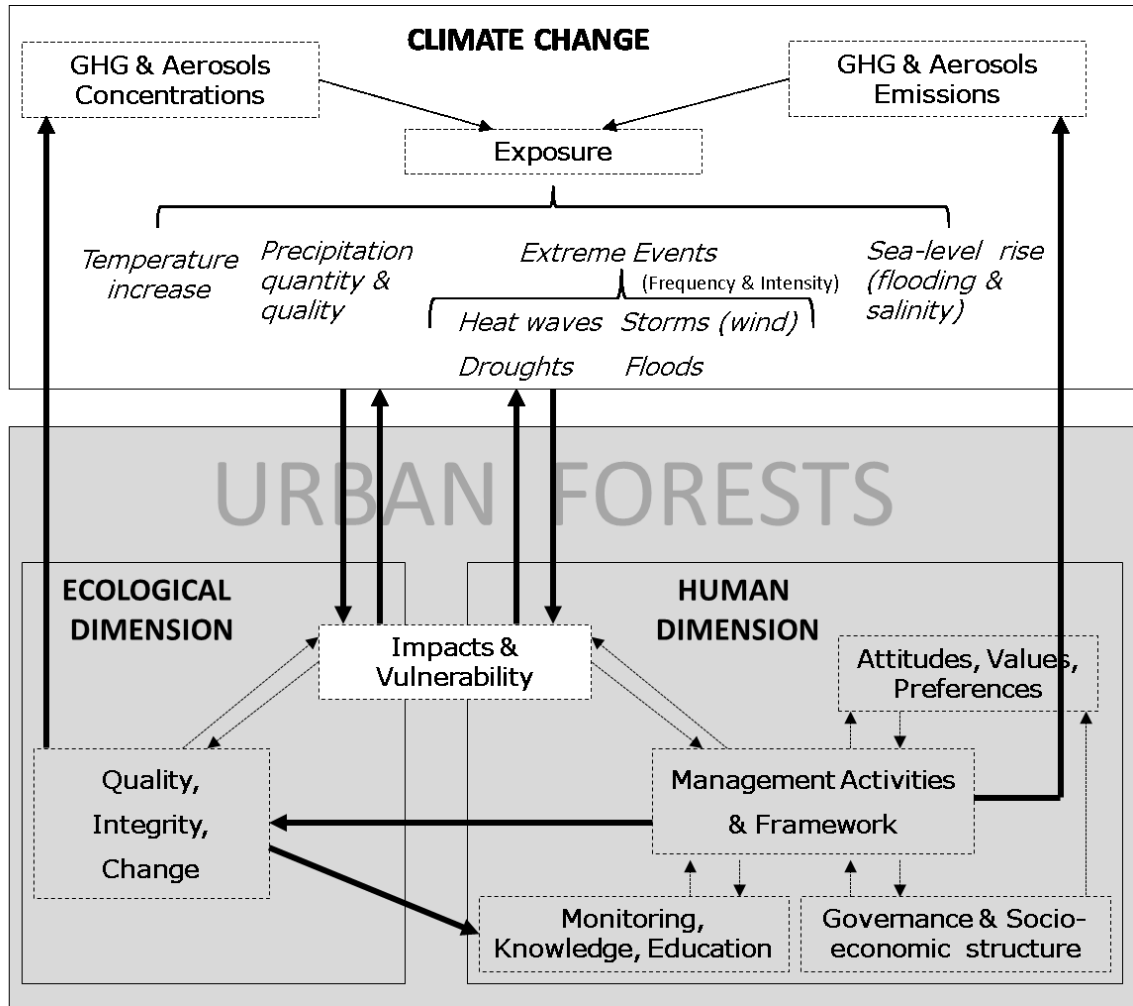


Figure 6.2: A conceptual map for adopting climate management into urban forest management

This conceptual map (Figure 6.2) is meant to be at a higher level of conceptualization, so no specific mitigation or adaptation actions are identified. The map demonstrates that climate mitigation and adaptation can be fitted into urban forest management and bring climate change to the forefront of urban forest decision-making. The map suggests two important ideas: 1) that a climate-sensitive urban forest management must respond to the

values that the community would rather sustain and to the specific vulnerability of the urban forest in question; and 2) that addressing climate change in urban forests depends on understanding and managing its vulnerability. Thus, undertaking a vulnerability assessment for the urban forest at the local level is necessary to understand the decisions that we take today towards the sustainability of this valuable resource.

## **6.7 Summary**

I have discussed in this chapter what climate change means for urban forest management and argued for expanding the literature on climate adaptation in urban forests. Informed by a discussion of climate science, and what climate management means in forests and urban areas, I reviewed how climate change has been understood in urban forest management, in references to its contributions, impacts, and responses. Climate change can be considered an added stressor to urban forests, its wide-ranging effects exacerbating many of the already-established stressors in the ecosystems. I revealed that the usual approach to address climate change in urban forests is mitigation, or the reduction of GHG emissions and carbon capture, and impact mitigation, or using the urban forest as a mean to increase resistance to future climatic changes. In addition, I argued that the discussion on climate adaptation is being guided by already-existing environmental strategies in urban forest management, which echoes the way climate is being managed at the urban level in general. I argue that any urban forest management framework fails to address the deep implications of urban forest sustainability if it does not address the climate question. If urban forest management is important to sustain the myriad values associated with urban trees, and if these values are threatened by climate change, then urban forests responses to this change should be framed appropriately by a clear understanding of climate adaptation. I mapped conceptually the way the ecological and human dimensions of urban forests interact with climate change and each other. By exploring this map I conclude that an effective climate adaptation response for the urban forest is only possible by understanding and managing urban forest vulnerability to climate change. Exploring how the vulnerability of urban forests to climate change can be assessed is the topic of my next chapter.

## **7 Chapter 7: Assessing the Vulnerability of Urban Forests to Climate Change**

### **7.1 Publication Information**

This chapter is based on the following publication led by me and co-authored by Peter Duinker, with added or modified content (section 7.2, Introduction; added references).

Ordóñez, C.; Duinker, P.; (2014). Assessing the vulnerability of urban forests to climate change. *Environmental Reviews*. Published Online 21 March 2014.

### **7.2 Introduction**

Climate adaptation is being embraced by many municipalities worldwide. An element of this is the planting and protection of urban trees. However, the fact that climate change will also have an impact on urban trees has been largely overlooked. As demonstrated in the previous chapter, climate change is a significant threat to urban forests. Although advancements have been made to understand what climate change means to urban forest management (e.g. Sukopp & Wurzel, 2003; Johnston, 2004; Ligeti, 2007; Yang, 2009; Roloff et al., 2009; BC-MCSCD, 2010), a thorough understanding of urban forest vulnerability to climate change is lacking.

Climate change vulnerability assessments (CCVAs) can be undertaken to provide a systematic understanding of ecosystem vulnerability, identify adaptation strategies, and help gear future management decisions that reduce climate impacts and enhance resilience (Füssel & Klein, 2006). Today there is little understanding of how CCVAs can be carried out for urban forests.

This chapter elaborates on the idea of urban forest vulnerability to climate change. Its purpose is to review and integrate the literature on urban forest vulnerability to climate change and develop a framework for carrying out CCVAs for urban forests. The



framework is focused in northern locations, particularly North-American and European urban forests, but I recognize that ideas may emerge that are applicable to similar, treed urban landscapes.

The chapter is laid out in the following way: in the first section I discuss climate change vulnerability concepts. The second section applies these concepts to urban forests by delving into a discussion of their exposure and impacts, and their sensitivity and adaptive capacity. The practical implications of undertaking a CCVA for urban forests are discussed in a later section. A summary is provided at the end of the chapter.

### **7.3 Climate Vulnerability**

Vulnerability is an important concept that helps grasp how a system is predestined to react to change (Timmerman, 1981). In general, vulnerability refers to the characteristics of a system that make it prone or unresilient to change (Adger, 2006). Vulnerability has been a pivotal concept in changing the climate discourse from one of mitigation and impact assessment to one of adaptation and vulnerability assessment (Burton et al., 2002).

Vulnerability is a broad term with myriad interpretations (O'Brien et al., 2007; Berkes, 2007). However, there is a general understanding that vulnerability is defined in the context of the system under consideration, the factors of vulnerability, the nature of the hazard or threat, and the time scale (Füssel, 2007). Factors of vulnerability may include exposure to the threat as well as the internal and external biophysical and socioeconomic characteristics of the system, such as its particular sensitivity, adaptive capacity, and the non-climatic factors and drivers that influence it (Füssel & Klein, 2006). Exposure is the nature and extent to which the system is exposed to significant climate variation, which encompasses temperature increases, precipitation changes, weather extremes and variability, among other elements. Sensitivity relates to the characteristics of a system that determine how it may react to exposure. Finally, adaptive capacity is the ability or potential of a system to respond successfully to change (Adger et al., 2004). This general

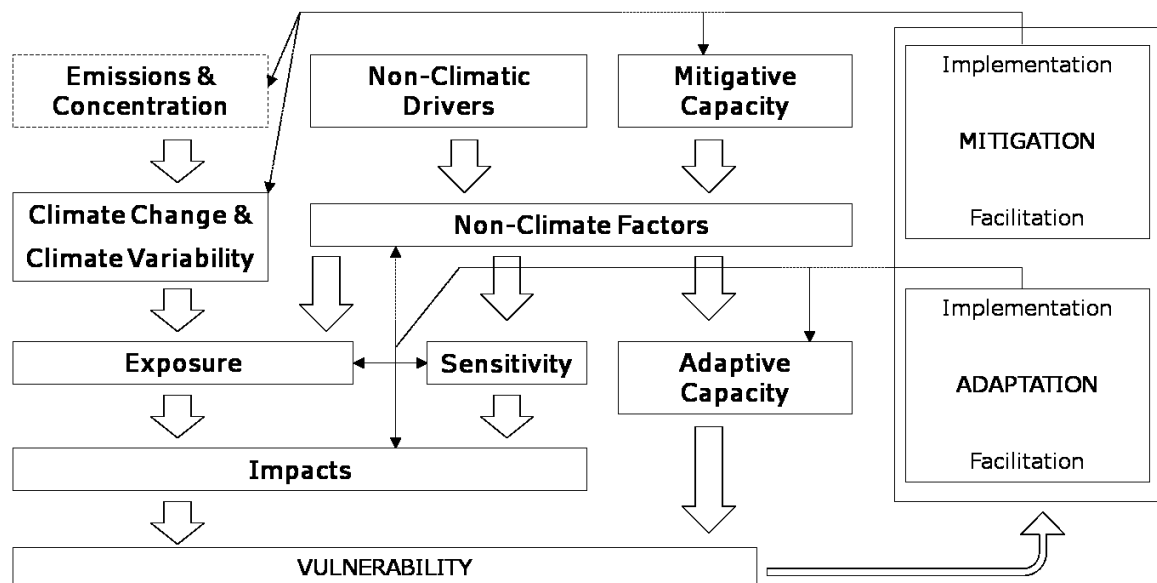
framework (Figure 7.1) applies to many types of ecosystems, including forests (Johnston & Williamson, 2007) and cities (Tyler & Moench, 2012) both of which inform urban forest climate vulnerability, as we shall see in the next section.

Regardless of the extent of the system, adaptive capacity usually involves coping characteristics related to socioeconomic factors (Yohe & Tol, 2002). Elements such as the existence of management institutions, their budgets, the quantity and level of skills of the staff employed, the ownership regime, governance and policy, social awareness and engagement, and economic valuation would all make a system more or less vulnerable (Kelly & Adger, 2000; Adger et al., 2004). What this means for ecosystems is not only that communities influence them, but that ecosystem vulnerability to climate change depends on a community's perception of risk; that is, climate vulnerability only has meaning in a social context (Berkhout et al., 2002). Thus, an understanding of ecosystem vulnerability requires a tacit knowledge of the values and expectations placed on it by a broad set of social actors at the local level (Adger, 1999; O'Brien et al., 2004). Ultimately, these values determine the way we think that climate change affects the ecosystem, how it affects us, and what we consider vulnerable or not.

Understanding ecosystem vulnerability to climate change is a requirement to develop adaptation strategies. Adaptation is the adjustment of a system in response to, or in anticipation of, changing environmental conditions, and it depends on the system's vulnerability, degree of impact, level of risk, and adaptive capacity (Brooks, 2003). Because adaptation can be planned, autonomous, anticipated, or reactionary, a move towards anticipated and planned adaptation can help reduce a system's vulnerability and increase its resilience (Adger et al., 2007). A vulnerability assessment can be the first step in this direction, providing a theoretical underpinning for differentiating which elements of the ecosystem will likely thrive and which will decline (Turner et al., 2003). It is important to note, however, that adaptation planning functions at a broader scale than a vulnerability assessment. Adaptive responses may be focused on particular vulnerabilities of that ecosystem, but not on others, due to practical or ideological reasons. Adaptive responses may be solely based on an impact assessment, although many authors would

refer to this as impact mitigation instead of genuine adaptation (Burton et al., 2002). Thus, an understanding of ecosystem vulnerability serves as a central cog in climate adaptation (Pielke, 1998).

Cities are crucial centres for climate adaptation and mitigation. Understanding vulnerability in urban areas is crucial for sustaining the economic activities of cities and the well-being of urban residents (Hallegatte & Corfee-Morlot, 2011). While urban climate change vulnerability research is growing in areas like water resources (Hunt & Watkiss, 2011), and coastal hazards (De Sherbinin et al., 2007), other areas such as natural services are still underdeveloped. One of the most important aspects of green infrastructure, which encompasses many natural services, is urban trees. They are well-cited in academic and non-academic literature as being a possible adaptation strategy for urban climate adaptation (e.g. Hamin & Gurrán, 2009; Zimmerman & Faris, 2010; Romero-Lankao & Qin, 2011). However, their vulnerability to climate change is not well understood. Below I elaborate on how climate vulnerability can be understood for urban forests.



*Figure 7.1: A general framework for understanding interactions of climate vulnerability elements (based on Füssel & Klein, 2006)*

## 7.4 Urban Forest Exposure and Impacts to Climate Change

Though climate change effects will vary across the globe, even modest projections suggest a considerable global mean surface temperature increase of 1.1-2.9°C by mid-century, and as much as 1.7-4.4°C if greenhouse gases (GHGs) continue to rise through late-century (Meehl et al., 2007). Vegetation in ecosystems will show the most prominent responses to climate change due to the dependence of global plant distribution on temperature (Parmesan & Yohe, 2003). The long-term effect of temperature increases will be that productivity falls (Fischlin et al., 2007) as air pollution and seasonal climate variability, both exacerbated by warmer weather, slow tree growth and cause stress (Bugmann & Pfister, 2000; Mohan et al., 2009). Forest range shifts will be a prominent latitudinal response in Northern areas (e.g. Kirilenko et al., 2000; Iverson & Prasad, 2002; McKenney et al., 2007; Bourque et al., 2010), restricting certain tree species to smaller areas or expanding the habitat range of others. Moreover, a higher concentration of CO<sub>2</sub> in the atmosphere may drive biomass growth in forests (Idso & Idso, 1994). However, much uncertainty remains about the positive effect of CO<sub>2</sub>-fertilization on forest productivity, with the problems of upscaling in modelling from plants to forests, and the role of limiting factors such as soil quality, being some of the top reasons to be skeptical about these positive effects (Oren et al., 2001). Thus, this exposure element is not included in this review. In addition, changes in disturbance regimes will also occur, such as storms, hurricanes, windstorms, pathogens, fire, drought, flooding, landslides, and their interactions (Dale et al., 2001). At the top of short-term concerns are invasive species and insect pests, which may rapidly become more widespread and abundant (Logan et al., 2003; Dukes et al., 2009; Smith et al., 2012), as well as wind (e.g. Peterson, 2000) and fire (e.g. Flannigan et al., 2000) damage.

Our understanding of urban climate exposure depends on the local downscaling of climate projections of temperature, precipitation, variability, extreme events, and sea-level rise (Wilbanks & Kates, 1999). As I discussed in Chapter 6, because of high resolution and the changing nature of local weather, good approximations of future urban climate are hard to obtain. Current climate projections do not account for urban areas due to the small climate potential (Stone, 2007). However, certain inferences can be made

from regional approximations by taking into consideration the particularities of the urban climate, such as the effect of enhanced temperature, or urban heat island (Souch & Grimmond, 2006), averaged at +2-3°C for most cities (Arnfield, 2003). Nevertheless, there is great seasonal variability in urban microclimate with some cities experiencing urban heat islands of almost +12°C in some periods (Blake et al., 2011). In terms of future climate, urban heat islands and air quality problems are expected to increase even within moderate climate scenarios (Wilby, 2007).

Again echoing some ideas from the previous chapter, it is known that cities suffer more heat stress (Gaffen & Ross, 1998) and that urban humidity regimes, at far as it has been assessed in the context of urban trees, often mimic drought conditions (Roloff et al., 2009). The opposite, urban flooding (Schreider et al., 2000) and urban-induced rainfall (Sheperd, 2006), are also important considerations, yet more research is need to understand how these affect urban trees in the long term. Urban habitat conditions already cause particular phenological responses, such as shortening of the growing season and prolongation of the end season (White et al., 2002) and changes in spring phenophases (Roetzer et al., 2000). There is an expected increase of frequency and intensity of wind events in future climate, which may exacerbate the significant loss of urban forest already caused by wind damage (e.g. Duryea et al., 1996; Burley et al., 2008; Thompson et al., 2011). Some tree species may be mal-adapted to these direct impacts as well as to other associated impacts such as insects and diseases, fire, and invasiveness (Johnston, 2004). Insects and diseases have been correlated to the reduction of urban forest canopy cover and reduction of urban forest health services (Donovan et al., 2013). However, it is still unclear the net effect of insects and diseases on urban forest services as a whole. More frequent and intense fires, particularly in peri-urban areas (Ligeti, 2007; Whitman, 2013), and increased invasiveness of species (Smith et al., 2012), which may affect ecosystem dynamics in naturalized urban forest areas, are also expected.

Climate exposure of urban trees can be characterized (Table 7.1). This characterization does not mean to prescribe all the required elements of a vulnerability assessment, but rather clarifies and categorizes the most important elements that may be included.

Ultimately, the detailed level of exposure and impact can only be determined at the local level (Schneider et al., 2007). For instance, while sea-level changes may only apply to coastal cities, snow events are only applicable to particular latitudes and altitudes. However, this characterization of exposure is simple and comprehensive enough to cover most of the relevant climate vulnerability themes for any urban forest.

*Table 7.1: Elements of climate exposure in urban forests*

<i>Type of Exposure</i>	<i>Element</i>	<i>Characterization by factor</i>
Direct	Temperature	Increase of temperature in the long-term
		Increase in the frequency and intensity of heat waves Increased temperature variability (e.g. maximum & minimum in shoulder season)
	Precipitation	Change in quality of precipitation (more or less snow/freezing rain) Increase in the frequency and intensity of rain events resulting in flooding
		Increase in the frequency and intensity of droughts
	Wind	Increase in the frequency and intensity of wind events
Associated	Sea-level rise	Increase in flooding events Increase in salinity concentrations in fresh water and soil
	Air Pollution	Increase in air pollution
	Fires	Increase or decrease in the frequency and intensity of fires
	Insects & Diseases	Increase or decrease in insects and diseases outbreaks and effects
	Habitat & Community	Increased invasiveness of species

## **7.5 Urban Forest Sensitivity And Adaptive Capacity To Climate Change**

Urban forest sensitivity and adaptive capacity can be characterized under two theme clusters: ecological and social. The ecological cluster receives most of the attention, since trees will have mainly biophysical reactions to the change in climate. Ecological sensitivities and adaptive capacities in forests are exhibited at the species level, capturing the responses to climate change at the tree species level, and at the habitat level,

capturing the broader ecosystem responses (Johnston et al., 2009). These two facets depend on forest structure, which refers to the species composition, age structure, health status, location, phenology, ecological linkages, and reproductive abilities (Johnston et al., 2009; Williamson et al., 2009). Moreover, any urban vulnerability assessment would be incomplete without full consideration of the wider community, since social engagement and knowledge, economic issues related to budgeting and valuation, and institutional and political issues related to governance and policies are important in the management of urban services (Wilby & Perry, 2006). In combination, these factors provide the broader management direction of the biophysically oriented adaptive strategies that may be identified by discussing ecological vulnerabilities. Below I identify the most important elements of climate sensitivity and adaptive capacity for urban forests (Table 7.2). Again, this characterization does not prescribe the required elements for a vulnerability assessment, but rather clarifies and categorizes the most important elements that may be included.

### *7.5.1 Ecological*

Because the ecology of urban trees can be partially understood through natural and hinterland forests, this discussion is informed by climate change and forest issues, although the emphasis is on urban-forest specifics.

#### *7.5.1.1 Species Structure*

The species composition of the urban forest seems to draw the most attention in determining climate sensitivity. This is unsurprising since forest resilience depends on its functional diversity, which is determined by its species composition (Holling, 1973; Peterson et al., 1998; Petchey & Gaston, 2009). Sensitivity at the species level in forests depends on tree diversity and representativeness, growth and reproduction, phenology, and physiological needs (e.g. temperature, hydrology, wind, and fire regimes). Sensitivity notwithstanding, evolutionary responses of tree species to climate change are expected, and some individuals and species may be better suited for the current climate than others (Bradshaw & Holzapfel, 2006). This adaptive capacity at the species level depends on

plasticity, dispersion, and evolutionary potential, which may in turn depend on population size, species distribution, generation type, and intra-species genetic diversity (Hamrick, 2004; Bradshaw & Holzapfel, 2006; Schwartz et al., 2006).

Some of these concepts have meaning in urban forest vulnerability. Urban forest structure is mainly characterized by low species diversity (Nowak, 1994). In Canada, a few dominant species represent approximately 50-70% of the urban forest in some cities (e.g. Kenney & Idziak, 2000). A homogeneous urban forest is intuitively more vulnerable to climate change because of the higher risk of tree loss due to species-specific threats, such as insects and diseases like the Emerald Ash Borer (Poland & McCullough, 2006). Moreover, many urban tree species may be unsuitable for the predicted future climate because of their climate range (Yang, 2009) or moisture sensitivities (Roloff et al. 2009). Because of this, urban forest adaptation can be geared towards optimizing species mix following a wide range of criteria including a balanced representation of species, genetic diversity, and other physiological criteria such as searching for southern propagules for northern countries (Yang 2009), and drought, frost (Roloff et al. 2009), wind (Kontogianni et al., 2011), and salinity (Florgård, 2000) resilience. Phenological considerations come into play, such as sensitivities to extreme or variable microclimatic conditions that already cause particular phenological responses (see exposure and impacts). Some growth and reproductive issues are also considered, such as rapid regeneration, which may be useful to counteract climate variability (Petchey & Gaston, 2009), and reproductive strategies and succession stages, which may be more or less favoured, as in the case of pioneer species (Hamrick, 2004; Bradshaw & Holzapfel, 2006).

Although species selection based on resistance to insects and diseases and urban habitat, and other growth and reproductive factors, is crucial for understanding climate vulnerability, other elements of urban forest structure may be important to consider. Taking examples from forest vulnerability assessments, the vulnerability of tree species may also be related to fragmented populations, endemic rare species, and low populations (e.g. Aubry et al., 2011; Brandt et al., 2014). Considering this, tree representativeness and



location and connectivity seem to be additional sensitivity elements. Given that location and connectivity are attached to habitat conditions, I discuss this element in the next subsection. As for tree representativeness, the concept adds to the notion of optimal species diversity and refers to increasing population sizes for a number of species categories, the most important of which are native and age class. Native tree species diversity captures the importance of rare and endemic tree species. This does not necessarily mean that native tree species do better in an urban environment - this can only be determined on species-by-species basis and on the particularities of the urban forest conditions. Rather, it refers to two practical considerations: 1. climate change will stretch the boundary at which nativeness is defined by influencing forest range shifts, which has practical meaning for tree survival since cold-adapted species will not do well in a future climate; and 2. the adoption of ecological principles into tree species selection (Ware, 1994), such as enhancing ecological integrity (Ordóñez & Duinker, 2012) and conserving endemic rare tree species (Stewart et al., 2009). Age class diversity captures the notion that seedlings and older trees may be less adaptable than mid-age trees (i.e. trees at the highest rate of growth), and other issues related to rapid regeneration mentioned above. Clearly, how these factors are specified at the local level depends on the particularities of the urban forest under consideration and the level of naturalization desired, which I discuss in the next subsection.

#### *7.5.1.2 Habitat and Ecosystem Dynamics*

As important as abating species-level mal-adaptation is to enhancing resilience, trees are still a key part of many ecosystems. Not only are most urban forest environmental benefits the outcome of there being a lot of trees (e.g. carbon sequestration, Nowak et al., 2002), but urban forest dynamics at the ecosystem level could affect the ecological processes of surrounding forests (i.e. rural forests) in the climate to come (Woodall et al., 2010). Taking an ecosystem and habitat perspective means moving beyond individual tree-species sensitivity and adaptive capacity and assessing the vulnerability of the ecosystem as a whole (Williamson et al., 2012b). In forests this means taking community structures such as connectivity of urban forest patches, ecosystem dynamics such as

competition, and ecosystem processes such as seed dispersion, decomposition, and nutrient cycling, as key components of vulnerability (Opdam & Wascher, 2004).

Ecosystem- and habitat-level dynamics have some meaning in urban forests. Some urban trees, particularly those in streets, are highly stressed (Nowak et al., 2004). Besides direct human disturbance, such as destructive building activities (Florgård, 2000) or bad tree pruning, the most evident stressors for street trees are small root space and soil compaction, poor soils, and poor provision of water (Sieghardt et al., 2005). Other stresses include the urban heat island, which causes some tree species to be mal-adapted (Sukopp & Wurzel, 2003; see also exposure and impacts). Together, stressors lead to artificially shortened life spans for street trees, in comparison to their expected life-spans, which is species-specific (Nowak et al. 2004). Beyond individual street trees, urban dynamics, which include human decisions, have negative effects on tree species diversity at the ecosystem level, with many urban forests in North America being dominated by a few tree species (see species vulnerability section). Finally, and beyond highly urbanized environments, urban trees in more naturalized environments are affected by fragmentation, caused mostly by urbanization, which influences many ecosystem processes, such as seed dispersal, negatively (McDonnell et al., 1997; Matlack, 1997; Kostel-Hughes et al., 1998; Heckmann et al., 2008). Taking this into consideration, climate change can be seen as an added stressor to the ecosystem in contrast to the effects of human-induced stressors. However, the degree to which one stressor is more important than the others is specific to the site and the tree. Ultimately, the determinant factor behind urban forest structure and function is human influence (Nowak, 1993). The idea here is to demonstrate how climate change can become a significant factor of stress for urban forests given their vulnerability at the ecosystem and habitat levels.

In contrast, other trees, particularly those already established in private lawns or parks, grow to be, in some cases, significantly large trees, again in comparison to their expected size or life-span in hinterland areas. Here the determinant factor can be a combination of human tending, fertilizers in the soil, or urban microclimatic effects, and may be site- and tree-specific (McPherson & Peper, 2013). Moreover, tree species diversity is high for

some urban forest sites, particularly parks (Bourne & Conway, 2014), and is being driven by changing landscape patterns in urban areas (Nielsen et al., 2014). This shows that although tree species diversity may be low at the ecosystem level, it is high at the habitat level, demonstrating that urban forest structure is highly differentiated. In many cases, and at the fine scale of an individual tree's biomass, or at the level of a particular landscape pattern, such as a park or private treed lawn, it can be argued that the influences of urbanization have a positive effect on urban forests. This is an important consideration, for these dynamics may compensate or mitigate the negative impacts of climate change. However, there is not enough evidence to draw from to illustrate how humans compensate for negative weather impacts on urban forests as a whole, such as watering private trees in a dry season, or draining soils during high rainfall. More research is needed to understand how human decisions mitigate or abate the negative effects of weather occurrences. This is related to the social dimension of urban forest vulnerability, which is discussed in the next section.

Based on this brief discussion, it is evident that another way to interpret ecosystem and habitat issues in considering climate sensitivity and adaptive capacity in urban forests is the degree of naturalization. Elements of naturalization may include reducing stress, improving growing conditions, enhancing plantings, connecting urban forest patches, and better location of trees. Stress reduction and improvement of growing conditions can take a very simple form, for example, establishing standards for soil volumes and watering regimes (e.g. City of Calgary, 2007). Planting enhancement echoes the notion that stress can be reduced by increasing the number of trees in the city, as urban heat islands, which are projected to increase due to climate change, can be mitigated by vegetation through the regulation of ambient temperatures, solar radiation, and evapotranspiration (McPherson et al., 1997; Shashua-Bar & Hoffman, 2000; Akbari et al., 2001; Streiling & Matzarakis, 2003; Gómez et al., 2004; Wong & Yu, 2005; Gill et al., 2007; Manning, 2008; Bowler et al., 2010). The traditional way to enhance urban forests is to plant trees in the available spots, but it may also involve planting more trees in one same spot, or planting densification. In general, the existing planting and stress reduction programmes in urban forest management are important determinants of vulnerability.

Connectivity and location encompass the arrangement of trees in relation to grey infrastructure and to each other. Together they capture the notion that many trees do not thrive in fragmented and highly urbanized environments (McKinney, 2002; Prasad & Badarinath, 2004) and that trees may cause damage to infrastructure if under stress or not properly tended (Lyytimaki et al., 2008). Increasing the size of tree communities, or urban forest patches (Wilby & Perry, 2006), promoting corridors and greenways, and planting trees in adequate sites according to their relation to infrastructure are ways to naturalize urban forests. Naturalization enhances ecosystem processes that are relevant to forest integrity at the habitat level. Naturalized spaces allow for increased seed (O'Brien et al., 2012) and tree (Nowak, 2012) recruitment, less biological homogenization (McKinney, 2006), better soil quality (Millward et al., 2011), and, at least theoretically and based in hinterland forest dynamics, higher genetic diversity (Hamrick, 2004). Other, less-technical aspects of naturalizing urban forests may also be influenced such as the provision of aesthetic (Nordh & Østby, 2013) and psychological (Peckham et al., 2013) values. Although realistically some urban trees may still need artificial care, assessing the level to which the urban forest is naturalized is a way to get into climate vulnerability without necessarily stressing naturalization as a normative notion for urban forest management in general.

## *7.5.2 Social*

### *7.5.2.1 Access, Awareness, and Engagement*

Urban forest vulnerability to climate change not only has meaning in the biophysical context, but also in the social context. Social issues reflect the fact that urban forest management is a social enterprise. For instance, public access to the urban forest resource, and community awareness and engagement are social themes that affect the way urban forest services are managed. Resource access is ultimately an expression of social equity, which is a prominent issue in climate vulnerability (Smit & Wandel, 2006). This does not escape urban resources, which are distributed unevenly (Tyler & Moench, 2012). In the case of urban forests, urban tree canopy cover can be correlated to higher

income, higher levels of education, age of neighbourhood (Heynen & Lindsey, 2003; Pham et al., 2013), and inversely correlated to ethnic minorities and home ownership (Landry & Chakraborty, 2009), among other social factors influencing resource distribution. This has serious consequences for the way some benefits are provided, such as climate amelioration (e.g. Streiling and Matzarakis, 2003), health (e.g. Donovan et al., 2013; Schipperijn et al., 2013), and amenity values (e.g. Donovan & Butry, 2010), although for many benefits it is difficult to distinguish between provision at the street or neighbourhood level and the coarse municipal level. Nonetheless, equal access to the urban forest resource contributes to addressing social sensitivities to climate stress.

Another social issue relevant to urban forest vulnerability is community awareness and engagement. Awareness can be fostered by the formal institution of management or through community-based groups, and through educational and informational activities, such as community courses, websites, pamphlets, and workshops. Community engagement refers to the existence of community groups, volunteer programmes, such as for planting, and community-based steering committees. Community groups, such as resident associations, are considered a luxury activity (Hope et al., 2006), since they are dependent on property ownership, income level, among other factors (Lorenzo et al., 2000; Conway et al., 2011). Nevertheless, they help raise awareness and empower citizens in relation to their urban trees (McLean & Jensen, 2004). This addresses resource continuity in management by referring to both public and private trees, which is crucial, for about half of the urban forest resource in North America is privately owned (e.g. Dwyer & Nowak, 2000; Kenney & Idziak, 2000; Nowak et al., 2001; Kuser, 2007). Although there is still much to understand about the governance dynamics displayed in formal and informal institutions behind urban forest management (Mincey et al., 2013), it is assumed that de-centralization of governance enhances resilience to climate change, since community awareness and engagement will ultimately result in more tree planting and protection, more public consultation, inclusion, and empowerment, and raising the level of importance of the urban forest within public administration (BC-MCSCD 2010, Ligeti 2007).

### *7.5.2.2 Economic*

A low budget is at the top of one's mind when one thinks of what makes the urban forest vulnerable to threats. In a planned and anticipated adaptation strategy, planting more trees, providing incentives for planting or replacement, selecting species better, producing information pamphlets, and allocating emergency funds may all take a negative toll on the urban forest management budget. Indeed, having the economic means to undertake climate adaptation measures is a crucial factor of vulnerability (e.g. Yohe & Tol, 2002; Adger et al., 2004; Klein et al., 2007; Schneider et al., 2007). Yet, however important it is to secure funding for urban forest enhancement and maintenance activities, it is difficult to predict whether a bigger budget will mean a more resilient urban forest. Besides the correlation of income and urban canopy cover at the neighbourhood level, there is yet no empirical evidence whether a city with higher per capita income is correlated with a higher quality urban forest. In fact, many urban centres with low income and budgets may display a good quality urban forest by all ecological and environmental measures simply by virtue of their immense natural forest remnants. This may be the case of cities in developing countries, although that is being challenged by increased urbanization in developing countries (Muthulingam & Thangavel, 2012; Chen & Wang, 2013; Andrade et al., 2013).

Besides budget, the economic activity associated with ecosystem management would make it vulnerable to change (Williamson et al., 2012a). In the case of forests, forest management takes its technology, resources, and institutional capacity from a system that is dependent on a centralized structure that determines its functionality, capital (i.e. financial, educational, property rights, and personal security), and information management (Johnston & Hessel, 2012). Such systems are less resilient to change given their socioeconomic inertia caused by a centralized and bureaucratic decision-making process, knowledge sharing, and resource allocation. Thus, reducing vulnerability implies increasing resourcefulness and cost-efficiency. This may involve, for example, pursuing economic independence from centralized budget allocations by seeking additional funding sources from provincial or federal agencies, the adjustment of institutional budget to specifically address climate adaptation, the adoption and/or development of

technology and innovation, and addressing cost-efficiency (BC-MCSCD 2010, Ligeti 2007). The existence of a carbon accreditation programme may also be included here, situated under adequate ecological considerations (Freedman & Keith, 1996).

Finally, a note must be made about economic valuation as a factor of climate vulnerability in urban forests. Economic valuation estimates urban forest ecosystem services in monetary terms and therefore makes it easier to facilitate economically-oriented decision-making in urban forest management (e.g. Tyrväinen, 2001; Oleyar et al., 2008; Young, 2013). Economic valuation has contributed to elevating urban trees to the level of urban service infrastructure (Nowak, 2006; Skärbäck, 2007). In many ways, the economic valuation of urban forest services helps not only to elicit an economic measure of climate impact, but also to develop a cost-benefit analysis of climate change adaptation practices. Together, these indicators come closer to the heart of economic vulnerability of an ecosystem (Eriksen & Kelly, 2007).

### *7.5.2.3 Institutional and Political*

What is done by the municipality is still the main focus of urban forest management. Municipal management can muster economic efforts, coordinate stakeholders and actors, harmonize municipal policy, and give a general direction to the management of urban trees. However, municipally-based management of climate vulnerability is challenged by an uncoordinated institutional framework, fragmented ownership and governance, and a limited budget (McCarney et al., 2011). It is also hindered by quality of knowledge and political will. Institutional knowledge contributes to climate vulnerability (Adger, 2001) and can be assessed by the quantity, diversity, and level of skill of the staff employed (Williamson et al., 2012b). This is applicable to urban forests, together with the degree of tune-in with public opinion (Chapter 3), knowledge of tree inventories (Miller, 1997), and establishing modelling techniques to understand urban tree responses to climate change (e.g. Whitman et al., 2013). Climate vulnerability may also involve the existence of municipality-coordinated responsiveness to climate-related threats, such as storms, insects and diseases, and fire. A formal programme in these areas helps divert resources efficiently and formalizes a planned approach to impending climate threats (BC-MCSCD

2010, Ligeti 2007). There is also a need for harmonizing municipal policies with urban forest ones by, for example, cementing the use of green infrastructure terminology (e.g. Nowak, 2006).

I can foresee that urban forest management will be challenged institutionally and politically by climate change in two important ways in relation to governance and policy issues. Preparing for these challenges demonstrates a will to reduce climate vulnerability, and therefore could be considered factors of vulnerability. First, if increasing ecological resilience and reducing impacts of climate change in the urban forest requires planting more trees and selecting adequate tree species, then many municipalities will find it challenging to meet their needs if local tree nurseries cannot produce enough of the right kinds of trees. In addition, with higher temperatures and wind events, pollen allergies may become more common, while wind-thrown trees may become a considerable liability issue for many municipalities. Addressing these issues may require adopting bylaws that simultaneously ensure public safety and prevent urban canopy loss. Obviously, whether a municipality has the ability to address liability by adapting existing tree bylaws may depend on the characteristics of urban forest management in each city.



Table 7.2: Elements of climate sensitivity and adaptive capacity in urban forests

Cluster	Theme	Elements	Characterization by factor
Ecological	Species	Diversity & representativeness	Species, genetic, native, and age class
		Growth & reproduction	Rate of growth, succession stage, and reproductive strategies
		Phenology	Budding, leafing, flowering, and fruiting
		Physiology	Requirements and tolerance to temperature, moisture, and salinity
	Habitat & Ecosystem Dynamics (Naturalization)	Location & connectivity	Patch connection, corridors/greenways, and tree arrangement in relation to infrastructure
		Planting enhancement	New plantings, densification, and forest patch size
		Ecosystem processes	Seed dispersal, competition, decomposition, and nutrient cycling and transport
		Stress & growing conditions	Soil, moisture, air pollution, insects and diseases, and human disturbances
Social	Access, Awareness & Engagement	Access to resource	Distribution of canopy cover/ecosystem services across socio-demographic factors
		Awareness	Information programmes (e.g. courses, website, pamphlets, etc.)
		Engagement	Education, community groups, volunteering, community-based steering committees
	Economic	Budget	Operational, incentives, emergency funds
		Carbon	Carbon accreditation programme
		Resourcefulness	New funding, new technology, cost-benefit analyses, funds for climate adaptation
		Valuation	Capturing the monetary value of trees by formal methods
	Institutional & Political		Staffing & Knowledge
			Communication
			Responsiveness
		Governance	
		Policies	

## **7.6 Climate Vulnerability Assessments in Urban Forests: Some Considerations**

Adaptation to climate change in urban forests implies taking management decisions with a predicted climate scenario in mind and adjusting to uncertainty. The focus of this review has been to understand urban forest vulnerability to climate change and its reduction as an adaptation strategy. I argue that to provide the best possible chance for sustaining the urban forest in a rapidly changing climate, it is essential that managers have the ability to identify what they need to do differently in the future, that is, which existing strategies and activities continue to make sense from a climate adaptation perspective. CCVAs are a key tool for informing adaptation planning and management (Füssel & Klein, 2006; Kelly & Adger, 2000). After discussing the themes behind urban forest vulnerability to climate change (see Tables 7.1 and 7.2) I now discuss the general characteristics of CCVAs for urban forests and outline some key considerations.

### *7.6.1 Principles, Goals, and Outcomes*

Developing and applying CCVAs to the urban forest will provide four essential contributions, as noted by Glick et al. (2011): First, CCVAs help identify which elements of the urban forest are likely to be most strongly affected by projected changes. Second, they help identify why these elements are likely to be vulnerable. Third, they help identify areas of future research. This is perhaps one of the main purposes of CCVAs in general, for it is the most common outcome when they are undertaken (Glick et al., 2011). And fourth, CCVAs provide critical information on where to put adaptive efforts, which may include: 1) building resistance to climate-related stressors; 2) enhancing resilience in order to provide the system with a better chance for accommodating and weathering changes; and 3) anticipating and facilitating ecological transitions that reflect changing environmental conditions (Walker et al., 2004). CCVAs also allow us to inform and craft adaptation strategies to allocate resources where they are most needed. At the least, CCVAs help us understand the direction of change in the urban forest's future and the factors that contribute to that change (Turner et al. 2003). This may imply whether there will be less or more urban forest, or less or more tree species in it.

### 7.6.2 Methodologies

Any CCVA must move towards an identification and assessment of sensitivity, and adaptive capacity, and elicit adaptive strategies that enhance resilience rather than resistance. Methodological approaches to a CCVA must fit this general framework.

Methods for undertaking CCVAs are based on models. These can be quantitative (e.g. using numeric indexes, response simulations, statistical validations), qualitative (e.g. using narratives and conceptualizations), or a mixture of both. On the one hand, quantitative assessment models can be based on ecological response models. These can vary between the conceptual characterization and expert-opinion based models to those based on mathematical modelling of habitat distribution, vegetation-habitat response, and physically-based constraints, among others (Glick et al. 2011). Such models can handle and synthesize large amounts of data to produce real numbers, indexes, or maps (e.g. Metzger et al., 2005). They can also be used to develop a one-size-fits-all assessment for comparison with similar systems, and in the case of the topic here, across cities and urban forests. Hitherto there is no comprehensive model for assessing urban forest vulnerability that addresses the diversity of factors discussed here. One could use models to capture one of the vulnerability themes, for example, the conceptual characterization and expert-opinion rating models that exist for individual tree species assessments (e.g. Young et al., 2011). They have the advantage to be simple enough to facilitate decision-making, but are not the sole basis to assess vulnerability of the whole ecosystem. Moreover, many quantitative models find it difficult to capture social and institutional indicators of vulnerability since many of these are difficult to translate into numeric terms.

On the other hand, qualitative models can be based on narratives and scenario analysis as ways to think about the future in words and not just in numbers (Swart et al., 2004). Qualitative scenario analysis can be used to explore issues of vulnerability and adaptation via participatory processes that can lead to a number of insights that simplify and clarify (Berkhout et al., 2002). Such collaborative efforts are ultimately abstracted mind games

based on a socially constructed image of reality, but can come close to being socially valid if explored jointly by multiple stakeholders and experts. These models are useful for capturing information that cannot be quantified, integrating social and ecological themes, exploring direction of thought in relation to climate change, and, if anything, providing a learning moment for managers (Gleeson et al., 2011). Since the realm of urban forest vulnerability to climate change is just taking off, this may be a good first stage for urban forest CCVAs since they can capture the totality of the climate threat and the totality of the urban forest system. These can also serve as a basis to develop numeric-based assessment models for particular vulnerability elements.

### *7.6.3 Limitations and Uncertainties*

There are limits to what CCVAs can do for ecosystem management. They do not provide priorities for management, as these are ultimately informed by the urban forest values of the citizenry and experts (Glick et al. 2011). They also do not provide an estimate of extinction risks or serve as the sole basis for assigning a risk status to a species. Rather, CCVAs provide a theoretical underpinning for differentiating whether an element of the urban forest will thrive or decline (Turner et al. 2003). Moreover, adaptation planning functions at a broader scale than CCVAs. In so saying, these assessments may provide insights into the relative vulnerabilities of urban forest elements as well as on the non-climatic factors that affect it. Some of these may go to the next level of identifying adaptive management responses, but others do not. Adaptive responses may also choose to focus on other vulnerabilities and stressors rather than those delineated by CCVAs due to practical or ideological reasons.

Finally, when undertaking CCVAs, we need to consider that we do not know the absolute magnitude of climate change and have no empirical basis to know exactly how urban forests may respond to it. We also do not know how our cities will continue to grow and evolve in the coming decades, or whether there will be cultural shifts that reduce or increase the importance of urban trees in society. However, uncertainty, or the expression of the degree to which a value is unknown because of disagreements of what is known or

even knowable, should not limit CCVAs and the development of adaptive options (Morgan et al., 2009). It is important not only to develop a language for addressing uncertainty in CCVAs, but also to consider the degree of confidence we might have in the conclusion of an assessment (Walker et al., 2003). The language used in the Intergovernmental Panel for Climate Change (IPCC) reports (IPCC 2007) is useful in this regard. It is important to remember that the least a CCVA can do is to tell us the direction of change and what factors are contributing. In the urban forest context, this may mean whether we expect more or less urban forest, species diversity, and survival rates, for example.

## **7.7 Summary**

In this chapter I reviewed and integrated the literature on climate vulnerability and urban forests and gave meaning to the notion of urban forest vulnerability to climate change. I argue that CCVAs are necessary for addressing climate adaptation in urban forests and contribute to successful climate adaptation in cities through the use of urban trees. CCVAs are incomplete if one stops at the level of impact assessment. By that I mean the assessment that identifies the impacts of climate change on urban forests and the ways to mitigate them. In urban forests, mitigating climate impacts may mean, for example, striving for higher species diversity if the urban forest is threatened by a species-specific insect or disease. Such an assessment adds climate considerations to a management strategy, but does not systematically assess the factors of susceptibility to help gear adaptive responses.

Here I discussed the themes that may be included in a CCVA for the urban forest. The most important themes in this discussion include urban tree species selection and diversity, naturalization, resource access, social awareness and engagement, budget and economic valuation, liability issues, and governance structures. I recognize that vulnerability assessments must be done at the local level and probably start from a qualitative, collaborative, and conceptual exploration of vulnerability of urban forests to climate change. These explorations may lead towards a quantitative evaluation of more-

specific vulnerability elements, such as for building biophysical response models. In general, CCVAs help us understand how and why urban forests are vulnerable to climate change, identify future areas for research, and determine what adaptation measures could be included in urban forest management. As urban forest management becomes more and more important in climate adaptation for cities, CCVAs can bring climate change to the forefront of the decision-making process in urban forest management, and urban forests to the forefront of urban climate issues.

In the next chapter I present and discuss the results of a CCVA for the urban forest in three Canadian cities. In a subsequent chapter I connect these results to urban forest values and discuss their implications in urban forest management.

## **8 Chapter 8: Climate Change Vulnerability Assessment of the Urban Forest in Three Canadian Cities**

### **8.1 Introduction**

Climate change is a considerable threat to social and ecological systems. Even a modest departure from mean temperature would imply considerable changes in regional and local weather (IPCC, 2007b). As I discussed in previous chapters, cities may be specially affected by temperature increases due to their microclimatic envelope, as well as by changes in precipitation, wind patterns, the frequency and/or intensity of droughts, floods, storms, and heat waves (Wilby, 2007), all the while distressing the majority of the world's population that lives in them (UN-HABITAT, 2012).

Understanding urban vulnerability to climate change is essential for attaining climate adaptation (Hallegatte & Corfee-Morlot, 2011). While much has been said about urban vulnerability in water resources (e.g. Hunt & Watkiss, 2011), the area of green infrastructure, especially urban trees, is still underdeveloped. While the enhancement of urban trees is a common urban adaptation measure (e.g. doubling tree canopy, City of Toronto, 2008), given their vital role in climate amelioration, the threat of climate change to urban trees has been mostly ignored. If urban forests are important for urban-climate adaptation, then urban-forest adaptation must also be carried out, and for this to happen urban-forest climate vulnerability must be assessed to maximize adaptation efforts. A way to address this concern is by undertaking a climate change vulnerability assessment (CCVA) of the urban forest.

I presented some guidelines in Chapter 7 on how to undertake a CCVA for urban forests using qualitative methods, which are useful for capturing information that cannot be quantified, integrating social and ecological themes, and thinking about the future collaboratively in words and not just in numbers. They represent a good place to start for CCVA assessment in urban forest, if anything, to evaluate direction of ecosystem change and the factors contributing to this change.

This chapter presents the results of an urban-forest CCVA assessment of three cities in Canada. The chapter is divided into three sections. In the first section I describe the CCVA method used. In a second section I present the assessment results. A third section delves into a detailed discussion of exposure, sensitivity, and adaptive capacity elements, the adaptive strategies that apply to the case studies, and the implications of adapting Canadian urban forests to climate change. Summary is provided at the end of the chapter.

## **8.2 Methods**

A CCVA was carried out in the Canadian cities of Halifax (formally known as the Halifax Regional Municipality, Nova Scotia), London (Ontario), and Saskatoon (Saskatchewan), with different urban forest characteristics (Table 8.1) and climatic projections (Table 8.2). The CCVA method was a qualitative, exploratory, and expert-based futuring method with a scenario in mind (e.g. Berkhout et al., 2002; Duinker & Greig, 2007), echoing some of the ideas behind participatory vulnerability analysis (Smit & Wandel, 2006; Douglas et al., 2008). The goal of the method was to achieve a consensual and informed judgement through the systematic exploration of urban forest vulnerability to climate change by consulting a panel of experts. The objectives were to identify the elements of climate exposure and urban forest sensitivity, the nature of the expected impact, and the adaptive capacities that exist. The goal was to obtain a sense of the importance of these elements and how they contribute to the total level of vulnerability of the urban forests. I also identified adaptive strategies that best fit these concerns,

A one-day workshop was delivered in each city with 10-16 expert participants each (total = 37). Participants included municipal urban foresters, arborists, city planners, landscape architects, staff from environmental, health, and education departments; academics with expertise in forest ecology and climate change, and members of environmental non-governmental organizations specialized in parks and waterways. Participants were selected via consultation with local municipal authorities and contacted via email or



phone. The workshop agenda included an introduction to the activity, two short presentations on urban forest characteristics (Table 8.1) and climate change projections (Table 8.2), and three discussion sessions guided by three sets of questions (Table 8.3). Flexibility was given to the direction of discussion. The discussions in the sessions were facilitated by the second author. Answers in each of the sessions were recorded textually and with the use of flipcharts, which were later translated into notes. This marked the end of the workshop activity.

The authors compiled data into a database and organized it into similar terms for exposure, sensitivity, impact, adaptive capacity, and adaptive strategies. Rudimentary figures were built for each city with the sensitivity and exposure elements that applied to that city, indicating the type of direct and associated impacts for each interaction. These illustrations proved essential for integrating and analyzing the data to assess overall vulnerability, and reveal similarities and differences among cities.

*Table 8.1: A snapshot of urban-forest characteristics for Halifax, London, & Saskatoon based on Statistics Canada (2006), City of London (2012), HRM (2012), CFS (2013), and M. Chartier (pers. comm.)*

<i>Characteristic</i>	<i>Halifax<sup>a</sup></i>	<i>London</i>	<i>Saskatoon</i>
Population	298000 (urban core)	360000	225000
Climate - forest zone	Atlantic – Acadian	Great Lakes – Mixed wood (edge of Carolinian)	Prairies terrestrial zone (edge of boreal plains) <sup>b</sup>
Number of trees (approx.)	9 million (urban core)	4 million (municipality)	100000-110000
Canopy cover (average % of land cover) and distribution (% of total in landscape category)	41% Urban core: 20% Outlying suburbs: 40-70%	24.7% Low density residential: 41%	Unknown (% of total urban trees in boulevards and centre medians: 60%)
Most common urban tree species (% of total urban trees)	Norway maple, European linden, and elm (approx. 50%)	Ash (genus) (approx. 10%)	Elm and Ash (genus) (approx. 50%)
Age/size diversity	Mostly mature/old (50-90years) in old neighbourhoods; varies in suburban and natural areas	77.5% of all trees < 15 cm in diameter	Mostly old (80-100years) in old neighbourhoods, young in new neighbourhoods
Main tree-loss concern(s)	Wind-throw, spruce budworm, fires (peri-urban areas)	Emerald ash borer	Water availability, Dutch elm disease
Common invasive species	Norway maple, Japanese knotweed	European buckthorn, Norway maple	European buckthorn, Siberian elm
Ownership regime	55% private	approx. 50% private	approx. 50% private

<sup>a</sup> Due to the great size of the Halifax Regional Municipality (HRM), the city and urban forest were defined within the urban core boundaries

<sup>b</sup> Trees are rarely naturally present in the Saskatoon area

Table 8.2: A modest climate scenario for Halifax, London, and Saskatoon based on Chiotti & Lavende (2008), Sauchyn & Kulshreshtha (2008), and Vasseur & Catto (2008)

Characteristics of Scenario		London (Southern Ontario)	Saskatoon (Prairies)	Halifax (Nova Scotia)	
<i>Parameters of temperature and precipitation scenario</i>		<i>Projections for 2080 by the GCM2 – Canada model, B2 scenario</i>			
<i>Climate Variables</i>	<i>Mean Winter temperature</i>	+ 4-5°C	+3.5-4°C	+ 4-6°C	
	<i>Mean Summer temperature</i>	+ 3-5°C	+ 3-3.5°C	+ 2-4°C	
	<i>Total Winter precipitation</i>	- 20%	+ 10-15%	+ 10-20%	
	<i>Total Summer precipitation</i>	- 10%	+ 0-15%	+ 10-20%	
	<i>Total Precipitation</i>	Unknown	+ 0-20%	+ 0-20%	
<i>Other Variables</i>	<i>Sea-level rise<sup>a</sup></i>	<i>Average level</i>	Not applicable	Not applicable	+ 0.73m
		<i>Storm surge</i>	Not applicable	Not applicable	2.67m

<sup>a</sup> Additional parameters for sea-level rise scenario (Halifax only): projections for 2100 with 2000 baseline

Table 8.3: Set of questions for each of the three workshop discussion sessions

<i>Session</i>	<i>Set of guiding questions</i>
Exposure, Sensitivity & Adaptive Capacity	<ol style="list-style-type: none"> <li>1. What exposure will the urban forest have to the expected changes in climate?</li> <li>2. How sensitive are the urban-forest components (species, tree ages, tree configurations, tree locations) to the expected climatic changes?</li> <li>3. If there were no adaptive capacity, and therefore no adaptation responses or actions, what impacts would we expect to see in the urban tree population?</li> <li>4. What adaptive capacities do urban trees have on their own? How might these mitigate the impacts?</li> </ol>
Adaptive Strategies	<ol style="list-style-type: none"> <li>1. What could you do about the vulnerability of urban forests?</li> <li>2. What should you do?</li> <li>3. Is doing this consistent with good urban forest management without climate change?</li> <li>4. What resources are needed? Can you get them?</li> <li>5. Here is \$1000 to spend now on vulnerability reduction; how will you spend it?</li> </ol>
General vulnerability and wrap-up	<ol style="list-style-type: none"> <li>1. Is the (insert city) urban forest vulnerable to climate change? If so, to what level? Why?</li> <li>2. Are you concerned? If so, why?</li> </ol>

### 8.3 Results

Exposure, sensitivity, and adaptive capacity elements, nature of impact, and adaptive strategies were recognized for each of the cities assessed (Figures 8.1-8.3). Some exposure elements were particular for each city. For example, winter precipitation was only discussed in Saskatoon and London, while sea-level rise only applied to Halifax. Other exposure elements were the same for all cities but had a specific quality. For example, variability in temperature in the shoulder season in Halifax was in terms of higher temperatures, while in London and Saskatoon was in terms of lower temperatures. The exposure elements that received the most attention in all the three cities judged by the many sensitivity associations were higher winds, drought, and seasonal temperature and precipitation variability expressed in terms of prolonged or contracted seasons. Concern for higher temperature was also common but had less sensitivity associations.

The discussion elicited only biophysical sensitivity elements of the urban forest (Figures 8.1-8.3). The elements most frequently mentioned in all three cities and that display multiple associations are young trees (seedlings and/or regeneration), followed closely by wet/dry-adapted tree species and cold-adapted or heat-intolerant species.

The kind of direct impact varied given the interaction between an element of exposure and one of sensitivity. The results capture this by differentiating between discrete impacts, such as increase in mortality, and combined impacts, such as decline in health and increase damage and mortality (Figures 8.1-8.3). Of these, increase in mortality was the most frequent impact. Moreover, the most frequently mentioned associated impacts by all three cities were susceptibility to insects and diseases (pathogens and fungi/molds), although the insect or disease of concern was specific for each city. In contrast, fire susceptibility as an associated impact was only recognized in Halifax (Figure 8.1).

Few adaptive capacities were recognized, with most of them referring to species selection, diversification, and pest management (Figures 8.1-8.3). Finally, the adaptive capacities recognized were mostly specific to each city (Table 8.4).

EXPOSURE		SENSITIVITY		IMPACT		ADAPTIVE CAPACITY
Cluster	Element	Element		Direct <sup>b</sup>	Associated	
Temperature Increase	Higher temperature (winter)	Cold-adapted, heat-intolerant tree species			Insects & Diseases driver (mold & fungi)	
	Days over 35°C	Cold-adapted, heat-intolerant tree species			Invasiveness of alien species driver	
Temperature Extremes		Young trees (seedlings / regeneration)				
	Hot, humid summers	Cold-adapted, heat-intolerant tree species			Insects & Diseases driver (pathogens)	
Temperature & Precipitation Variability (Seasonal)	Prolonged or contracted seasons	Phenologies			Insects & Diseases driver (pathogens)	
	Variable temperature & humidity in shoulder season (i.e. higher temperature)	Trees in peri-urban areas			Increased fire susceptibility (dry wood)	
	Less rain & soil moisture deficit	Wet/Dry-adapted tree species			Invasiveness of alien species driver; Insects & Diseases driver (pathogens)	
Drought		Trees in urban core				
	Cumulative, multi-year drought	Trees in peri-urban areas			Increased fire susceptibility (dry wood)	
Higher winds		Caliper trees <sup>a</sup>				
		Conifer tree species			Increased fire susceptibility (deadwood)	Diversification of tree species
		Mid-to-mature large trees			Insects & Diseases driver (pathogens)	Diversification of tree species
		Coastal trees				
		Trees in riparian areas				
Sea-level rise		Structurally weak trees			Insects & Diseases driver (pathogens)	Norway Maple phase-out
		Caliper trees <sup>a</sup>				
		Coastal trees				
	Higher storm surges/flooding	Trees in riparian areas				
	Salt water intrusion	Coastal trees				
		Salt-sensitive tree species				Diversification of tree species

a = Caliper trees refer to trees with Diameter at Breast Height (DBH) of approx. 5cm

b = Direct impact categories: **Combined impact: mortality, health, & damage** **Increased mortality** **Increased damage** **Decreased health/growth**

Figure 8.1: Exposure, sensitivity, category of impacts, and adaptive capacity results for Halifax

Cluster	EXPOSURE		SENSITIVITY		Direct <sup>a</sup>	IMPACT		ADAPTIVE CAPACITY
	Element	Element	Element	Element		Associated		
Temperature Increase	Higher temperature (overall)	Wet/Dry-adapted tree species	Wet/Dry-adapted tree species	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer)	
		Cold-adapted, heat-intolerant tree species	Cold-adapted, heat-intolerant tree species	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens); Range shift	Integrated Pest Management plan (Emerald Ash Borer); private care-taking of some relevant species	
		Trees in urban core	Trees in urban core					
Temperature extremes	Days over 35°C	Young trees (seedlings / regeneration)	Young trees (seedlings / regeneration)	Invasiveness of alien species driver		Invasiveness of alien species driver	Integrated Pest Management plan (Emerald Ash Borer); private care-taking of some relevant species	
		Cold-adapted, heat-intolerant tree species	Cold-adapted, heat-intolerant tree species	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer); private care-taking of some relevant species	
		Young trees (seedlings / regeneration)	Young trees (seedlings / regeneration)					
Temperature & Precipitation Variability (Seasonal)	Prolonged or contracted seasons	Phenologies	Phenologies	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer)	
		Trees in natural areas	Trees in natural areas	Changed succession dynamics (pioneering species favoured)		Changed succession dynamics (pioneering species favoured)		
		Cold-adapted, heat-intolerant tree species	Cold-adapted, heat-intolerant tree species				Integrated Pest Management plan (Emerald Ash Borer); private care-taking of some relevant species	
Drought	Less rain & soil moisture deficit	Fruiting tree species	Fruiting tree species					
		Variable temperature & humidity in shoulder season (i.e. lower temperature)	Variable temperature & humidity in shoulder season (i.e. lower temperature)					
		Wet/Dry-adapted tree species	Wet/Dry-adapted tree species	Invasiveness of alien species driver; Insect & Disease driver (pathogens)		Invasiveness of alien species driver; Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer)	
Winter Precipitation	No snow	Trees in subdivisions	Trees in subdivisions					
		Young trees (seedlings / regeneration)	Young trees (seedlings / regeneration)					
		Wet/Dry-adapted tree species	Wet/Dry-adapted tree species	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer)	
Shoulder Season / Summer Precipitation	Freezing Rain	Mid-to-mature large trees	Mid-to-mature large trees	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer)	
		Salt-sensitive tree species	Salt-sensitive tree species					
		Structurally weak trees	Structurally weak trees					
Higher winds (including tornadoes)	Abundant snow in shoulder seasons (Spring)	Wet/Dry-adapted tree species	Wet/Dry-adapted tree species	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer); Norway Maple phase-out	
		Street Trees	Street Trees	Invasiveness of alien species driver		Invasiveness of alien species driver		
		Trees in riparian areas	Trees in riparian areas					
Precipitation Variability	Abundant rain resulting in flooding	Young trees (seedlings / regeneration)	Young trees (seedlings / regeneration)					
		Trees in riparian areas	Trees in riparian areas					
		Wet/Dry-adapted tree species	Wet/Dry-adapted tree species	Invasiveness of alien species driver		Invasiveness of alien species driver		
Higher winds (including tornadoes)	Precipitation Variability	Trees in wetlands	Trees in wetlands	Invasiveness of alien species driver		Invasiveness of alien species driver		
		Mid-to-mature large trees	Mid-to-mature large trees	Insect & Disease driver (pathogens)		Insect & Disease driver (pathogens)	Integrated Pest Management plan (Emerald Ash Borer)	
		Street Trees	Street Trees					
Higher winds (including tornadoes)	Precipitation Variability	Trees in subdivisions	Trees in subdivisions					
		Structurally weak trees	Structurally weak trees					

b = Direct impact categories: Combined impact: mortality, health, & damage; Increased mortality; Increased damage; Decreased healthy/growth

Figure 8.2: Exposure, sensitivity, category of impacts, and adaptive capacity results for London

Cluster	EXPOSURE		SENSITIVITY		IMPACT		ADAPTIVE CAPACITY
	Element	Element	Element	Element	Direct <sup>b</sup>	Associated	
Temperature increase	Higher temperature (winter)	Young trees (seedlings / regeneration)					
		Cold-adapted, heat-intolerant tree species			Insect & Disease driver (pathogens)		Elm phase-out
Temperature & Precipitation Variability (Seasonal)	Prolonged or contracted seasons	Phenologies					
		Fruiting tree species			Insect & Disease driver (pathogens)		Elm phase-out
Precipitation Variability (Seasonal)	Variable temperature & humidity in shoulder season (i.e. lower temperature)	Mid-to-mature large trees					
		Fruiting tree species			Insect & Disease driver (pathogens)		Diversification of tree species; elm phase-out
Drought	Less rain & soil moisture deficit (winter)	Young trees (seedlings / regeneration)					
		Caliper trees <sup>a</sup>					
		Young trees (seedlings / regeneration)					
		Caliper trees <sup>a</sup>					
Winter Precipitation	Cumulative, multi-year drought	Wet/Dry-adapted tree species					
		Young trees (seedlings / regeneration)			Invasiveness of alien species driver		Street tree watering program
Shoulder Season / Summer Precipitation	Freezing Rain	Mid-to-mature large trees					
		Structurally weak trees			Insect & Disease driver (pathogens)		Diversification of tree species; elm phase-out
Higher winds	Abundant snow in shoulder seasons	Young trees (seedlings / regeneration)					
		Trees in parks					
Higher winds	Abundant rain resulting in flooding	Wet/Dry-adapted tree species					
		Mid-to-mature large trees			Invasiveness of alien species driver		Street tree watering program
Higher winds	Abundant snow in shoulder seasons	Young trees (seedlings / regeneration)					
		Structurally weak trees			Insect & Disease driver (pathogens)		Diversification of tree species; elm phase-out

a = Caliper trees refer to trees with Diameter at Breast Height (DBH) of approx. 5cm

b = Direct impact categories: Combined impact: mortality, health, & damage Increased mortality Increased damage Decreased health/growth

Figure 8.3: Exposure, sensitivity, category of impacts, and adaptive capacity results for Saskatoon

Table 8.4: Adaptive strategies results indicating cities where they were mentioned

Strategy	Elements	Cities
Climate proofing by species selection	Resistance to higher temperatures, drought, and water-logging (in riparian areas), wind (i.e. short at maturity, deeper roots, wood firmness ), and insects & diseases	All three
Climate proofing by maintenance and planting standards	Improve drainage in parks; develop non-potable water irrigation and soil volume and quality requirements; no plantings on water-competitive sites; increase plantings in nursery from seed; strict rules for arborist training; frequent young tree pruning	Saskatoon
	Increase whip plantings, density (tree-to-tree distance and group plantings); and native/rare/at-risk tree species representation	All three
	Remove fire hazard species and trees from highly-stressed urban sites	Halifax
	Intensify insect & disease monitoring and data collection	All three
Climate proofing by diversification	Decrease % representation for any one genus; increase age and size diversity	All three
	Increase representation of tree species at the edge of climatic zone or native to forest region	Halifax & London
	Increase ratio of conifers to non-conifers	London & Saskatoon
Climate proofing by naturalization	Enhance natural parks (natural regeneration); more trees in train & park corridors	Halifax
Institutional, political, & community	Investigate feasibility of own nursery or enhance capacity	Halifax & Saskatoon
	Communicate urban forest issues via city climate agenda or other existing agenda (e.g. "livable cities", "forest city", "health" agendas)	Halifax & London
	Develop or utilize existing zoning instruments for urban forest protection	Halifax
	Seek NGO partnership for volunteer plantings and advancing green infrastructure policy; communicate better with private landowners to avoiding cutting small trees	Halifax & Saskatoon
Economic	Increase budget for new plantings (internal & private) & fire tree removal	Halifax
Knowledge & research	Develop urban-forest-climate response and valuation models to identify impacts	Halifax & London
	Develop urban forest habitat classification system & long-term study on tree-survival/health/growth	Halifax
	Establish experimentation and demonstration plots at nursery	Halifax & Saskatoon



## 8.4 Discussion

### 8.4.1 *Climate Change Projections & Exposure*

As with most climate projections, the climate scenario used in this assessment (Table 8.2) contains relatively confident temperature projections but less-certain precipitation ones given that these vary considerably depending on the emission scenario, the spatial scale, and the model used (Meehl et al., 2007). The key to understanding climate scenarios is to assume changes in precipitation quality and manifestations along the extreme values of temperature and precipitation ranges (IPCC, 2007b). These two notions resonate in the choice of exposure elements for discussion in each city (Figures 8.1-8.3) with most of the attention going into higher winds, more drought, and enhanced seasonal temperature variability. Although there are many other exposure elements to consider (Figures 8.1-8.3), these three elements express the most important climate exposure considerations and reflect current urban forest loss and damage concerns. For instance, extreme wind events are rare in Canadian urban environments, but when they occur they can cause considerable short-term urban forest loss (e.g. Halifax, Burley et al., 2008). This may be enhanced with the probable increase in frequency and intensity of storms in all three cities (Chiotti & Lavende, 2008; Sauchyn & Kulshreshtha, 2008; Vasseur & Catto, 2008). Moreover, although it is difficult to give meaning to drought in a city environment given the complexity of urban water availability, drought is a common urban forest concern (Roloff et al., 2009). Projected increases of drought may cause additional stress to urban trees. Saskatoon is a special example (Figure 8.2), given that no tree is native to the city, yet drought is already affecting the boreal forest north of it (e.g. Hogg et al., 2008). Finally, seasonal temperature and precipitation variability expressed in terms of prolonged or contracted seasons already affects urban tree phenology (e.g. White et al., 2002), and this may be exacerbated with higher temperature and moisture variability (Chiotti & Lavende, 2008; Sauchyn & Kulshreshtha, 2008; Vasseur & Catto, 2008).

#### *8.4.2 Direct and Associated Climate Impacts*

Impacts were characterized according to the direct effects of climate exposure elements on sensitivity elements and the indirect effects these sensitivity elements may be exposed to due to other climate-driven stimuli (Figures 8.1-8.3). These effects were included as an indication that further health, damage, and mortality concerns are expected besides the ones caused by direct climate exposure. The most frequently mentioned associated impact was insects and diseases and invasive species, which reflect current urban forest concerns. For instance, significant urban forest loss in North America has been caused by insects and pests (e.g. Poland & McCullough, 2006) and climate change may exacerbate this stress factor (Dukes et al., 2009). Moreover, there is a general recognition that climate change will enhance the ability of invasive species to reduce ecological and environmental functions of ecosystems in Canada (Smith et al., 2012). Although invasive plant species are already a concern in all three cities (Table 8.1), it is still uncertain whether climate change influences these species directly and more research may be needed in this area.

#### *8.4.3 Sensitivity, Adaptive Capacity, & Adaptive Strategies*

Almost every exposure element identified in this assessment, including extreme and variable temperatures and humidity, winter precipitation, and wind, increases seedling and small-tree mortality. This may challenge urban forest enhancement, identified in the introduction as a prominent effort to mitigate higher urban temperatures. Needless to say, data produced by the monitoring of young tree survival is important information to progress research in this area. Previous calls for monitoring urban-forest health have not discussed new planted streets extensively (e.g. Mcpherson, 1993).

Ascertaining young-tree survival is an important consideration. The adaptive strategies that target this including planting smaller trees (i.e. whips), planting trees closer together (i.e. densification), improving habitat conditions via soil and watering standards or naturalization, and establishing experimentation plots in nurseries (Table 8.4). Whip planting and densification are not well-established in the arboricultural tradition, although

some Canadian municipalities refer to their possible use (e.g. City of Victoria, 2009; City of Nanaimo, 2010; City of Kingston, 2011). The assumption is that whips may adapt better as they grow in uncontrolled environments in contrast to caliper trees, and that group plantings may increase chances of survival for at least some of the plantings, although whips and dense plantings may require more tending. Moreover, naturalization, or increasing the naturalness of the urban forest through connectivity and enhancing natural forest areas, is an interesting strategy aimed at tree survival. The notion resonates with the suggestions of some authors that most urban forest regeneration occurs in natural areas (Nowak, 2012) and that seed recruitment is encouraged in the microclimate of more naturalized areas (O'Brien et al., 2012). Finally, a limited availability of good-quality tree stock from nurseries challenges achieving planting goals and developing customized solutions to climate adaptation (e.g. species diversity, species resilience). Experimentation plots could be used for research and to increase public acceptance of what the urban forest could look like before taking it out to the street.

The sensitivity of tree species with specific temperature and moisture requirements includes the elements of wet/dry-adapted tree species and cold-adapted, heat-intolerant tree species, which can be discussed together given the close relationship between temperature and moisture. In general, this sensitivity reflects the notion that species will be mal-adapted to a climate that most species have not naturally evolved in (Johnston et al., 2009). This will be more evident in urban areas, which display an enhanced temperature increase and moisture deficit (Sukopp & Wurzel, 2003; Yang, 2009). This means that optimizing tree-species selection and diversifying the urban forest are important considerations, particularly given the low diversity of the urban forests in these three cities (Table 8.1). The adaptive strategies that reduce this vulnerability include climate-proofing by avoiding cold-adapted tree species, increasing representation of species that withstand extreme humidity changes, such as water-logging or drought, and decreasing representation of tree species affected by known insects and diseases (Table 8.4).

The strategies noted above reflect the notion that representativeness may be a more important concept to enhance resilience to climate change than species richness itself (Hamrick, 2004). This is relevant since small population sizes may make some tree species more vulnerable to climate change (e.g. Aubry et al., 2011; Brandt et al., 2014). The favouring of native, endemic, and at-risk trees species mentioned by all three cities (Table 8.4) echoes this idea. Furthermore, because addressing mal-adaptation means addressing forest range shifts, assisted migration is an important consideration for cities positioned along natural forest boundaries (Yang, 2009; Woodall et al., 2010; Rostami, 2012). This notion is almost meaningless in Saskatoon given that trees are not natural to the area and the natural vegetation south of that city is grassland. The call for choosing species at the edge of the climatic zone or native to the forest region indicates that a balance must be achieved between the risk of bringing in a new species, such as the rate of introduction overtaking the capacity for the new species and other established species to thrive, reproduce, or even survive, and the learning opportunity through trial and error (Park & Talbot, 2012).

Other sensitivity elements that are worth discussing include the mid-to-mature large trees, structurally weak trees, and tree phenology. Some authors have mentioned the possible susceptibility of large mature trees given the possibility of increased wind-throw and damage (e.g. Yang, 2009). As mentioned before, although infrequent, wind-throw can be a reason for significant urban forest loss in Canadian cities (e.g. Halifax, Burley et al., 2008; Vancouver, Lawson, 2010). Infrastructure damage due to wind-throw is also a big concern in urban forests in general (e.g. Duryea et al., 1996; Jim & Liu, 1997). This may cause significant reduction in the environmental services of trees, given the strong relationship of these to trees of large stature (e.g. Xiao et al., 2000; Nowak et al., 2006; Kenney, 2008). Increasing resilience to wind throw may comprise not only planting trees that are smaller at maturity, but also improving the growing conditions of large trees and avoiding structural damage, another big contributor lack of urban forest health (Florgård, 2000; Kontogianni et al., 2011). Finally, the mentioning of phenological sensitivities echoes what has been said about urban forest particular phenological dynamics (see Roetzer et al., 2000; White et al., 2002; Sukopp & Wurzel, 2003). However, this element

does not seem to contribute significantly to vulnerability gives its low impact level (Figures 8.1-8.3).

The brief discussion of these biophysical sensitivities, adaptive capacities, and strategies indicates the possibility of establishing some of these elements as vulnerability indicators. Developing response models and populating these elements with data was important for Halifax and London (Table 8.4) and will be a good way forward for creating future urban-forest growth scenarios under a changing urban climate. Moreover, research and experimentation are needed to fine-tune and verify the climate-proofing strategies discussed here. The idea of experimentation plots indicated by Halifax and Saskatoon is crucial to fulfilling the knowledge need (Table 8.4).

It is important to note that although institutional, social, and economic sensitivities were not captured in this assessment, the development of these is crucial for addressing vulnerability of the urban-forest management system. The adaptive strategies identified here give some direction as to what elements may be important for choosing vulnerability indicators in these areas (Table 8.4). For instance, institutional capacity was addressed through the existence of zoning instruments for urban forest protection and driving political attention to urban forests by adhering urban forest issues to the official city agenda. These two elements are important to influence the way municipal governments implement long-term planning, since some authors note that short-term institutional perspectives make it hard to adopt climate adaptation (Næss et al., 2005). Moreover, governance issues are addressed with the existence of tree-protection communication strategies that deliver the right message to the community. This is crucial since almost 50% of the urban forest in each city is not owned by the city (Table 8.1). As the field of urban forest adaptation to climate change advances, more indicators can be recognized. An important step has been made here to facilitate this advancement.

Overall, it can be said that climate change is both a threat and an opportunity to urban forests in Canada. This research demonstrated that the urban forests of Halifax, London, and Saskatoon are vulnerable to climate change, but this vulnerability is relative to the

specific exposures, sensitivities, and adaptive capacities recognized in our CCVA assessment. In many ways, embracing adaptive management may be the cornerstone for managing climate change in urban forests, as it demands monitoring of action implementation and system response and strongly promotes system-scale experimentation, thus jointly embracing uncertainty and finding systematic ways to reduce it (Duinker & Trevisan, 2003). This may also work for developing indicators and robust climate-response models that consider both species and habitat-level urban-forest vulnerability, among other future avenues for research in urban forests and climate change, which are crucial to successful climate adaptation in cities.

#### *8.4.4 Limitations and Further Research*

A number of limitations are evident in the way these CCVAs can be used for making inferences about how to identify, evaluate, and reduce urban forest vulnerability to climate change.

Foremost, many of the inferences in this study are not framed under a species-specific perspective. For instance, and as inferred by the data, stating that particular climate drivers will increase urban young tree mortality regardless of the species misses the species-specific aspect of forest vulnerability to climate change. Certain tree species in Canada have particular vulnerabilities to climate change, while others may be more resilient (Johnston et al., 2009). Moreover, some have argued that the only way to understand an ecosystem's vulnerability to climate change is to undertake species-based assessments (e.g. Young et al., 2011). However, as discussed in Chapter 7, the rationale for undertaking this kind of exploratory assessment was to assess the vulnerability of the whole ecosystem. Ultimately, in this assessment the species-specific vulnerability to climate change in urban forests is captured under the themes of cold-adapted, heat-intolerant species, and wet/dry-adapted ones, among others. The idea that most, if not all, young urban trees, regardless of species, are vulnerable to climate change would not have been captured if the CCVA delivered was species-based. Thus, there is some strength in

the insights gained with this type of assessment as it captures vulnerability at an ecosystem level for different characteristics of trees (see Chapter 7).

Furthermore, the ecological conditions of the three cities, although diverse and representative of some of the most important inhabited regions in Canada, do not encompass all the possible ecological conditions under which urban trees grow. A relevant environment for exploring the influence of temperature variability in climate change projections is high-altitude ecosystems (Meehl et al., 2007). Forest responses at high-mountain elevations are expected to be large, with many high-altitude species being at risk of disappearing due to climate change (Parmesan & Yohe, 2003; Mora et al., 2013). However, Canada has very few high-altitude cities, thus it is unclear how this will be useful in Canada. Nevertheless, and at a global scale, it would be ideal to undertake a CCVA for urban forests in cities at high altitude and explore different ideas from those contained in these case studies.

As mentioned in Chapter 7, it is difficult for an urban forest CCVA to account for the macro-level urban changes that may occur in the future, particularly changes in the degree of urbanization, changes in population influx, and changes in the design of the built environment. Some explorations on how urban forest management is carried out in highly-urbanized environments indicate a lack of space for tree-planting and high levels of stress in street trees (e.g. Jim, 1998; Zhu & Zhang, 2008). Indeed, exploring the influences of infrastructure conditions in enhancing or reducing climate effects on urban trees is an important endeavour, particularly considering that in some urban areas tree-planting is occurring in unconventional urban spaces, such as on top of buildings (e.g. Jim, 1999). As such, this CCVA taps more into the ecological climate vulnerability of urban trees rather than the vulnerability caused by the physical and chemical influences of the built environment on the way trees grow. More research is needed to understand how the built environment enhances or reduces climate vulnerability for urban forests and for how to infuse future CCVAs with this information.

Finally, the influences of human tending and economics are crucial issues that were not elicited thoroughly in these CCVAs. Some of these were discussed briefly in Chapter 7 (section 7.5.1.2). Generally, more information is needed on how human activities enhance or reduce the vulnerability of urban trees to weather stress in order to understand climate change responses in urban forests. Moreover, and although participants in this study recognized that budgets have little to do with their vulnerability (Table 8.4), the emergent idea of changing tree-planting strategies will probably affect the municipal urban forest budget. Exploring changes in budget in relation to tree planting, and, in a broader way, the economic activity around urban forest enhancement, is an important feature of understanding the economic dimension of urban forest vulnerability to climate change. For instance, vital economic studies have been done for comparing urban forest enhancement against other strategies for air quality regulation (Escobedo et al., 2008). However, no similar studies exist for comparing GHG emission reduction, although broad-scale studies suggest some possible avenues for valuating GHG emission reduction through urban forest management (e.g. Chen & Jim, 2008). From an adaptation perspective, it will be interesting to explore economic issues comparing urban-forest micro-climate amelioration strategies to other types of strategies in cities.

## **8.5 Summary**

In this chapter I presented an approach to assess the vulnerability of urban forests to climate change through an exploratory, expert elicitation-based method delivered in the Canadian cities of Halifax, London, and Saskatoon. The results of this research show that temperature increases and variability, higher winds, and drought are important climate exposure elements, and young tree survival and tree species mal-adapted to extreme changes in moisture and extreme heat are important sensitivity elements. Insect and diseases and invasiveness are also important impacts. The sensitivity of young trees and mal-adapted species to the future climate may challenge urban forest diversity, species representativeness, and urban-forest enhancement efforts in these cities. This means that the cities not only need more trees, but the right kinds of trees in the right places. Taking measures to increase urban-forest species representativeness and density, to experiment



and develop alternative planting strategies and species-selection criteria, to increase cooperation and coordination among municipal entities to enhance the importance of urban forests, and to communicate better with the public, will help Canadian urban forests adapt to climate change. How these vulnerability elements threaten urban forest values, and how a values-based urban forest management framework accommodates climate change considerations are topics for the next chapter of this dissertation.

## **9 Chapter 9: Linking Urban Forest Public Value Provision and Urban Forest Climate Vulnerability: Integrating and Mapping Insights**

### **9.1 Introduction**

Urban adaptation to climate change is dependent on the sound management of urban nature. One of the most important aspects of urban nature is urban trees. Urban forests provide myriad values to urban residents including climate amelioration (Chapter 6) and psychological wellbeing (Chapters 4 and 5), among many others. The provision of these values through urban forest management is threatened by a variety of stressors. One of these stressors is climate change (Chapter 6). With its wide-ranging effects, climate change may exacerbate some of the already-recognized stressors in urban forests. In Canada, the issue of addressing the vulnerability of urban forests to climate has not been addressed in many Canadian UFMPs (Chapter 3). This is crucial since urban forests are also vulnerable to climate change and the adaptation of urban forests to climate change is also required (Chapters 7-8).

In general, the biophysical changes in urban forests triggered by climate change will affect the degree to which urban forest management provides values to people (Chapter 5, section 5.5). However, up till now, there is no indication as to what is the mechanism involved in the way climate change vulnerability threatens the provision of urban forest values. Understanding this mechanism is important, and this can be done by linking the empirical work in this dissertation.

In previous chapters, I explained how urban forest managers can respond to public urban forest values not only through technical fixes, like planting more trees or increasing tree diversity, but also by enhancing the natural experience in the city through the provision of high quality, diverse, and accessible urban forest spaces. I also demonstrated how adopting a values-based paradigm of urban forest management means encompassing a broader set of urban forest values and democratizing the management process by probing

the public consistently, thus helping advance an alternative, community-based stewardship of urban tree management (Chapter 5).

In parallel, I explained how climate change has been addressed in urban forest management chiefly through mitigation and linking adaptive strategies to already-existing environmental ones. I argued how tackling climate adaptation implies reducing the climate vulnerability of urban forests, and how this has not been done systematically yet (Chapters 6 and 7). Using a participatory assessment method and based on the opinion of urban forest experts, I showed how three urban forests in Canada will be exposed to higher winds and ice storms, increased variability in temperature and precipitation, particularly contributing to increased drought conditions, and insects and diseases. These exposure elements and impacts will increase the mortality of young and newly-planted urban trees and increase the mortality, damage, and decrease the health of mal-adapted urban trees species. They will also affect to a lesser extent urban trees of large stature, trees in peri-urban areas, particularly coniferous, trees that are structurally weak, trees that are stressed, and trees in highly urbanized areas, or those that are surrounded by concrete or pavement. Reducing their vulnerability implies taking measures to increase urban-forest species representativeness and density and experimenting with alternative planting strategies and species-selection criteria. It also entails increasing cooperation and coordination among municipal entities, with the goal of enhancing the importance of urban forests. Finally, it also involves communicating better with the public (Chapter 8).

These insights inform the following discussions. The focus here is to understand the mechanism of how urban forest vulnerability to climate change affects urban forest value provision. This is done more systematically than simply connecting the results textually through a discussion. Rather, I chose to do an analysis of the data that will provide me with a map of linkages that simplifies the main ideas behind the influence urban forest vulnerability to climate change has on urban forest value provision. Ultimately, this allows me to explore the most promising ways to manage urban forest public values in a changing climate, thus responding to the third question of this research and fulfilling the final goal of this dissertation. I aim to make connections to what vulnerability means to

value provision and urban forest management, thus enhancing current urban forest management practices and aiding practitioners' decision-making.

The chapter is divided into two sections. The first section connects urban forest public values to climate vulnerability through a simple conceptual mapping method. The second section is a discussion that helps understand how these two themes are related and how a values-based and climate-change-sensitive urban forest management can be achieved. The chapter is summarized at the end.

## **9.2 Conceptual Mapping Analysis**

A point of departure for understanding how climate change vulnerability affects urban forest public values is to discuss how urban forest sensitivity elements identified in Chapter 8 influence value provision using the value themes developed in Chapter 5. Sensitivity elements are the focus of this analysis because they provide information on urban forest characteristics, here simply called urban-tree traits, which can be correlated to value provision and climate change, thus providing an indication of linear influence. The general purpose of this analysis is to understand how the elements of urban forest that are most likely to be affected by climate change influence value provision. This is possible given the insights gained in the literature review in Chapter 2, the research on public values in Chapters 4 and 5, and the empirical research that recognized the most pressing sensitivity elements in Chapter 8. To this end, I re-organize the data contained in the previous chapters, develop a mechanism based on logical associations that relates climate drivers, urban-tree traits (as expressions of urban forest sensitivity elements), and urban forest public values, and map these linkages in a more systematic way than simply discussing the results textually. The analysis and its results are explained below in more detail.

This analysis was carried out in four stages. The first stage was to simplify the information on climate exposure and impacts in Chapter 8 with simple terms that expressed climate drivers. The second stage was to transform the sensitivity elements into

expressions of urban-tree traits and relate them to the simplified climate drivers, derived from the stage above, and as included in Chapter 8. The third involved simplifying the values typology contained in Chapter 5 and relating them to urban-tree traits. Finally, the fourth stage involved mapping how climate drivers, urban-tree traits (as expressions of urban forest sensitivity), and urban forest values are linked.

### *9.2.1 Climate Exposure and Impacts as Climate Drivers*

The objective in this stage of analysis was to re-organize the data according to the most important sensitivity elements, following the data on Figures 8.1-8.3, extract the associated climate exposure and impact elements, and simplify them as climate drivers. The results (Table 9.1) show that the most significant climate drivers that influence urban tree vulnerability are: 1) temperature and precipitation variability that results in drought and heat stress; 2) temperature and precipitation variability that results in ice storms; 3) increase in frequency and intensity of wind events; 4) increased effects of insects and diseases, and invasiveness; and 5) increased probability of fire. Since susceptibility to fires is correlated to drought and heat stress, given that it is dry and hot conditions that exacerbate fires (Chapter 8), this element can be eliminated as a stand-alone driver. Ice storms can be related to wind events and create a stand-alone physical driver of wind and ice. And finally, insects and diseases and invasiveness can be considered together as a biotic climate driver. Thus, three simplified climate drivers can be used to facilitate the mapping of linkages: 1) drought and heat stress; 2) wind and ice; and 3) insects and diseases, invasiveness.

*Table 9.1: Selected sensitivity elements and associated exposure elements and impacts  
(based on Chapter 8)*

<i>Category</i>	<i>Sensitivity Element</i>	<i>Associated Climate Exposure Elements</i>	<i>Associated Impacts</i>
Size & age of urban trees	Young trees	Abundant snow in shoulder seasons (Spring)	
		Cumulative, multi-year drought	
		Days over 35°C	
		Higher temperature (winter)	
		Higher winds	
		Hot, humid summers	
		Increased air pollution	
		Less rain & soil moisture deficit	
	Variable temperature & humidity in shoulder season (i.e. lower temperature)		
	Mid-to-mature large trees	Freezing Rain	
	Higher winds		
	Variable temperature & humidity in shoulder season (i.e. lower temperature)		
Species of urban trees	Cold-adapted, heat-intolerant tree species	Days over 35°C	Invasiveness of alien species
		Higher temperature	Insects & Diseases
		Hot, humid summers	Insects & Diseases
		Prolonged or contracted seasons	
	Wet/Dry-adapted tree species	Abundant rain resulting in flooding	Invasiveness of alien species
		Abundant snow in shoulder season (Spring)	Invasiveness of alien species
		Cumulative, multi-year drought	Invasiveness of alien species
		Higher temperature	Insects & Diseases
		Less rain & soil moisture deficit	Insects & Diseases
		No snow	Insects & Diseases
Location of urban trees	Street trees	Abundant snow in shoulder seasons (Spring)	
		Higher winds	
	Trees in urban core	Increased air pollution	
		Less rain & soil moisture deficit	
	Trees in subdivisions	Higher winds	
	Less rain & soil moisture deficit		
Condition of urban trees	Structurally weak trees	Abundant snow in shoulder seasons (Spring)	Insects & Diseases
		Higher winds	

### *9.2.2 Sensitivity Elements as Urban-Tree Traits*

The objective in this stage of analysis was to re-organize the data according to the most important sensitivity elements, following the data on Figures 8.1-8.3, extract the associated most important elements, convert them into simplified urban-tree traits, and associate them with the applicable climate drivers (above). The results (Table 9.1) show that sensitivity elements can be classified according to four themes: 1) the size and age of urban trees; 2) the species of urban trees; 3) the location of urban trees; and 4) the condition of urban trees.

The size and age of urban trees category includes the sensitivity elements of young trees and mid-to-large mature trees (Table 9.1). These two elements represent urban-tree traits of their own, while mid-to-mature large trees can be simply termed large trees. They are related to climate drivers in the following ways (Table 9.1): 1) young trees are mostly affected by drought and heat stress and wind; and 2) mid-to-mature trees are mostly affected by wind and ice. Although wind is coupled with ice as a climate driver, it is important to note the caveat that ice was not recognized in Chapter 8 as an element affecting young trees (Chapter 8). These associations were mapped accordingly (Figure 9.2).

The species of urban trees category includes the sensitivity elements of cold-adapted, heat-intolerant tree species and wet/dry-adapted tree species (Table 9.1). These two sensitivity elements can be amalgamated under the more generic urban-tree trait of tree species, which in this context captures the species-specific sensitivity to climatic changes. They are related to the climate drivers of drought and heat stress and insects and diseases, invasiveness (Table 9.1). These associations were mapped accordingly (Figure 9.2).

The location of urban trees category includes the sensitivity elements of street trees, trees in the urban core, and trees in subdivisions (Table 9.1). All of these elements can be amalgamated under the urban-tree trait of trees surrounded by urban infrastructure, which represents trees in the urban landscape that are surrounded by concrete, asphalt, and

buildings. They are related to the climate drivers of drought and heat stress and wind and ice (Table 9.1). These associations were mapped accordingly (Figure 9.2).

Finally, the condition of urban trees category includes the sensitivity element of structurally weak trees (Table 9.1). The element can be renamed as stressed trees and reflect an urban-tree trait, and which implies trees that have a poor health condition associated with already-existing urban forest stressors, in this case structural damage. However, the climate drivers associated with this urban-tree trait will be the same as those associated with trees surrounded by urban infrastructure, since many stressed trees are exposed to urban forest stressors by the fact that they are in more urbanized environment. Thus, this element is related to the all climate drivers, chiefly drought and heat stress, wind and ice, and insects and diseases, and invasiveness. These associations were mapped accordingly (Figure 9.2).

### *9.2.3 Urban-tree Traits and Urban Forest Values*

The objective in this stage of analysis was to relate the urban forest values in Chapter 5 to the urban-tree traits (above). However, the data on urban forest public values in Chapter 5 were rich, and difficult to manipulate for this analysis. Therefore, value descriptors were condensed by selecting the most important value themes based on their frequency of mention, as indicated in Figure 5.7 (Chapter 5). The dozens of descriptors identified in this figure were converted into 24 themes by selecting only the top descriptors or amalgamating others into comprehensive or overarching ones. The resulting themes were categorized according to the same frequency of mention used for the descriptors, including high, medium, and low frequency of mention. Some descriptor categories were condensed more than others, but low differentiation was compensated by a high frequency of mention. For instance, all the aesthetic descriptors were amalgamated into a general “aesthetics” theme, with the theme receiving a high frequency of mention. Similarly, many psycho-social and natural/ecological descriptors were amalgamated into few themes, but most received a high frequency of mention. In contrast, environmental and economic descriptors retained their original wording but only clean air received a



high frequency of mention. The idea was to simplify the list of descriptors while retaining a differentiation of themes and a sense of importance through frequency of mention (Figure 9.1).

The relevant urban-tree traits in this discussion, chiefly young trees, large trees, tree species, trees surrounded by infrastructure, and stressed trees (see above) can be associated to urban forest values in very general terms. The most important ideas behind this association are discussed below.

The size and age of urban trees influence urban forest values in the following way: trees of large stature satisfy urban forest values the most, since many urban forest values related to aesthetic, environmental, and psycho-social categories are strongly associated with large trees (Chapters 2, 4, and 5). On the other hand, young trees, or trees of small size and of young age, are not associated strongly with urban forest values, since most people do not recognize them as important features of urban forests that satisfy their values. However, young trees do express the trait of age diversity, which can be associated with biodiversity (Chapters 2, 4, and 5). These associations were mapped accordingly (Figure 9.2).

Broad generalizations relating tree species and values are hard to make, except for the general notion that species diversity influences biodiversity, aesthetics, and sense-of-place values. Generally, the way the tree species trait is related to values will depend on the way species are categorized. For instance, in terms of a simple broadleaf/needle-leaf, or conifer/non-conifer, categorization, broadleaf trees influence environmental and aesthetic values strongly, given the relationship between leaf area and environmental services, and leaf-colour change and visual aesthetics (Chapters 4 and 5). In terms of a native/non-native categorization, native trees influence connection to nature and sense of place strongly (Chapters 4 and 5). Finally, flowering and fruiting trees influence food and aesthetic values. In short, tree species can only be associated with biodiversity, aesthetics, and sense-of-place values. These associations were mapped accordingly (Figure 9.2).

The location of trees is highly related to urban forest values, and in general, the closer trees are to people, the more valued they are, both in terms of environmental services (Chapter 2), and in terms of psycho-social effects (Chapters 4 and 5). These associations were mapped accordingly (Figure 9.2).

Finally, it is logical to say that only trees that are in good condition influence values positively, while trees in bad condition do not influence values at all. There is the possibility that trees that need maintenance generate employment opportunities. However, employment is not recognized as an important public value related to urban forests (Chapters 4 and 5; Figure 9.1). Thus, stressed trees do not influence values at all in this analysis (Figure 9.2).

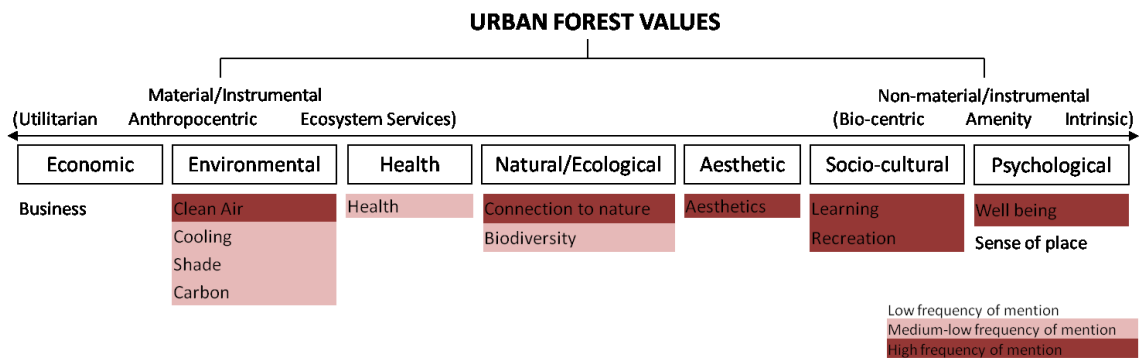


Figure 9.1: Urban forest values simplified (based on typology in Chapter 5)

#### 9.2.4 Map of Linkages between Urban Forest Vulnerability and Values

The relationship between urban forest vulnerability to climate change and urban forest values is explored by mapping the linkages between climate drivers, urban-tree traits, which express sensitivity to climate change, and urban forest values (Figure 9.2). The map shows some important patterns. Starting from the climate drivers, drought and heat stress will strongly affect values provision through their effects on trees surrounded by urban infrastructure. Wind and ice will affect values through their effects on large trees. The map also suggests a simple decision-making mechanism for reducing urban forest vulnerability to climate change and providing the most urban forest values. This may

involve planting the right species of trees that can grow to large statures close to infrastructure, while at the same time ensuring that they survive their infancy and are not stressed. Lowering stress may mean ensuring trees are not structurally weak, but also that they have more natural conditions, as discussed in Chapter 8.

However, the map of linkages has limitations. One of the most important limitations is that it considers urban-tree traits to be isolated from each other, when in reality, urban-tree traits are not mutually exclusive. For instance, large trees could be surrounded by infrastructure and be stressed. Young trees can be of a particular tree species that is cold-intolerant. The most important relationship is perhaps the fact that young trees have the potential to become large trees in the future, and depending on their species, location, and condition, they can respond to climate drivers in different ways. An expression of this limitation is that the map shows how multiple climate drivers affect tree species and stressed trees, but it also shows that these have a limited or non-existent influence on value provision (Figure 9.2). In addition, it shows how insects and diseases, and invasiveness affect tree species diversity but how this urban-tree trait does not affect values significantly. This is intuitively contradictory, since stressed trees of a species that is cold- or heat-intolerant can be surrounded by infrastructure and be large, thus it does actually influence values strongly. Moreover, insect and diseases can increase the mortality of many urban tree species, and if this has a high representation in the species mix of the urban forest, then its effects on value provision can be devastating. Thus, the influence that urban forest vulnerability has on value provision may be higher than suggested by the map and it is useful to note that the map has limitations in the way urban-tree traits interact.

Despite its shortcomings, the map is useful to serve as a basis for discussion to explore how urban forest vulnerability to climate change is related to urban forest value provision. This is addressed in the following section.

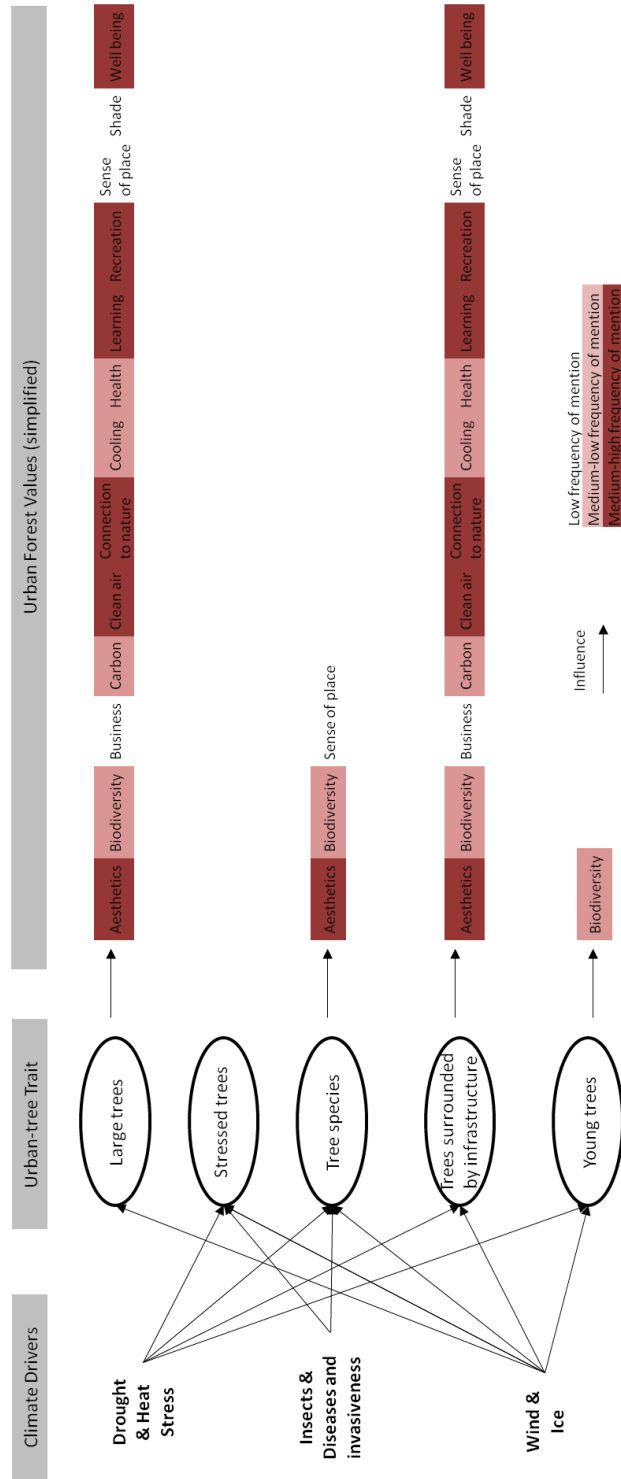


Figure 9.2: Conceptual map of linkages displaying results of analysis integrating climate drivers, urban-tree traits (as expressions of sensitivity) and urban forest public values, indicating direction of influence and frequency of mention of value descriptors

### 9.3 Discussion

The analytical exercise in this chapter suggests that the way urban-forest vulnerability to climate change influences public value provision and satisfaction depends on three main characteristics of trees: how big they are, how close they are to infrastructure and people, and the naturalness of their surroundings. This has implications for value provision, as discussed below.

The map exercise suggests that young trees, the most climate-sensitive aspect of urban forests, does not influence value provision significantly, while large trees, only a moderate climate-sensitive element, influences value provision strongly (Figure 9.2). The literature also confirms this. Trees with a prominent leaf area provide the most environmental benefits, given that leaf area is the single most important factor for air filtration and moisture regulation (Xiao et al., 2000; Nowak et al., 2006; Kenney, 2008). Medium-size trees are associated with increased carbon capture and large trees are associated with high carbon storage (Nowak et al., 2002). Thus, the imminent damage of large stature trees due to climate exposure will have considerable impacts on urban-forest value provision and reduce value satisfaction, even though these trees are only moderately sensitive to climate change (Chapter 8). Thus, it is safe to say that young-tree mortality poses no immediate threat to urban-forest value provision. It is only in the potential of these trees attaining a large size that will have a long-term effect on the way urban forest public values are satisfied.

However, this insight must not be taken too literally. It is useful to point out that, at least some people will have values associated with young trees, and ecologically, young trees are vital for the replacement of trees and health of the ecosystem. Ultimately, more research is needed to understand how young tree mortality is actually affected by weather changes and how young trees influence value provision.

Trees that are close to infrastructure and people influence value provision significantly (Figure 9.2). These trees influence climate amelioration the most (e.g. McPherson et al., 1997; Shashua-Bar & Hoffman, 2000; Wong & Yu, 2005; Gill et al., 2007) and people

have strong aesthetic, psychological, and environmental connection to them (Chapters 4 and 5). Their decline due to climate change may mean a considerable reduction of their climate-mitigating function, which is a curious, if not ironic, effect of climate change on urban forests. However, and as stated before, more research is needed to understand how urban tree mortality is actually affected by weather changes.

As pointed out in the description of how the conceptual map was created, the stressed trees urban-tree trait is connected to trees surrounded by urban infrastructure given that many trees that are stressed are in that condition due to the fact that they are located in highly urbanized environments. Trees surrounded by urban infrastructure influence value provision strongly. This is an interesting connection, since it may mean that tree stress is also associated with value provision. This insight is echoed in the literature. For instance, the decline of structurally weak trees due to climate change may affect safety concerns in the community, making people feel threatened by trees instead of connected to them (e.g. Lyytimaki et al., 2008). Earlier I argued how naturalizing the habitat in which urban trees grow is a way to reduce their vulnerability to climate change (Chapter 8), and also a way to influence value provision, since people have strong aesthetic, psychological and natural/ecological associations to natural treed spaces (Chapters 4 and 5). This is also echoed in the literature, where natural treed spaces are valued greatly by the public due to their biodiversity and aesthetics (Hofmann et al., 2012; Peckham et al., 2013; Nordh & Østby, 2013). More research is needed to understand how naturalization of tree growing conditions can help reduce urban tree vulnerability to weather changes in the short term and to climatic change in the long term.

Finally, and while on the topic of naturalization, it is important to note that the connection between tree species and natural spaces is not captured in the conceptual map since trees in natural areas was not used as an urban-tree trait. Tree species diversity is associated with the naturalness of the tree environment, since some tree species may more frequently found in natural areas than others. Although tree species diversity is higher in many highly-urbanized areas in Canada, such as parks (Bourne & Conway, 2014), some tree species are represented well in more natural areas due to the favouring

of broadleaf tree species and heat-tolerant species in urban areas (e.g. Roloff et al., 2009). Earlier I argued this for boreal tree species (e.g. balsam fir, birch, black spruce), which may be specially affected by climate change and are examples of cold-adapted, heat-intolerant tree species that are more frequently found in naturalized areas (Chapter 8). Thus, it is not incorrect to assume that at least some of the tree species susceptible to extreme changes in temperature and moisture are located in natural areas, and that their decline may influence the provision of values associated with such areas. Considering that naturalized areas are valued strongly by people due to their ecological and aesthetic qualities, and provision of spaces where people feel calmer, more connected with nature, and where they can undertake a particular set of activities (Chapters 4 and 5), it is logical to assume that climate change in these areas may affect some of these values considering its effects on tree species diversity. More research is needed to understand how species diversity is related to natural areas and values provision, and how it is affected by climate change in the long term.

#### **9.4 Implications for Management**

Although young trees are strongly affected by climate change, but their influence on values is low, without young-tree survival the number of mature trees and values satisfaction will also eventually decline. This means that the management strategy that connects public value provision and vulnerability to climate change is one based on the idea of not only planting more trees, but planting the right kind of tree, in the right place, under the right conditions. This is a strategy that facilitates adaptation to climate change without reducing values satisfaction. These two themes of management are discussed below in more detail.

It was mentioned earlier in this thesis that most cities want to plant more trees in order to provide environmental services (Chapter 3) and address climate change (Chapter 6). Certainly, planting more trees will increase the chances that at least some trees will survive future climatic conditions, but the strategy is disconnected from the values people assign to their urban forest. That is, the strategy must be completed with the ideas of

increasing the number of trees that are close to infrastructure and people and providing more natural, high quality, diverse, and accessible urban forest spaces. This may require redesigning some of the usual urban forest arrangements in urbanized spaces by experimenting with different habitat conditions, such as soil space and tree spacing, and urban tree arrangement types, such as pocket parks, rather than just planting more street trees. This strategy is tied into those that ascertain young-tree survival, which are planting smaller trees (i.e. whips and seedlings), planting trees closer together (i.e. densification), improving habitat conditions via soil and watering standards or naturalization, and establishing experimentation plots in nurseries (Chapter 8). Moreover, planting strategies must also adopt the notion of tree-species optimization to diversify the urban forest. Uniformity, a long-standing practice in the design of urban forest streetscapes in North America, and non-native favoritism have been two of the reigning traditions in urban forest management (Chapter 3). Some of these species may be mal-adapted to the future climate, either because of their big sizes and climatic range (Sukopp & Wurzel, 2003; Yang, 2009; Rostami, 2012) or their inability to withstand extreme temperature and humidity changes (Roloff et al., 2009). Moreover, diversity enhancement not only addresses climate-proofing but also enhances value provision (Chapter 8). For instance, by guiding tree-species selection according to evenness and representativeness instead of just richness itself, we favour tree species with low population sizes, particularly native, endemic, and at-risk trees species, which are sensitive to climate change (Chapter 8, Table 8.4), and in turn satisfy aesthetic, biodiversity, and nature-connection values (Chapters 4 and 5).

Furthermore, despite the strong relationship between providing a wide array of urban forest values and an effective climate adaptation strategy, urban forest losses and transformations are inevitable in the future. Facilitating forest range shifts is an important consideration for urban forests, particularly in a city positioned along natural forest boundaries where urban forests can influence hinterland forest dynamics (Woodall et al., 2010). The call for choosing species at the northern edge of their climatic zones and native to the forest region will definitely increase the diversity of tree species and facilitate these transitions. For example, London (ON) is a city at the northern edge of the



Carolinian forest, where tree species diversity is high. Bringing some new tree species into the city that are native to the Carolinian forest but perhaps not present in Ontario may enhance the diversity of tree species in the London urban forest and facilitate ecosystem transition. However, careful ecological considerations must be taken before overwhelming urban forest representation with artificial migration (Park & Talbot, 2012). It is not my purpose to advocate for an aggressive planting strategy that focuses solely on southern tree species that are not native to the forest region. Rather, facilitating this transition must be done with careful thought on the ecological and phytological characteristics of each tree species.

From a values perspective, a strategy of assisted migration in urban forest management will influence value provision as new tree species are being planted and old ones are being removed. Thus, learning through adaptive management (Duinker & Trevisan, 2003) is fundamental in a climate-sensitive and values-based urban forest management as values are being challenged or sacrificed by climate strategies.

Finally, the idea of facilitating transition in urban forests is important in a world that is increasingly urban, where more people, globally speaking, are connected to the trees of the city than those of the countryside or hinterland. People are living within an urban forest as they go about their daily urban lives, and, whether consciously or unconsciously, urban trees influence people positively. Public opposition to certain climate-motivated urban forest management strategies is to be expected. Pruning, planting, and cutting down trees may be intensified. Strengthening the communication channels with the public, enhancing educational opportunities, promoting community-based governance of urban trees, and starting to develop a liability policy related to wind-throw and allergy issues (Chapter 7) are important measures to take up in the future to align climate adaptation policy closer with a values-based philosophy in urban forest management.

## 9.5 Summary

In this chapter I presented an approach to understand how climate vulnerability in urban forests influences value provision. I also discussed ideas on how best to manage urban forest values in the face of a changing climate. Based on a qualitative and conceptual mapping analysis exercise, I am confident to say that public values and climate sensitivity are not only related, but integrating them is fundamental to urban forest management. The mapping analysis had limitations, particularly in the way it considered urban-tree traits as isolated entities, and thus their association with climate drivers and value provision. Ultimately, the urban-tree traits that were recognized as sensitive to climate change and as important to value provision, chiefly, large trees, young trees, stressed trees, tree species, and trees surrounded by infrastructure, are exhibited simultaneously in any urban forest.

Nonetheless, the analytical exercise was useful to gain insights on the relationship between urban-forest climate vulnerability and value provision. Urban-forest climate vulnerability influences value provision through the possible decline of large mature trees and the trees close to infrastructure and people. Although the influence of young trees on value provision is low, ascertaining young tree survival is crucial for value provision, as high young-tree mortality will mean that the number of mature trees will eventually decline and reduce values satisfaction significantly. Without a strategy that goes beyond planting more trees and that increases the number of trees close to infrastructure and people and provides a more natural habitat for trees, values will not be satisfied. Facilitating ecosystem transition without reducing values satisfaction is another management consideration. This will be difficult without strengthening communication with the public and probing the public constantly about the level of value satisfaction. This chapter also commented on how many questions remain unanswered, questions that promise interesting avenues of research. I will discuss this in my next and final chapter.

## **10 Chapter 10: Conclusion**

### **10.1 Advancing the Values and Climate Agenda in Urban Forest Management**

Urban forests are one of the most important natural resources for the world's population. Their importance sometimes goes unnoticed in many ecosystem assessment reports (e.g. MEA, 2005; FAO, 2012), perhaps because of their small contribution to the world economy, global biosphere regulation, and environmental services. However, their services and benefits contribute significantly to urban quality of life (McPherson et al., 1994; Dwyer & Nowak, 2000; Chiesura, 2004), they are valued deeply by people (Chapters 4 and 5), and are ultimately an integral part of urban sustainability.

One of the big challenges of urban forests today and addressed in this dissertation is how to incorporate public values and climate change simultaneously in urban forest management. In light of this concern, my objectives were to: 1) understand the values people hold in relation to urban forests broadly and deeply; 2) understand how urban forests and their values are being managed; 3) understand how vulnerable urban forests are to climate change; 4) understand how urban forest vulnerability to climate change influences urban forest public value provision; and 5) propose the best way to manage urban forests in light of these considerations and thus fulfil public values. The ultimate goal was to understand how urban forest public values can be managed sustainably in a changing climate, enhance current urban forest management practices, and aid practitioners' decision-making.

Based on an interdisciplinary and socio-ecological research platform, I achieved the objectives of my research. First, I theorized at the beginning of this work how understanding what people consider important about urban forests was important for approaching urban forest management through a socio-ecological perspective, and ultimately to complement, enhance, or broaden the scope of management to include a broad range of values. I discussed how harmonizing and managing the desired ecological

or social functions and structures of urban forests depends on an understanding of the public values we set out to manage (Chapter 1). Through a review of urban forest values (Chapter 2) and an examination of urban forest management plans (UFMPs; Chapter 3), I revealed that the values concept is best to understand the psychosocial underpinnings behind urban forest management and provides a paradigm to overcome the lack of detail in ecological, social, and economic management themes in earlier urban forest management frameworks (e.g. Clark et al., 1997; Kenney et al., 2011). The goal of advocating for a values conceptualization was not to invalidate the services, benefits, and attitudes literature on urban forests. I do not see these bodies of literature and perspectives as mutually exclusive, and, in many ways, they represent complementary approaches to portray why urban forests are important. Moreover, a values-based management style is not a way to challenge the guidance of the expert knowledge held by urban forest management actors. Rather, I see public value as an all-encompassing concept that captured the values of all urban forest management actors, including experts (Chapter 1). As pointed out by Dwyer et al. (1991), a deep understanding of values provides the purpose for urban forest management, while Nowak (2006) argues that the services/benefits perspective helps advance the urban forest agenda politically given the convincing nature of economic argumentation. Together, these approaches can help provide a more comprehensive array of values for the public and obtain political support.

Although Dwyer et al. (1991) argued for a deeper understanding of values, they had little empirical basis for their idea. In Chapter 2, I demonstrated that little had been done in the past twenty years to advance this topic. The main limitations of the urban forest literature in capturing public values lay, in part, in the inadequate conceptualization of the urban forest as an ecosystem, a geographical bias, and the lack of depth in the methodological approaches. By exploring values in Canadian and Colombian urban forests, I contributed to the development of a richer urban forest public values typology (Chapters 4 and 5). This new typology does not aim merely to change the use of language but rather demonstrate that the urban forest values system is complex and interconnected, with each theme existing within a network of reactions, effects, priorities, and guiding principles, rather than discrete constructs. The typology reveals the richness in psycho-social themes

as a contrast to the richness in environmental and economic themes in the literature, and it offers a set of public values data based on a conceptualization of the urban forest as a broader ecosystem (Chapters 1 and 2), and offers another view on the matter besides the dominant U.S. and European one. Ultimately, my research is a small contribution to the growing body literature on urban forest public values that contributes to a better understanding of why people care about urban treed landscapes and what they want from them and for them.

As demonstrated with my analysis of UFMPs (Chapter 3), a values perspective does not only provide a basis to provide what the public wants from their urban forests, but it also provides a broader and deeper set of criteria for urban forest management. This means that many social, ecological, and economic themes of management that are vaguely referred to in Canadian UFMPs can be strengthened through a values perspective. A close look at the public values typology developed in this research (Chapter 5) reveals that many social, ecological, and economic themes may have more prominence in urban forest management if its actors guide themselves according to these ideas. This perspective can help make operational some of the most important management themes that are only vaguely addressed in urban forest management today, such as nativeness, naturalness, connectivity, public stewardship, public engagement, economic issues, adaptive management, and climate change.

Urban forest values are being challenged by a plethora of short- and long-term issues. I argued how climate change is an important challenge that has gone mostly unaddressed (Chapter 5). By reviewing the literature on climate change and urban forests, I showed how there was little understanding on how to adapt urban forests to climate change (Chapter 6). I gained insights on this by exploring climate change vulnerability in urban forests, both theoretically (Chapters 7) and empirically (Chapter 8). Based on these explorations, I concluded that young tree survival is the most important aspect to consider about urban forest vulnerability to climate change. The exploratory approach to elicit this information had some limitations, yet it would not have been possible to obtain such broad ecosystem-level insights if I had based my CCVA on a species-based assessment

(Chapter 8). Reducing the vulnerability of urban forests to climate means that management must make an effort to experiment with and develop alternative planting strategies and species-selection criteria, to enhance the naturalization of the urban forest wherever possible, to increase cooperation and coordination among municipal entities to enhance the importance of urban forests, and to communicate better with the public.

The directions of management that result from incorporating values and climate change in urban forest management are not divergent, but complementary. Ultimately, as I demonstrated in Chapter 9 through a analytical exercise, urban forest vulnerability to climate change influences value provision. I argued that a way to address climate change and satisfy public values in urban forest management is to change our planting strategies. Although some authors already argue for planting species that will be adapted to the future climate (e.g. Sukopp & Wurzel, 2003; Yang, 2009; Roloff et al., 2009; Rostami, 2012), I advocate for a broader climate-adaptation strategy that addresses ecological, social, institutional, and political considerations to complement this simplified notion of climate-proofing. This strategy is characterized by planting the right species of trees that can grow to large statures close to infrastructure, while at the same time ensuring that they survive their infancy and are not stressed, which is achieved by planting trees under more-natural conditions. In some ways, climate change is both a threat and an opportunity to advance the values agenda and bring specificity to ecological, social, and economic themes that are not being addressed today.

All in all, these insights are useful to give meaning to the idea of managing urban forest values in a changing climate. This idea is based on research that has its limitations, and these have been discussed explicitly throughout the dissertation (particularly sections 5.3.2 and 7.6.3). However, the limitations of this research do not weaken the insights gained. Rather, and together with its implications for urban forest management, they open promising avenues of future research, as I shall explore below.

## 10.2 Future Research

This dissertation has used creative methods to answer questions about public values and climate change vulnerability in urban forests, thus addressing a complex and interdisciplinary problem effectively. Many of these methods had not been used before and were exploratory in nature. Their limitations and uncertainties are inherent, as discussed explicitly in previous chapters. However, despite its need for complementation and validation, and its limitations and uncertainties, at the very least, this study provides direction for future research in urban forest values and climate vulnerability topics.

### *10.2.1 Complementation and Validation of Research*

Regarding complementation and validation, the approaches for analyzing how sustainable urban forest management is interpreted and practiced today (Chapter 3) could be replicated in other spheres, given of course that similar management frameworks are being used locally and that UFMPs are publicly available. The method used in this dissertation complements other methods for understanding how urban forest managers think and how urban forest programmes work (e.g. Clark & Matheny, 1998; Kuhns et al., 2005; Ottitsch & Krott, 2005; Conway & Urbani, 2007; Janse & Konijnendijk, 2007; Conway et al., 2011; Barker & Kenney, 2012; Seamans, 2012; Young, 2013), which, in conjunction, come close to understanding urban forest management in its entirety.

Moreover, the values-elicitation and CCVA methods used in this research could be cross-validated in other locales. There is high utility in exploring urban forest values elsewhere, particularly in non-North-American and non-European countries where almost no work has been done. Such case studies are important because this is where most of the urban growth goes today and perhaps where urban forest management is most dire. Other values-elicitation methods may emerge in the future, and they could validate, complement, or challenge altogether the urban forest public values typology presented here (Chapter 5). For example, a method that has lots of potential is online surveys, which has seldom been used in urban forest values research before, or even in the services, benefits, and attitudes fields. Ultimately, advancing our understanding of urban

forest values is only possible using a combination of many methodological approaches and case studies. Finally, my urban-forest CCVA method, which is expert-based and participatory in nature, could be applied to other locales to help elicit different ideas about urban forest vulnerability to climate change. However, rather than being used elsewhere, the method could actually be used as a basis for more systematic assessments, as I discuss next.

### 10.2.2 CCVA Models, Methods, and Strategies

An exciting field of research exists in CCVAs for ecosystems in general, and CCVAs for urban forests in particular. A possible step in the right direction is to undertake a mixed-method approach using the elements identified in the methodology used in this dissertation as the basis for the assessment. One pathway is to rate the interactions between the exposure and sensitivity elements using the framework developed as a result of my CCVA. This could produce consistent and quantitatively-based results (Figure 10.1). The data-collection mechanism can be characterized by an expert-elicitation rating using, for example, a Delphi technique (Dalkey & Helmer, 1963; Linstone & Turoff, 1975; Okoli & Pawlowski, 2004). This may be a stricter way to add detail to urban forest vulnerability to climate change by using the results of this CCVA as a fixed framework.

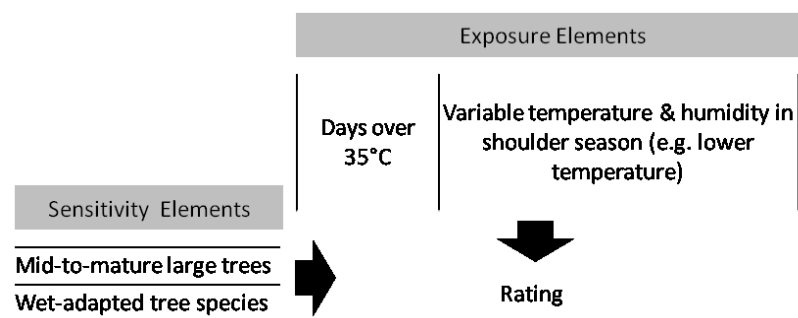


Figure 10.1: Example of rating chart for undertaking a CCVA for an urban forest, indicating selected sensitivity and exposure elements (based on Chapter 8)

Another pathway for an urban-forest CCVA is to assess the vulnerability of urban forests according to species-based or ecological-response models. The species-based model



could devise a rating method for each tree species in the city, similar to what other CCVAs have proposed (e.g. Young et al., 2011) and done for forests (e.g. Aubry et al., 2011; Brandt et al., 2014) and other ecosystems (e.g. Chin et al., 2010). This assessment model is a long way away from being able to assess the vulnerability of urban forests holistically, but it can offer a sense of the biophysical response of particular urban tree species to climate change. Again this could be done via expert opinion, or by populating a criteria-and-indicator (C&I) framework with available data. This will be restricted to the quality of the data and to the mathematical assumptions in the rating mechanism.

The development of an ecological response model, just as Glick et al. (2011) proposed for natural areas, is a promising but complex endeavour. This will basically comprise a grow-out model that couples urban forests and climate scenarios and produces future urban forest structure scenarios. To build such a model, three set of measures may be needed: urban forest structure data, climate projection data, and tree maintenance data (Table 10.1). Urban forest structure data may be accessed through datasets like those that exist for UFORE (Nowak & Crane, 2000). Climate projection data for the city may be difficult to come by, so regional projections could be used initially, as was the case for my own CCVA (Chapter 8). Urban forest maintenance data are scarce, as many municipalities do not keep track of this information (Chapter 3). Nonetheless, some coarse assumptions could be taken from UFMPs or the opinion of maintenance crews (Table 10.1).

Table 10.1: Possible data needs for an urban forest grow-out model under future climate

<i>Data clusters</i>	<i>Data</i>	<i>Indicator</i>	<i>Example of units</i>
Urban forest structure	Canopy cover (Leaf area)	Crown width	m <sup>2</sup>
		Crown light exposure(categorical)	Categorical
		Percent canopy missing	m <sup>2</sup>
		Crown dieback	m <sup>2</sup>
	Tree species	Species diversity	Categorical
		Temperature needs	°C
		Water needs	ml/year
		Soil quality needs (categorical)	Categorical
		Approximate leaf area	m <sup>2</sup>
		Wind resistance	Categorical
	Age/size composition	Age/size diversity	Categorical
		DBH (diameter at breast height)	cm
		Total tree height	m
		Wind resistance	Categorical
Tree maintenance	Newly planted trees	Number of trees (by landscape categories)	Categorical
		Age/size of trees when planted	DBH (above)
		Mortality rate	# trees/year
	Pruning	Canopy removed	m <sup>2</sup> /year
Biomass removed		gC/year	
Climate Scenario	Temperature projections	Annual/seasonal average temperature	°C
	Precipitation projections	Annual/seasonal average precipitation	ml/year
	Sea-level	Average rise	m
	Extreme events	Heat waves	Categorical
		Winds	Categorical
		Flooding	Categorical

DBH = Diameter at breast height

A few observations must be made about the nature of the data needed to build such model. For instance, an ecological growth model for forests that integrates climate change requires assumptions about tree growth under future climatic conditions (e.g. Steenberg et al., 2013). Although our understanding of urban tree growth has increased immensely in the last 20 years, most of the research has been carried out in US cities and some uncertainties remain unaddressed (McPherson & Peper, 2013). Undeniably, assuming natural forest conditions as the basis for an urban tree growth model will limit coupled urban-forest and climate change simulations. Moreover, Canadian urban forest data exist in different forms, and only recently has there been a move to standardize them under the UFORE model (Chapter 3). Nonetheless, UFORE data sometimes provide a skewed impression of the urban forest. For example, in London (ON) a UFORE-based data collection revealed that 77.5% of all the trees in the city were <15 cm in diameter, with the most common tree being European buckthorn, which is an invasive non-native shrub or small tree (City of London, 2012). A grow-out model based on this information could lead to an incongruent projection of how the urban forest will look under a future climate. Certainly, a careful consideration of data needs must be undertaken for modelling urban forests according to climate conditions, yet the insights to be gained from such an effort are substantial.

### *10.2.3 Adaptive Urban Forest Management*

I mentioned repeatedly in my discussions how a values-based and climate-sensitive urban forest management needed to embrace adaptive management, and this idea provides the basis for a wide set of future research considerations. This is because adaptive management demands monitoring of action implementation and system response and strongly promotes system-scale experimentation, thus jointly embracing uncertainty and finding systematic ways to reduce it. One of the uncertainties emerging from my research that could be embraced by adaptive management is the development of a monitoring programme for newly planted trees. It is useful to note that this is one of the important data needs for modelling urban forest and climate change interactions (Table 10.1). The programme is useful since more urban trees and natural spaces are desired from a values

and climate standpoint. This involves planting more trees and enhancing urban forest types like pocket parks instead of focusing on street trees only. A monitoring programme is crucial to understand how urban trees evolve in a changing climate and how they provide values to the community as soon as they are planted in the ground.

However, several questions arise with these strategies, chiefly: which natural spaces does the citizenry prefer?; what are the ecological, environmental, social, and economic value considerations of such spaces?; what is the best way to manage those spaces?; and what is the best way to enhance learning and adopt findings for management? These questions speak to the idea that, in a more general sense, adaptive management helps us address uncertainty in the urban forest management endeavour as a whole. Increasing adaptability in the management of ecosystems is crucial to enhance resilience and adapt to climate change (Lee, 1993; Holling & Gunderson, 2002). Enhancing adaptive capacity in relation to climate change has even more relevance in urban areas, where complex socio-ecological dynamics coexist, and where rapid or sudden changes are usually the determinant pace of change (Folke et al., 2005; Tyler & Moench, 2012). Thus, the superficial way in which adaptive management has been adopted in urban forest management so far, at least in Canada (Chapter 3), needs to be corrected in favour of a more comprehensive and systematic way to learn and change on the basis of the results of the activities on the ground and the policies of municipalities at a bigger scale.

Finally, enhancing public engagement is an important issue for adaptive management, as learning in urban forest management is not just about the knowledge of the practitioners, but the knowledge of the urban forest community as a whole. In my UFMP analysis (Chapter 3), I noted how some municipalities in Canada choose to address this either via the creation of community-based steering committees or through neighbourhood-based volunteer groups. Some authors have pointed out the importance of some of these strategies (e.g. McLean & Jensen, 2004; Janse & Konijnendijk, 2007; Wolf & Kruger, 2012; Mincey et al., 2013; Conway & Bang, 2014) while others point out to their shortcomings for addressing social inequity in urban forests (e.g. Conway et al., 2011). In this context, three important questions arise: what are the most promising public

engagement strategies out there; which ones are best to fulfill the values and climate agenda; and how can the outcome of implementing these strategies be assured to be better management of the urban forest? Creating research agendas around these questions will help bring specificity to a values-based and climate-sensitive urban forest management.

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# APPENDIX 1

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Peckham, S.C., Duinker, P., and **Ordóñez, C.** (2013). Urban forest values in Canada: views of citizens in Calgary and Halifax. *Urban Forestry and Urban Greening* 12 (2), 154–162.

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