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Climate Change Mitigation and Adaptation in Urban Forests: A Framework for Sustainable Urban Forest Management

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SUMMARY

Sustainable urban forest management is important to sustain the myriad values associated with urban trees. These values are threatened by the advent of climate change. Urban forests responses to this change should be framed appropriately in our interpretation of urban forest sustainability and its management. While the usual approach to address climate change in the urban forest setting has concentrated in climate mitigation, chiefly greenhouse gas emission reduction, much is to be desired about climate adaptation. It is argued here that any sustainable urban forest management framework fails to address the deep implications of urban forest sustainability if it does not address the climate question. This paper demonstrates that climate mitigation and adaptation can be integrated in a sustainable urban forest management framework that is inclusive of climate considerations and strives to sustain a strong array of environmental, social and economic values. It is shown here that such a framework may contain management practices that consider the net effect of both decreasing vulnerability and emissions. In the biophysical realm, these practices may include, but are not limited to: planting more trees, planting better adapted species to the future climate, reducing tree stress, among others. Management practices fit to the social and economic realm may include addressing institutions, ownership and valuation of ecosystem services, among others.

KEYWORDS: Urban forests, climate change, urban forest sustainability, urban forest management

1. INTRODUCTION

The management of urban services has become crucial to respond to the dramatic urban transformations of the last decades. In a world where more than half of the world is urban (UN-HABITAT 2008), our progress toward urban sustainability is determined by the management of services of the urban realm. An issue of concern in urban sustainability is climate change. There is today little doubt that there would be significant changes in the world's climate in the following decades (IPCC 2007) that will in turn affect urban services. The urban forest is one of such services that every city in the world shares. However, urban forest master plans do not embed climate change significantly in their framework and/or strategies. Approaches have focused on climate mitigation as a function of urban forests, while climate the development of climate adaptation has been limited in such a context.

A framework for sustainable urban forest management that incorporates climate change needs to address both mitigation and adaptation. This paper will develop such a broad framework by defining the concepts behind it using the traditional jargon of both urban forest and climate studies. These concepts have particular meanings in the urban forest realm in contrast the discussions of climate change in hinterland forest management. The paper focuses on the development of what climate adaptation means for urban forests, thus filling significant gaps in the literature. Empirical information to support climate adaption claims is based on the Point Pleasant Park restoration study in Halifax, Canada.

The paper is structured in the following way: first the ideas behind the urban forest and climate change are discussed. These ideas are integrated in a fourth section that includes a discussion about urban forest contributions to climate change, vulnerability and impacts. A fifth section discusses the implications behind an urban forest response to climate change in terms of mitigation and adaptation. The way climate could be included in a sustainable urban forest management framework is explained in a later section. Final concluding remarks are given at the end.

2. THE URBAN FOREST

The urban forest can be defined as the trees of the city. Urban forests differ from hinterland forests in several ways. Firstly, urban forests have a diverse structure. Urban trees can be found in 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.
Moreover, urban trees are also con
nected to human activities and infrastructure (i.e. urban forest connectedness; Dwyer &Nowak 2000). In addition, urban forests have a particular dynamic because of the coupling of natural development processes and human processes that influence their development, both of which operate at a variety of rates (Nowak 1993). Finally, urban forests are valued environmentally, socially and economically. Some examples of values in these categories are identified in Table 1.

Table 1 *Some urban forest values*

Category	*Value*	*Example*
Environmental	Air pollution removal	(Nowak *et al*. 2006)
	Urban hydrology regulation	(Xiao *et al.* 2000)
	Urban micro-climate regulation	(Heidt & Neef 2008)
Social	Positive psychological effects	(Ulrich 1984),
	Aesthetic quality	(Smardon 1988)
	Emotional and spiritual benefits	(Chiesura 2004)
Economic	Increased real-estate prices	(Tyrväinen & Miettinen 2000)
	Recreational opportunities	(Nowak *et al*. 2001)
	Savings due to environmental function	(McPherson *et al.* 1999)

The range of values associated with the urban forest demonstrates how crucial its sustainability is in everyday urban life and the need to develop a disciplined and comprehensive framework for its management. Past interpretations of this concept have focused on tree-caring goals, where sustainable urban forest management means the implementation of sound tree maintenance techniques (e.g. Clark *et al.* 1997). However, urban forest sustainability is more than what trees need. Urban forest sustainability should also be driven by what people need, or what people value, represented by the three value categories in Table 1. Furthermore, the urban forest community can be broadly seen as the trees, people and infrastructure in the city. These two notions then imply a vision of sustainable urban forest management as an action that, if applied today, is able to provide a strong array of values at all times, in consideration of time and space scales, except when natural or human catastrophes prevent such (Ordonez & Duinker 2010). How the urge of climate management fits this broad conceptualization is a matter of further discussion.

3. CLIMATE CHANGE

The anthropogenic acceleration of climate change is projected to cause significant environmental changes across most biophysical and societal systems. The world's forests are of particular concern, because they comprise a key natural resource that is valued the most by people. Canada, for example, is one of the five most forest-rich countries, which together comprise more than half of the world's forest, and there is a particular concern amongst Canadians about the effect of climate change on this ecosystem. This concern goes beyond the evident economic dependence on hinterland forests. With almost 80% of Canada's population concentrated in the urban realm, Canadians should be concerned about the threats of climate change to the innumerable values associated with the urban forest.

Though climate change effects vary across the globe, even the most modest predictions of temperature rise project 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 the increase of average annual temperature by the end of the century could be as high as 2-4.5°C.

Temperature increases may initially drive forest productivity (Boisvenue & Running 2006), but the farther the projections go, productivity can fall (Fischlin *et al.* 2007). 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). Temperature also drives the spread of pests and disease, like the recent outbreaks of mountain pinebettle in BC due to lack of low-temperature winters (Carroll *et al.* 2004).

Furthermore, 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 2007). Even a modest 2°C departure from mean temperature would imply different climate conditions from those under which most forests have evolved in recent centuries according to (IPCC 2007). For a list of such projections for significant urban regions in Canada I refer to Duinker & Ordonez (2010).

The single or combined result of these climatic changes will drive changes in forest ecosystem resources, site conditions, disturbances, and individual tree variables (Williamson *et al.* 2009). For a list of associated effects in forests due to influencing climate variables, I refer to Duinker & Ordonez (2010).

4. CLIMATE CHANGE AND URBAN FORESTS

The interactions between climate change and urban forests include three main elements: urban forest contributions, urban forest vulnerability, and the impacts of climate change on urban forests. Though much of the discussion about climate change and urban forests is determined by the effects on hinterland forests exposed above, there are significant differences about the climate and urban forest interaction.

4.1 Urban Forest Contributions

Urban forests contribute to climate change by controlling GHG emissions. In the US, for example, urban forests capture about 23million 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, Jonsson 2004, Scott *et al.* 1999) or by regulating the hydrological regime of cities (Sanders 1986) 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 the urban forests may also contribute depending on its carbon-intensity and related emissions (Nowak 2000).

4.2 Urban Forest Vulnerability

Vulnerability is a given condition of a system that makes it prone to change and its incapacity to adapt (Adger 2006). For the urban forest system, vulnerability can have three dimensions: environmental, social and economic.

The environmental dimension of vulnerability is perhaps the most important one when we deal with trees, and is directly related to the structure of an urban forest. Its species composition and mix, its age structure, health status, location, among others, make it all vulnerable to climate change. The species composition of the urban forest has drawn attention recently. Some studies have shown how some urban tree species may be unsuitable for the climate predicted by future (Yang 2009). The arrangement of trees in relation to the grey infrastructure and to each other (i.e. ecological connectivity) is also an element of urban forest vulnerability (Wilby & Perry 2006). Increases in the urban population of cities developing countries, for example in India, produce a less connected urban forest (Prasad & Badarinath 2004). More information on age structure is needed, as it is well known that young trees are more resilient to change while seedlings and old trees are not.

Other elements of this dimension include the stresses to which urban trees are subject. The most evident are small root space and soil compaction, poor soils, and poor provision of water. Direct human disturbances of the urban forest, due to destructive building activities (Florgård 2000) or bad pruning, for example, may be also drivers of stress. Other less evident stresses include microclimate effects. Indeed, the effects of climate change on urban areas will depend on urban heat islands (UHI), the influence of urban surface on moisture and cloud coverage, among other factors (Arnfield 2003).An example of this is the maldaptation of certain native tree species to the microclimate of several European cities (Sukopp & Wurzel 2003). Here, native species are unable to thrive and other more tolerant species take over. Urban trees also flower earlier than their rural counterparts (Roetzer *et al.* 2000) and have an extended leafy season (White *et al.* 2002). The effects of urban microclimate may be intensified by the effects of climate change. Urban trees are subject to a myriad of stresses, which make the life-span of an urban tree short (Nowak *et al.* 2004) and contribute to their climate vulnerability.

The social and economic dimensions of urban forests are less evident, but important nonetheless, as they demonstrate that there is more influencing their vulnerability than biophysical factors. Elements such as the existence or not of institutions that deal with an urban forest, their budget, the quantity and level of skill of the staff employed, the property values related to urban trees, would make urban forests vulnerable to change.

Many other elements within these three dimensions of vulnerability can be recognized. A few considerations of higher hierarchy are included in Table 2 together with some fitting elements. Though this list of considerations is thoughtful to wrap our thinking around urban forest vulnerability, it would be unwise to develop a more exhaustive list of considerations. After all, assessing the vulnerability of urban forest systems is a local matter, as vulnerability assessments in general are (Schneider *et al.* 2007). Vulnerability assessments are important as they must precede impact studies and be a determinant factor in deciding the elements of an urban forest climate response.

Table 2 *Considerations for an urban forest vulnerability assessment*

Dimension	*Category*	*Elements (examples)*
Environmental	*Urban forest structure*	Species Composition Species Mix Tree arrangement in relation to infrastructure Tree arrangement in relation to each other (ecological connectivity) Age structure
	Urban Forest natural resilience	Degree of acclimatization (phenotypic change) Degree of biological adaptation (genotypic change) Ability of species to migrate
	Urban forest stresses	Building activities Pruning Urban microclimate Soil availability Water availability
	Climate Change Scenario (predicted)	Temperature Frequency and intensity of precipitation Frequency and intensity of climate disturbances Sea-level rise
	Time horizon and space scale	
Social	*Institutions*	Number and kind of institutions Level of skill of staff Quantity of staff
	Ownership	Kinds and patterns of ownership
Economic	*Valuation*	Property values Saved infrastructure costs due to urban forest functions
	Institutions	Budget

4.3 Climate Impacts on Urban Forests

Climate change would generate a significant loss and gain of urban forest habitat/land due to the loss or gain of ecosystem quantity. In general, climate change means that forest ranges, hinterland and urban, are moving in a latitudinal and altitudinal manner. This shift is corroborated with studies in Canada, a country with such a considerable forest resource (McKenney *et al.* 2007). This impact also involves sea-level, which could rise from 0.18 to 0.59cm globally by the end of the century (IPCC 2007).These shifts may restrict certain tree species to a smaller or bigger area, changing the forest structure.

Another impact of significance is the change in forest habitat due to changes in ecosystem quality. Changes may involved changes in precipitation, temperature and frost events, soil quality, including sea-level, which can affect the salinity of certain soils and water bodies in coastal ecosystems, among others variables of change. Under these new conditions certain tree species would lose their ability to thrive. In particular, ecosystem change would affect their regeneration rates, their representativeness in the forest, their age diversity, and their general health and aesthetics (CCFM 2009). For example, tree species more suitable to the new conditions may invade a site that had before not been suitable. This invasion may be by species belonging to the native forest surrounding the urban forest or otherwise by alien species, and this would happen more copiously in unmanaged areas, like naturalized parks or abundant tree stands, in the long-term. Moreover, young, healthy trees may be more capable to endure climate change, while seedlings and old trees will probably not.

An impact of great concern is the change in frequency and intensity of disturbances, such as extreme weather events and pests and diseases. In most climate models, disturbance increase either in frequency or intensity and occur at a local to regional scale. An increase in intensity and decrease of frequency hurricanes or droughts, for example, would mean more damage to urban forest stands and individual trees. Pests and diseases have an intense effect on individual species, as discussed in section 3, which in turn affects the species mix in the urban forest.

Human influences in the urban forest may downplay many of these impacts. Firstly, environmental quality is a determinant of forest species ranges at a broad scale. Climate impacts on the urban forest occur at a small scale. Here, other factors may take part in the thriving of species, such as seed dispersal, biotic interactions, genetic adaptations, and human decisions that involve urban sprawl, replacement of green infrastructure by grey infrastructure among others. However, the long-term significance of climate change impacts can never be underestimated. The quantification of such impacts depends on the resolution of small-scale models, which is still low for many coupled forest-climate models. The development of these models is an ongoing process that must take into account urban microclimates (Wilby 2007) and other factors of stress. Finally, environmental changes in the urban forest environment affect the way the urban forest functions and the values it provides. The response of the urban forest community would in turn affect the urban forest resource, by augmenting or minimizing such impacts hereby discussed.

5. AN URBAN FOREST RESPONSE TO CLIMATE CHANGE

5.1 Mitigation

Climate mitigation refers to the reduction of GHG emissions. As discussed, urban forests reduce GHG emissions by capturing carbon from the air and reducing energy use. However, carbon storage by urban trees is not a significant contribution to reduce global, national or even local emissions. Nonetheless, it is not a trivial contribution. An urban forest management can increase carbon capture by increasing the urban canopy cover. Bigger and younger trees capture more carbon, and 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 releases emissions, and reduction in this area would involve tackling the technological, social and economic factors involved.

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). Nonetheless, the operationalization of such response in management is difficult to address without a coupled mitigation-adaptation approach, as the impacts of climate change may downplay many of the GHG emission reduction effects.

5.2 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. There are two facets of an adaptation response in an urban forest setting: adjusting the urban forest to change and using urban forests to help cities adapt to change. As for the first facet, adaptation in natural ecosystem should not mean return to a past natural state. With climate change, the notion of natural state is challenged and climate baselines for forest management can no longer be considered as ideal (Spittlehouse & Stewart 2003). Adaptation to climate change in urban forests implies taking management decisions with a predicted climate scenario in mind and adjusting to uncertainty. As for the second facet, an urban forest adaptation response would be incomplete without full consideration of the wider urban forest community, chiefly, the people and infrastructure within (Wilby & Perry 2006).

A climate management strategy can be focused on reducing the system's climate vulnerability and increasing its climate adaptive capacity (Adger *et al.* 2007) according to the considerations included in Table 2. Both responses reduce the degree of climate impact and the level of climate risk. One of the most important elements in an adaptive strategy is the selection of climate-resilient species. Developing a species-selection matrix, on the basis of a wide range of criteria, is at the core of this element. While the a criteria of searching for southern seeds in northern countries may be suitable (Yang 2009), also drought and frost resilience inform the specialist in selecting adequate urban tree species (Roloff *et al.* 2009). More criteria may come into consideration at any particular moment for species selection. For example, after hurricane Juan hit Nova Scotia, Canada, in September 2003, more than 70% of the mature trees of Point Pleasant Park in the city of Halifax were lost. While considering the environmental recovery of the park, the managers considered future climate scenarios for the locality. With a few criteria in mind (see Table 3), American basswood (*Tilia americana* L.) and Butternut (*Juglans cineria* L.) were deemed suitable to be planted in the park. Assisting the migration of these species to Nova Scotia through planting in impending decades would seem a reasonable adaptive response to climate change.

Table 3 *Criteria in selecting tree species for Point Pleasant Park Recovery Plan*

Considerations	*Criteria*	*Candidate species*
Climate change	Increase in temperature	Southern tree species well-suited for warmer temperatures
	Increase in frequency and intensity of windstorm events	Species with deep root systems
Environmental	Moist soils and proximity to water	Any species that thrives on moist soils and/or close to water bodies
	Native to the broad forest ecosystem (Acadian Forest)	Any species with ranges in NB and NS (Particularly, St John river valley)
Social desirability	Rapid regeneration	Fast growing species*
	Similar forest aesthetics	Aesthetically pleasing or well-known

Based on (NYPPaysage *et al.* 2008) and personal communication

Climate-adaptation may include other practices such as optimizing species mix. Standards for species mix already exist to tackle pests and diseases, and stipulate than no one species should represent more than 15% of all species in the urban forest (Miller & Miller 1991). The arrangement of urban forests in relation to infrastructure could also be optimized. Climate modelling studies have shown that the proximity of vegetation to the city's infrastructure aids in regulating the urban microclimate a crucial element in ameliorating the effects of an increase in temperature in the urban realm (Gill *et al.* 2007). Keeping ecological corridors to increase the ecological connectivity of the urban forests could also determine adaptability (McKinney 2002). Other elements of urban forest structure, such as age structure have not been well studied, as well as variable permutations of the well-known management strategies above. Future research is much required in this area.

The social dimension of urban forest adaptation involves reducing vulnerability in areas of institutions, ownership, equity, education, which is related to adaptive capacity, participation, among others. Addressing such issues may involve the adjustment of institutions, consultation, inclusion and empowerment, and raising the level of importance of the urban forest within public administration and community governance. However, how these elements may be specified is a matter of debate. Urban forest adaptation also means that management must respond to the urban forest values that people in the urban forest community would rather sustain considering climate change. Studies or urban forest values that take a climate change response into account is a matter of future research.

Finally, the economic dimension of urban forest involves reducing vulnerability in areas of valuation of urban forest functions and benefits, institutional budget, among other issues related to natural resource economics. Addressing such issues may involve the adjustment of institutional budget, the development of technology and innovation, cost-efficiency, among others. However, how these elements may be specified is a matter of future research and case studies.

6. A CLIMATE-INCLUSIVE SUSTAINABLE URBAN FOREST MANAGEMENT FRAMEWORK

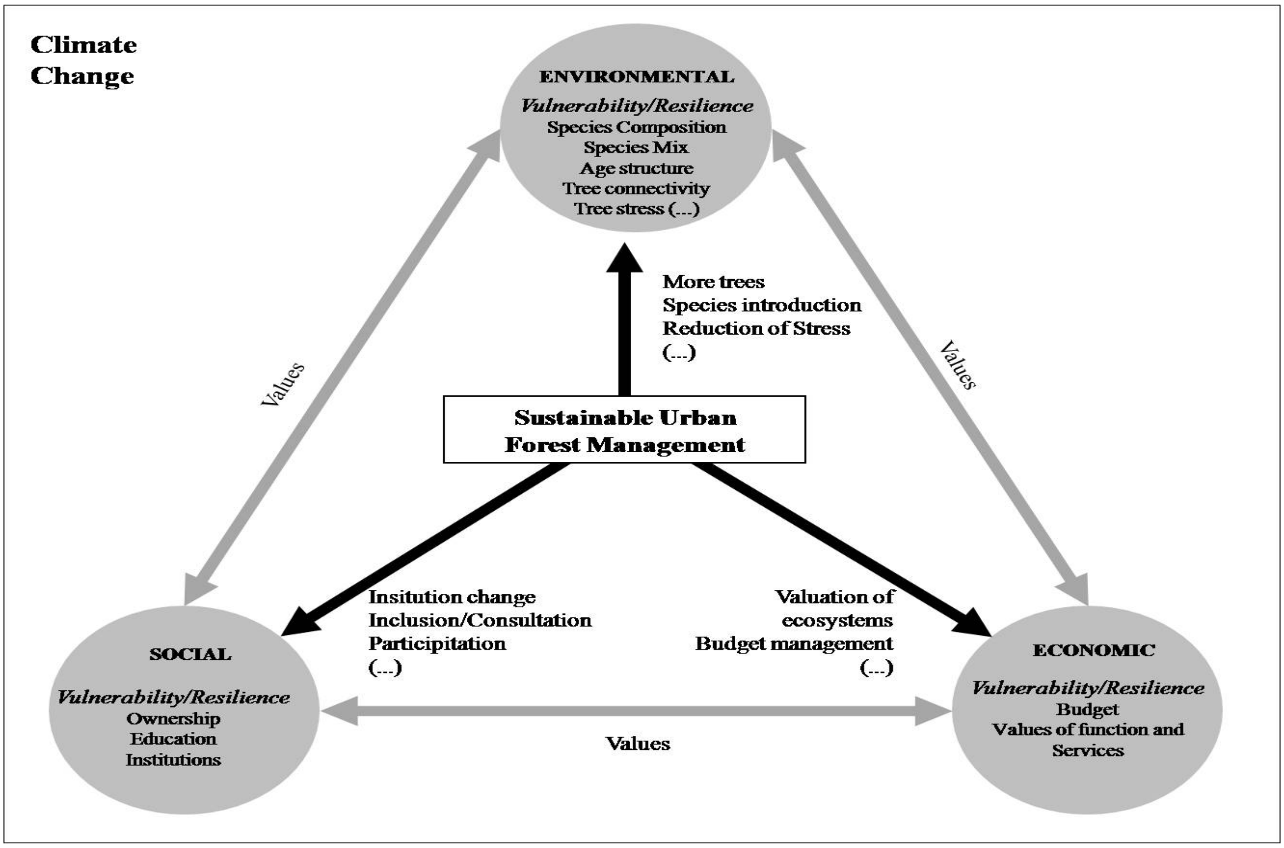
Climate change is irrevocably related to sustainability (e.g. Munasinghe & Swart 2005, Swart *et al.* 2003). Therefore, climate must be accommodated in a sustainable urban forest management framework. This can be done by integrating adaptation and mitigation to the local management strategies of the urban forest with a few considerations regarding management practices.

The implications of doing adaptation and not mitigation, or mitigation and not adaptation, or neither, can be visualized in a four-option palette as developed for local climate management strategies in general by (Bizikova *et al.* 2007). This can be accommodated to the urban forest context. On one end there is no management scheme to increase the number of trees in the city or to maintain them at adequate stress-free levels, as examples of elements to increase carbon capture or decrease urban forest vulnerability. This no-action plan has a net effect of increasing both emissions and vulnerability. A biased mitigation-only approach would concentrate on planting more trees in better locations, but with no consideration of species climate maladapatation or any other element of an adaptive response, the net effect would be decreased emissions combined with increased vulnerability. A biased adaptation-only approach would concentrate on planting trees that are, for example, better adapted to future climatic conditions, but does not consider planting more or to plant them in connection with the grey infrastructure. The net effect of this response would be decreased vulnerability but increased emissions. A better devised framework that forces decisions to consider the net effect of decreased vulnerability and emissions, would involve planting more trees, planting them at better locations, and planting better adapted species to the future climate.

A sustainable urban forest management framework strives to sustain the environmental, social and economic values associated with the urban forests with time and space scales in mind. Such a framework should not be the result of a problem-fixing approach, but rather be conducive to sustain the strongest array of values at all possible times, with objectives, targets and indicators in mind. In order to be climate inclusive, as our discussion of the urban forest climate response adduced, such a framework should be multidimensional and include elements that address climate mitigation and adaptation uniformly. The integration of both responses is crucial to the development of urban forest climate management strategies, as they are closely interconnected and contribute to each other's goals (Klein *et al.* 2007).

Following these considerations, a framework for sustainable urban forest management, including possible actions, can be visualized as shown in Figure 1. This framework is meant to be at a higher level of conceptualization, so the actions recognized are by no means exhaustive. This would depend on the locality's own urban forest structure, vulnerability issues, climate scenario, and so on.

Figure 1 *A sustainable urban forest management framework inclusive of climate considerations*



7. CONCLUSIONS

This paper has shown how an urban forest climate response can be fitted to a broad sustainable urban forest management framework and comprise both mitigation and adaptation responses. Though climate issues are not addressed significantly in many urban forest management plans developed in North America (e.g. BaltimoreCity 2007, Clark 2006, Kenney 2008, Nowak & O'Connor 2001), it is expected that concerns for climate impacts and vulnerability may bring climate to the forefront of sustainable urban forest management in the future. Examples such as the Point Pleasant Park recovery in Halifax, Canada, serve as beacons in the decision-making processes of future climate management.

The framework hereby presented leans toward the environmental dimension of sustainable urban forest management. It is of no surprise that techniques for the sound maintenance of trees in the urban setting are well-developed. Conversely, social and economic urban forest values are much dependent on urban forest structure. However, more information on how climate change may be taken into consideration when developing social and economic actions within a climate-inclusive sustainable urban forest management framework must be developed by future research and case studies.

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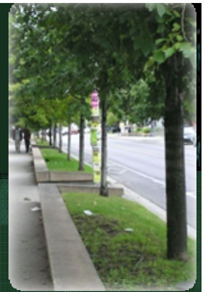
CLIMATE CHANGE MITIGATION AND ADAPTATION IN URBAN FORESTS: A FRAMEWORK FOR SUSTAINABLE URBAN FOREST MANAGEMENT

CFC Conference, Edinburgh

29-06-2010

C. Ordonez, P. Duinker, & J. Steenberg



OVERVIEW

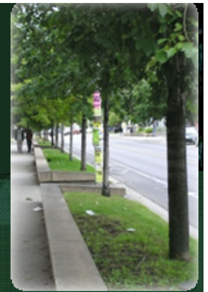
1. **Introduction:**
   Urban areas, Urban Forests, Climate Change

2. **Climate Change and Urban Forests:**
   Contributions, Vulnerability, Impacts, Responses

3. **Climate-Inclusive Sustainable Urban Forest Management**

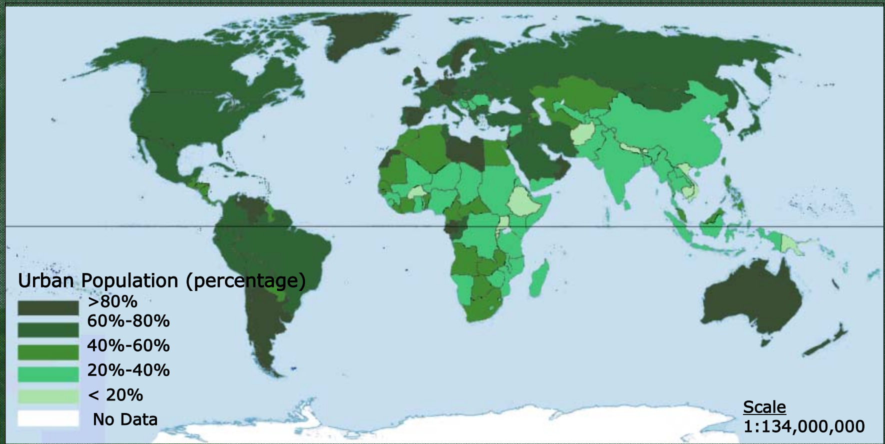
4. **Conclusions & Future Research**

INTRODUCTION

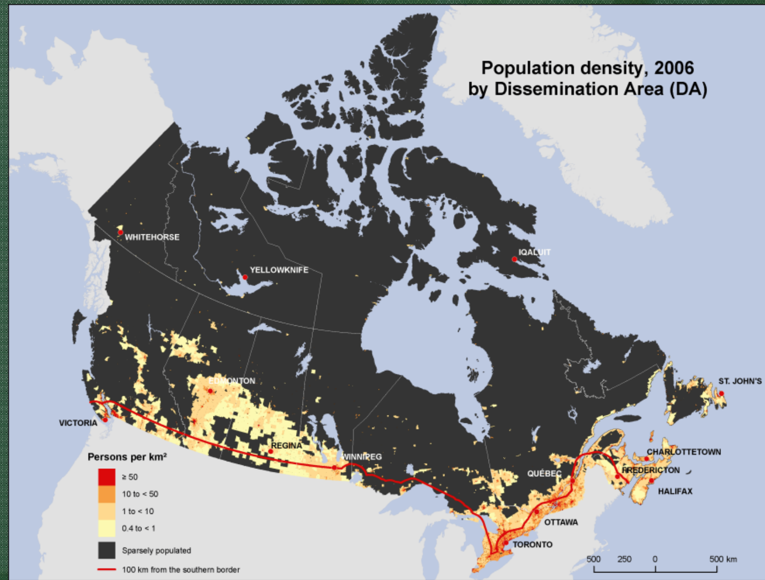


Urban Areas

- Most of the world's population is urban (UN-HABITAT, 2008)



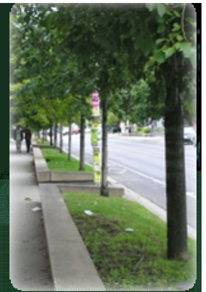
(TEI, 2007)



(SC, 2006)

- Urban services → Sustainability

INTRODUCTION

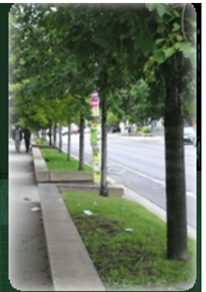


Urban Forests

Halifax (courtesy PD, 2009)

INTRODUCTION

CLIMATE CHANGE
MITIGATION AND ADAPTATION
IN URBAN FORESTS

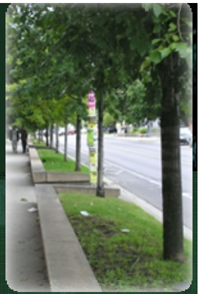


Urban Forest Values

Category	*Value*	*Example*
Environmental	Air pollution removal	(Nowak *et al*. 2006)
	Urban hydrology regulation	(Xiao *et al.* 2000)
	Urban micro-climate regulation	(Heidt & Neef 2008)
Social	Positive psychological effects	(Ulrich 1984),
	Aesthetic quality	(Smardon 1988)
	Emotional and spiritual benefits	(Chiesura 2004)
Economic	Increased real-estate prices	(Tyrväinen & Miettinen 2000)
	Recreational opportunities	(Nowak *et al*. 2001)
	Savings due to environmental function	(McPherson *et al.* 1999)

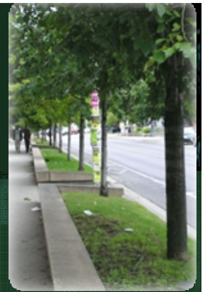
- ❑ Values-based urban forest sustainability **(Ordonez & Duinker, 2010)**

INTRODUCTION



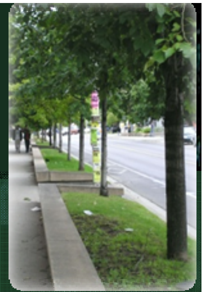
Climate Change

- ❑ Changes:
  - Temperature (~ 1.3-1.9°C by 2050) **(Meehl *et al.* 2007)**
  - Precipitation (Quantity and Quality)
  - Sea-level (~0.18-0.59m = Flooding and Salinity) **(IPCC, 2007)**
  - Extreme weather events (floods, drought, storms,)



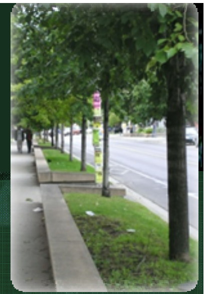
Urban Forest Contributions

Function	***Example***
Direct carbon capture	(Nowak & Crane 2002).
Shade effect on infrastructure (less GHG emissions)	(Akbari, 2002)
Shade effect and albedo reduction	(Heisler 1986, Scott et al. 1999)
Hydrological regime & urban microclimate	(Souch & Grimmond 2006)
Loss of canopy cover & trees	(many)
Emission of VOCs	(many)
Tree maintenance (e.g. transport)	(Nowak 2000)



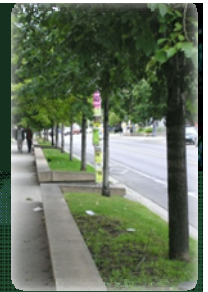
Urban Forest Vulnerability (1)

Dimension	***Category***	***Elements (examples)***
Environmental	*Urban forest structure*	Species Composition
		Species Mix
		Tree arrangement in relation to infrastructure
		Tree arrangement in relation to each other (ecological connectivity)
		Age structure
	Urban Forest natural resilience	Degree of acclimatization (phenotypic change)
		Degree of biological adaptation (genotypic change)
		Ability of species to migrate
	Urban forest stresses	Building activities
		Pruning
		Urban microclimate (UHI)
		Soil availability
		Water availability
	Climate Change Scenario (Uncertainty)	Temperature
		Frequency and intensity of precipitation
		Frequency and intensity of climate disturbances
		Sea-level rise
	Time horizon and space scale	



Urban Forest Vulnerability (2)

Dimension	***Category***	***Elements (examples)***
Social	*Institutions*	Number and kind of institutions
		Level of skill of staff
		Quantity of staff
	Ownership	Kinds and patterns of ownership
Economic	*Valuation*	Property values
		Saved infrastructure costs due to urban forest functions
	Institutions	Budget

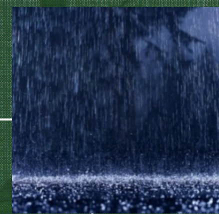


Climate Impacts on the Urban Forest

- ❑ Ecosystem quantity (forests moving altitudinal and latitudinal)
- ❑ Ecosystem quality:

Climate Variable

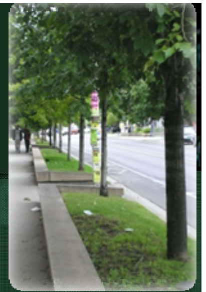
Temperature *Precipitation* *Wind*



FOREST

Growth (Productivity)	Phenology
Evapo-transpiration	Fires
Decomposition	Community Relationships
Regeneration	Soil stability
Insects and Diseases	Tree Mortality
Soil Nutrients	Water Bodies and Soil Wat

(see Duinker, 2010)



Urban Forests and Climate Mitigation

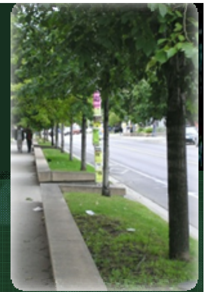
- ❑ GHG emission mitigation: small, but not trivial
- ❑ Bigger and younger trees capture more carbon

(Nowak et al. 2002)

- ❑ Certain species capture more carbon
- ❑ Arrangement of trees in relation to buildings increases energy efficiency
- ❑ Impacts of climate change may downplay mitigation efforts

Urban Forests and Climate Adaptation

- ❑ Adapting Forests and/or adapting cities
- ❑ Return to a "past natural state" challenged **(Spittlehouse & Stewart 2003)**
- ❑ Reducing vulnerability and increasing resilience **(Adger *et al.* 2007)**
- ▪ Environmental considerations:
  - → Selecting Climate-resilient species **(Roloff *et al.*, 2009; Yang, 2009)**
  - → Other local criteria for selection
- ▪ Other social & economic considerations
  - → Increase institutions, budget, address ownership issues



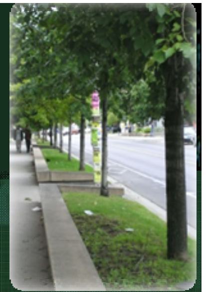
Example: Point Pleasant Park

Consi	*ecies*
Climat	species well-suited … peratures
	eep root systems
Enviro	at thrives on moist … se to water bodies
	th ranges in NB and … , St John river
Social	pecies
	easing or well-

Based

Point Pleasant Park after Hurricane Juan (courtesy PD, 2009)

CLIMATE CHANGE & URBAN FORESTS

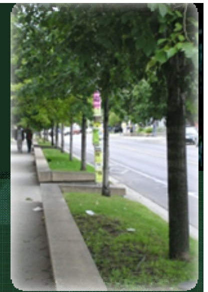


Example: ***Point Pleasant Park***

- Species 1: *Tilia Americana* L. (American Basswood, American Linden)

Canadian Range

Tree appearance



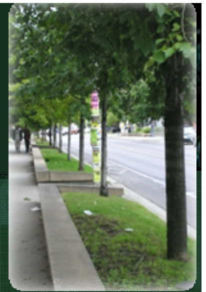
Example: Point Pleasant Park

- Species 2: *Juglans cineria* L. (Butternut, White Walnut)

Canadian Range

Tree appearance

CLIMATE-INCLUSIVE SUSTAINABLE URBAN FOREST MANAGEMENT



Climate Change

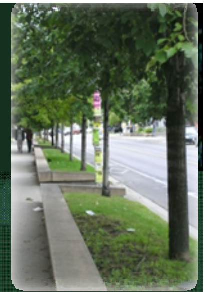
ENVIRONMENTAL
Vulnerability
Resilience

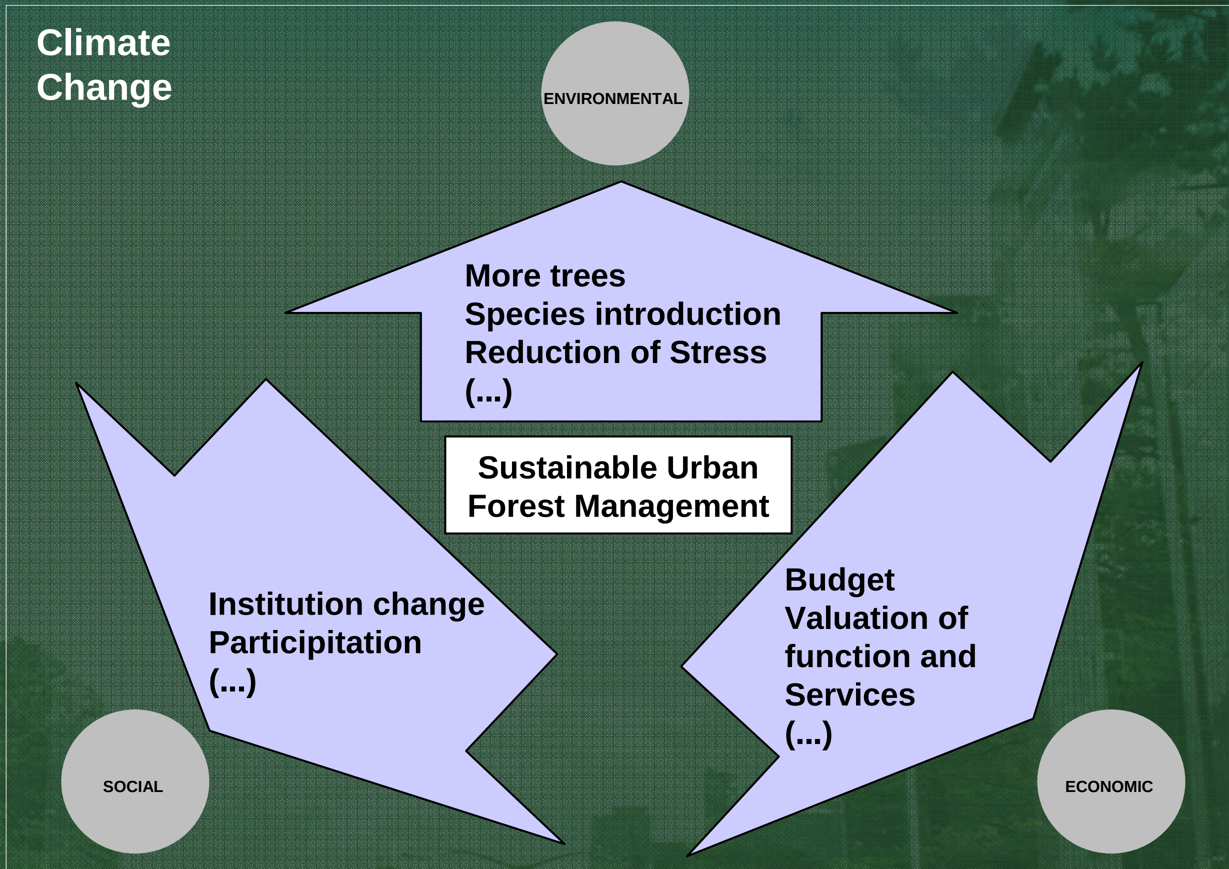
Sustainable Urban Forest Management

SOCIAL
Vulnerability
Resilience

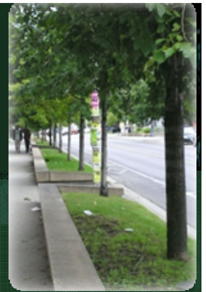
ECONOMIC
Vulnerability
Resilience

CLIMATE-INCLUSIVE SUSTAINABLE URBAN FOREST MANAGEMENT





CONCLUSION & FURTHER RESEARCH



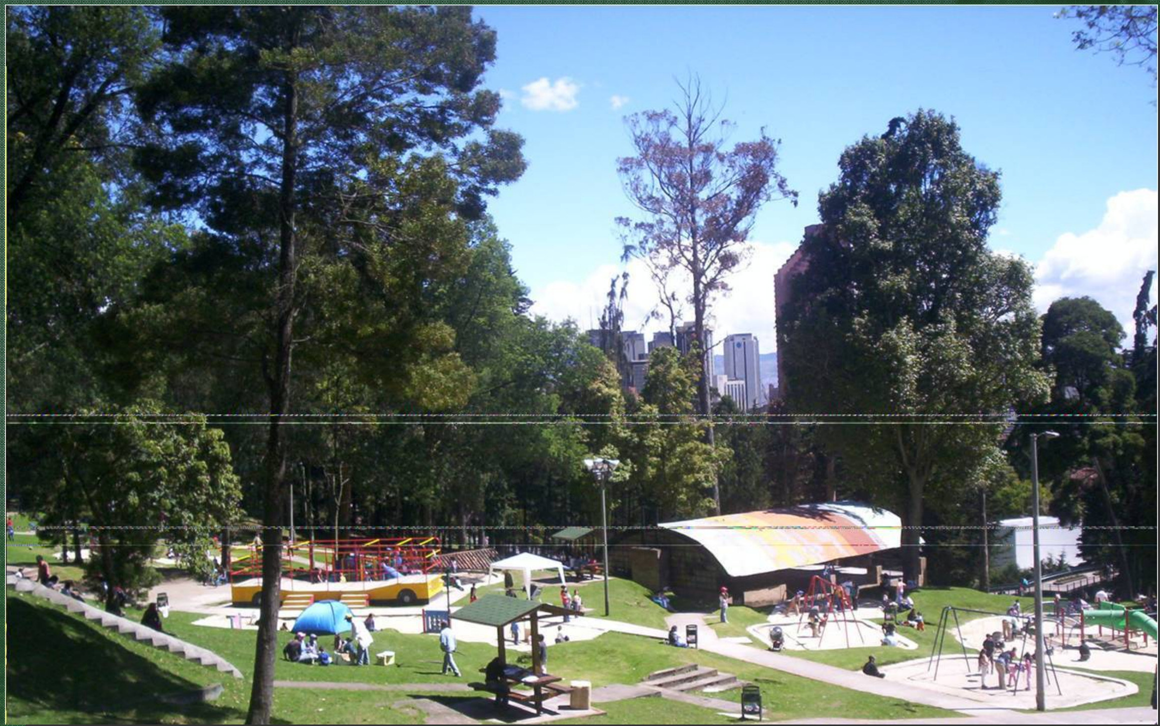
Effective Sustainable Urban Forest Management

- Vision: *To sustain the environmental, social and economic values associated with the urban forests with time and space scales in mind*
- Climate mitigation AND adaptation
- Reduction of vulnerability and increasing resilience:
  - Climate Scenario
  - Impacts and risks
  - Urban Forest stressors
- Environmental bias?

London (courtesy PD, 2009)

END

Questions?



Bogotá