Policy Memo: City of London Urban Forest Climate Change Action Plan

Canada recently committed to bold climate action during the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change held in Paris in December 2015. Reaching these targets, particularly the ambitious goal of not exceeding a 1.5 degree Celsius rise in global temperatures, will require cooperation and dedicated efforts by Canada's municipalities. Irrespective of national commitments, municipalities will experience increased environmental (and likely, societal) pressure to both mitigate and adapt to local climate change.

During COP21, scientists warned that with current projections, and without a concerted effort to combat climate change, the global average temperature will increase between three and five degrees Celsius. Canada will experience an increase in temperature twice that of the global average, ranging from six degrees Celsius to an alarming ten degrees Celsius. Consequently, Canada's ecosystems are expected to shift and alter at unprecedented rates as they come under environmental stress. This situation applies equally to Canada's urban forests. Given a projected rise of 4 degrees Celsius in London, Ontario (if international efforts can hold the global average to two degrees Celsius, the City's local climate will more closely resemble that of Kentucky.

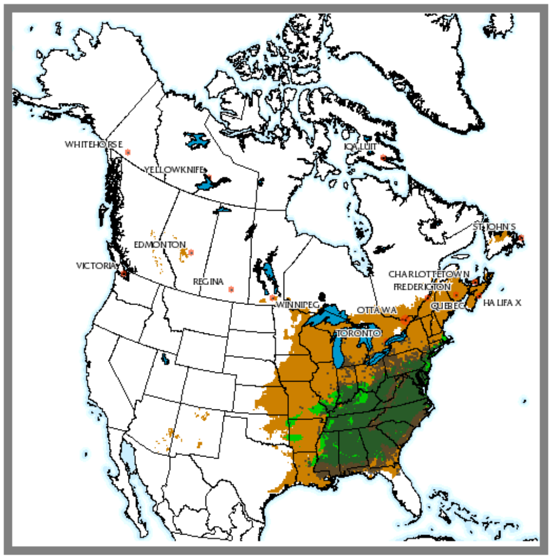
Urban forests play a vital role in mitigating the effects of climate change, by lowering urban temperatures, cleansing the air, providing shade, reducing energy use, etc. They will be crucial in ensuring a healthy environment for urban citizens. However, with rapid changes in temperature, and the resulting extreme weather events and drought expected to accompany this rise, London's urban forest may be ill equipped to thrive and provide the city with environmental, health and social benefits, particularly as certain plant species cannot migrate quickly enough to keep with the pace of global warming. As such, the City must evaluate its options for the future of its urban forest.

Option 1: **Status Quo**. As the City of London experiences environmental change over the next five, ten and thirty-five years, one policy option is to simply let nature take its course. Under this scenario, the City would continue its efforts to reforest London with the help of local non-governmental organizations, local citizens and perhaps with the aid of provincial and/or federal grants. In this case, the City would not adapt species choice to a changing climatic reality, instead allowing London's urban forest to evolve of its own accord. In this case, some species may fair better than others, but the theory would rest in "survival of the fittest" and hopes would rest on the trees building tolerances. In parks, ESAs and other forested areas, the City would allow natural reseeding to occur without interference.

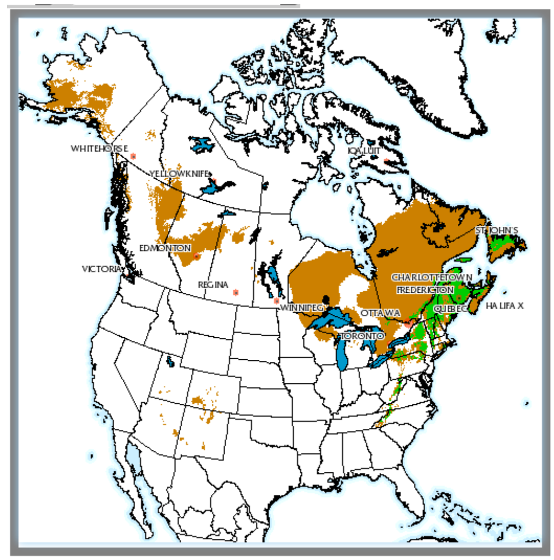
Option 2: **Plant more drought tolerant and disease resistant trees with the expectation that these species would fair better in a hotter, drier environment.** Tree selection could also include those species which may better survive extreme weather events, which are expected to become more frequent in the coming years. Under this scenario, more attention is given to the robustness of the trees, than to their "native" status. While this scenario has obvious benefits in terms of overall tree survival, the City would experience the unintended negative effects of invasive non-native species. Currently, London's most common tree by stem count is the European Buckthorn and by size is the Norway Maple. Both these species are invasive, and buckthorn in particular can have particularly ravaging effects in London's ESA's and other woodlands. Though Norway Maple is invasive, this species continues to be planted within the City's limits. With temperature rises and climatic alteration, invasive species are already forecasted to become more aggressive and more pervasive, as stressed native species cannot effectively compete with more weedy species that do not have natural checks and balances. As such, this particular option is not recommended. The economic and ecological costs of introducing hardy yet non-native (i.e. non-continental species) outweigh any benefits that may arise from this policy.

Option 3: **Assisted Migration.** As the climate warms, the natural range of species will shift. Such shifts have occurred regularly throughout history, with evidence of large range shifts taking place during the ice age and little ice age in the Earth's recent past. However, the current rate of change is so great that many species, in particular slow moving species, will likely not possess the capability to shift at a rate fast enough to ensure their survival. Trees and forests, for example, cannot shift to a more suitable climate as quickly as insects and other more mobile and quick adapting species.

Given that range shifts are predicted to occur, and given that the City can expect that its urban forests will experience stress due to increased temperatures and altered weather patterns (thereby exposing them to greater risk of disease and death), option three proposes that the City look to more southern locations which are projected to closely resemble London's future climate to deduce which trees would naturally shift their range northward (all things being equal) and plant those trees on London's streets to ensure a greater survival of seedlings and better guarantee a healthy urban forest. In London's case, the selected trees would include those currently found in Kentucky. In essence, the City would assist the migration of tree species that are naturally too slow moving to keep apace with the rapid warming of the climate. Trees are slow growing; to ensure mature trees are available to provide seed to existing woodlands, the City must start planting them today. A failure to maintain healthy woodlands as our climate changes will exacerbate air quality impacts, reduce their ability to help combat climate change, and have a significant impact on quality of life here in London.



Current range of tulip-tree (Liriodendron tulipifera)



Future range of tulip-tree, based on composite-AR5 model and RCP 8.5 emissions scenario

One possible criticism for option three involves the risk of unleashing a future destructive invasive species into London's ecosystem. Traditionally, ecologists have viewed any species not native to an area and began reproducing and outcompeting native species as "invasive". This label, however, loses meaning in light of climate change, when inevitably more southern species will naturally shift northward. Such a scenario more closely resembles a simple range expansion rather than an "invasion". At the same time, with a warming climate, a growing number of non-continental species will likely become invasive in the traditional sense as they can survive warmer winters and as native species become stressed due to climate conditions. Given these two different scenarios, the City must re-evaluate how it classifies invasive species. The traditional definition of invasive species does not differentiate between those coming from a shared landmass (i.e. the southern United States) through either a range expansion or a range shift, and those arriving through human introduction from a separate landmass (i.e. Norway maple). With a changing climatic reality, differentiation must be made between non-native species. As such, the City should adopt a "continental" approach to species classification instead, which would include: **native** (species already native to London); **non-native continental (**species native to other parts of North America); **non-native, non-continental** (species from other continents which are not (yet) invasive); and **invasive, non-continental species** (species already defined as invasive and having no natural range in North America). This classification system would prove very beneficial during the tree selection process and would greatly reduce the risk of spreading invasive species.

Recommendation: In 2012 over the course of a discussion around the City's Tree Planting Guidelines, TFAC members identified a set of concerns linked to climate change: range changes and assisted migration; invasive species; and health impacts from pollen. The recommendation to factor climate change into London's urban forest plan constitutes a substantial (and much needed) overhaul of current tree planting guidelines. Option three currently represents the best option for the City of London. Given the current shift in temperatures and weather patterns, and given the need to ensure a healthy and robust urban forest for the social, economic and environmental benefit of the City, London should plant both species that are currently native to London and adapted to today's climate, as well as species expected to become native to London as their range shifts. The City should cease planting non-continental invasive species immediately to eliminate future financial costs of invasive species removal. This policy option will present minimal cost to the City and serves more as a good practices guide in the face of climate change.

In conjunction with policy option three, TFAC proposes the creation of a network of **Climate Change Sister Cities**, to link communities based on their 2050 climates. These connections would facilitate information exchange between municipalities, as well as foster local awareness the future of London's climate.

Finally, to reduce air quality impacts from pollen (which increases with rising temperatures), TFAC recommends integrating OPALS ratings into the Tree Planting Guidelines. In addition, the City should locate low-pollen species and/or female trees in areas where people are more likely to have respiratory problems (e.g. around hospitals, retirement homes, etc.)

Climate Change and Urban Forestry in the 21st Century: A case for proactive policies to guarantee a healthy environment and society in the City of London

"Anticipated global climate change is expected to combine with continued suburban sprawl and associated land cover change to amplify potentially hazardous climate-related conditions in urban areas" (Solecki and Olivieri, 2004, p. 106).

"Seedlings planted today not only need to grow well under present conditions but in climates forty to fifty years from now" (Cullington and Gye, 2010, p. 31).

Introduction

Society generally recognizes that the global climate is changing. The strong global investment in the recent Conference of the Parties 21 held in Paris (December 2015) provides testament to public acknowledgement that our climate is in flux, and without concerted action on the part of governments, businesses and citizens, our climate will come under severe stress. Temperatures are rising, precipitation patterns have become unpredictable, and extreme weather events are now both more common and severe. Recently, global carbon dioxide concentrations reached 400 parts per million (ppm), a level not witnessed in a million years or longer (Sutherland, 2015). Human actions have led to a rise of over 120 ppm since pre-industrial times, half of which occurred since 1980 (Sutherland, 2015). These high levels of atmospheric carbon dioxide are not only *currently* affecting our climate, but will also bring unquantifiable effects for centuries. Dr. Carmen Boening, a scientist in the Climate Physics Group at NASA's Jet Propulsion Laboratory cautions that "Earth's climate [has] never had to deal with such a drastic change as the current increase, which is therefore likely to have unexpected implications for our environment" (Sutherland, 2015). Climate projects predict that by the end of the 21st century, the mean annual temperature for North America will be 2-5 degrees Celsius higher than the average temperatures of the last thousand years. Precipitation will increase in the winter and decrease in the summer, which will significantly affect human society and ecosystems (Spittlehouse and Stewart, 2003). During the Paris Conference 2015, scientists warned that Canada can expect an increase in temperature twice as high as the global average, signifying a rise of 5.4 degrees Celsius in the best case scenario, and an alarming

10.8 degree increase in the worst case scenario. Canada, therefore, as well as its many municipalities, must take concrete action now to both *mitigate* and *adapt to* climate change. **London has witnessed a general warming pattern over the past twelve years.** The 2001-2012 humidex values which lay above 30 degrees Celsius increased by 27 percent in June, and 21 percent in July over the 1971-2000 period (Berry et al., 2014). Records indicate that the greatest increase in warming occurred in the average minimum temperatures; winters have become warmer (Berry et al., 2014). Along with rising temperatures, Ontario has experienced, and will continue to see, changing weather patterns. According to the Institute for Catastrophic Loss Reduction, winters in southwestern Ontario will experience a five to twenty percent increase in precipitation and a five to ten percent decrease in snowfall (Berry et al., 2014, p. 20). Extreme precipitation events involving rainfall over 20 mm will rise 10 percent by 2050. Tornados have already become more frequent in Ontario; between 2006 and 2009 the province experienced 29 tornados (Berry et al., 2014).

The Intergovernmental Panel on Climate Change (IPCC) defined vulnerability to climate change as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including variability and extremes" (IPCC, 2007 in Berry et al., 2014, p. 11). Climate change will affect cities disproportionally higher than rural areas due to the urban heat island effect (Ordóñez et al., 2012). Clearly, climate change brings with it a number of costs – economic, social, environmental and health (Town of Oakville, 2014A). Communities must learn to adapt and must become proactive in their decision-making to minimize these negative impacts. In 2007 Ontario unveiled the Climate Change Action Plan, which aimed to reduce greenhouse gas emissions to 15 percent below 1990 levels by 2020 and 80 percent by 2050. This action plan followed the trend of focusing more on mitigation rather than adaptation. However, scientists warn that "even if all the greenhouse gas emissions were to stop tomorrow, the excess greenhouse gases already in the atmosphere would continue to affect climate for the next thirty to forty years" (Cullington and Gye, 2010, p. 2).

Decision-makers increasingly accept that in conjunction with reducing emissions, communities must learn to adapt to changing climate realities. Indeed, Ontario introduced "Climate Ready: Ontario's Adaptation Strategy and Action Plan 2011-2014", which outlined the necessity of adapting to the inevitable effects of global climate change. In addition, Natural Resources Canada and the Ontario Ministry of the Environment joined with other non-governmental organizations (NGOs), and governmental and academic groups to form the Ontario Regional Adaptation Collaborative, to provide communities and decision-makers with the knowledge and tools necessary to prepare for the risks associated with climate change (Town of Oakville, 2014A).

Forests are often a dominant feature in urban landscapes, and thus, it is critical to mitigate the impact climate change will have on them (Ordóñez et al., 2012). Climate change affects urban forests in a myriad of ways, most notably by inhibiting urban forests' ability to survive and mature (Ligeti et al., 2007). In the past, forests proved resilient, able to adapt to changes in the climate. However, today's forests are more vulnerable due to levels of land fragmentation and degradation unseen during past rapid temperature changes (Noss, 2001). Trees are increasingly threatened by urban intensification, diseases and pests, climate change and related extreme weather events (City of London UF Strategy, 2014). Urban forests are particularly plagued by these problems since they are by nature fragmented, and receive greater exposure to harmful substances (air pollution). They likewise have limited opportunities for migration and reproduction.

London seeks to set itself apart from other cities by the size and beauty of its urban forest, the complete collection of trees growing within the city and the surrounding areas. Currently 25 percent of London is covered by urban forest. However, with the arrival of the Emerald Ash Borer (EAB), most of London's ash trees are expected to perish, reducing the forest cover to 23 percent (Berry et al., 2014). It is difficult to imagine the face of London should it lose much of its trees to climate change. The City's urban forest provides a wide range of services, beyond contributing to the aesthetic beauty of the city. Urban trees provide a number of ecosystem services, as well as social, health and economic benefits. They provide shade in hot weather, thereby lowering incidences of heat related morbidity and mortality, provide protection from wind, and ameliorate some negative effects of climate change, such as increased air pollution. London's urban forest sequesters 370 tons of pollutants annually, which produces savings of $4.5 million in decreased healthcare costs each year (City of London UF Strategy, 2014). Trees also host a wide variety of biodiversity, and do so within a fragmented landscape (typical of an urban area), serving as steppingstones to the wider regional biodiversity (Lawton Report, 2010; City of London UF Strategy, 2014). Trees also serve to reduce energy costs by shading buildings. Consequently, London needs to consider how to manage its urban forest to improve its resiliency so that it may thrive in the future climate. As such, it is crucial that urban planners select trees, keeping changing climate in mind, to ensure a healthy and well-adapted urban forest.

Many uncertainties surround climate change. Given ecological complexity, scientists cannot precisely predict how species or ecosystems will react to an altered atmosphere (Schwartz, 2012). While scientists employ niche models to determine new ideal habitats for species once their current habitat becomes intolerable, it is impossible to foresee how new species interactions will constrain or allow species to migrate to areas highlighted by computer models (Schwartz, 2012). Nevertheless, uncertainty should not preclude action; it is important to prepare for the certainty that temperatures will change, as will weather patterns. A positive step would be to improve London's tree coverage to improve air quality, reduce the risks from extreme heat, counter the UHI effect and prevent the negative feedback cycle that would ultimately deprive London of a healthy urban forest. The following paper outlines the climate change issues affecting the city and proposes novel solutions to the problem. Forests will be able to adapt to the change in climate, but it may be preferable for humans to guide the direction and timing of adaptation (Spittlehouse and Stewart, 2003).

London's Changing Climate and the Forecast for its Urban Forest

London's climate is changing, and despite global efforts to mitigate climate change, accumulation of carbon dioxide in the atmosphere will continue to affect the city.

Rising Temperatures. **Concurrent with rising temperatures, London will experience more frequent extreme heat events.** From 1971-2000 London averaged approximately 2.4 days a year with a humidex rating above 40 degrees Celsius. From 1981-2010 that number rose to 2.7 days a year. In July 2006 London experienced two days with temperatures above 45 degrees Celsius and on July 14, 1995 temperatures reaches over 50 degrees Celsius (Berry et al., 2014). Cold days and nights are likely to become less frequent, which may contribute to greater survival of tree pests. The Localizer reports allow regions to get climate change projections from a group of Global Climate Models. Below are the projects for London.

SR-A2 Air Temperature (Mean)

Celsius	Annual	Winter	Spring	Summer	Autumn
1971-2000	7.6	-4.9	6.6	19.4	9.3
2020s	8.8+/-0.3	-3.7+/-0.5	7.7+/-0.5	20.7+/-0.4	10.6+/-0.3
2050s	10.2+/-0.6	-2.1+/-0.7	9.1+/-0.7	22.1+/-0.8	11.8+/-0.5
2080s	12.0+/-1.0	-0.4+/-1.0	10.7+/-1.0	24.1+/-1.5	13.7+/-0.9

(CCCSN.ca, June 24, 2013)

Altered Precipitation Patterns. **With changing climate, precipitation is expected to increase, except in the summer.** Moreover, the region is likely to experience more frequent extreme precipitation events. Both issues are detrimental to London's urban forest. Drought in the summer will stress trees (particularly younger trees), while heavy precipitation and flooding arising from extreme weather events, will also threaten their survival. Projections for London regarding precipitation are not currently available (Berry et al., 2014).

Extreme Weather Events. **With climate change Ontario can expect to incur more extreme weather events, such as greater snowstorms, severe windstorms and intense rainfall.** Research from the United States revealed that hundred-year storms are now occurring every three to twenty years, and five hundred year floods will occur every 25-240 years by the end of the twenty-first century (Berry et al., 2014). Southwestern Ontario faced a rise in tornados recently. Between 2005-2009, 95 tornados touched down in the province. Between 1995-2004 (twice the time), 105 tornados occurred (Berry et al., 2014).

No-analog climates. With rapidly changing climate comes the issue of no-analog climates. According to García-López and Allúe, "a no-analog climate can be defined as a combination of climatic values outside the current global climatic range or envelop of combinations of planetary known climatic values in a space formed by climatic variables" (García-López and Allúe, 2013, p.1). In essence, no-analog climates represent a situation where a climate exists for which no previous data is available. No-analog climates contain climatic combinations not currently present in the current landscape, including different patterns of temperature, precipitation, frequency of extreme weather events and seasonality (Schwartz, 2012). The concern, then, is that current scientific models to predict species interactions, migration patterns, survival, etc. are less effectual since data cannot be created from an unknown situation. Thus, uncertainty remains as to how species within a region will react to a new reality, both individually and in their interactions with other species. New species combinations and, therefore, new ecosystems may arise.

Schwartz (2012) warns that these future no-analog climates may seriously impact the ability for ecosystems to adapt to new conditions, putting pressure and uncertainty on their future management. These conditions may require unorthodox methods of conservation practice and novels ways of defining Nature (Marris, 2011; Lorimer, 2012). For London, this issue may not seem as pressing, as the city can likely trust that its environment will roughly emulate that of a region in the United States just to the south. However, decision-makers must be mindful that species may not interact as expected as the globe enters an era of uncertainty, and thus they should be open to accepting new species assemblages, which may include species hitherto treated as invasive.

Climate Change and its Effects on the Urban Forest

Even with conservative climate change projections, changes in temperature will fundamentally alter precipitation patters, disrupt regular evapotransportation cycles and lead to extreme weather events (IPCC, 2007 in Ordóñez et al., 2012), all of which will play upon the life-cycles of trees, altering their ranges and their phenologies (Iverson et al., 2004 in Ordóñez et al., 2012; Araújo et al., 2011; Dawson et al., 2011; Iverson et al., 2004). These changes will become even more pronounced by the end of the century. Trees' ability to cope will depend on intrinsic factors (i.e. species biology and genetic diversity) and extrinsic factors (i.e. the pace and scale of climate change) (Dawson et al., 2011). Below will follow a look at seven issues concerning forests. Each is treated separately but ultimately they are closely intertwined, as one issue may lead to the occurrence of another. The first four factors represent the direct effect of climate change on the trees, and the three subsequent factors represent the predicted result of those issues. **With trees' vulnerability to climate change, they will require strong, creative, and proactive management**

programs to ensure their continued survival and good health particularly in harsh, urban environments (Ligeti et al., 2007).

Stress. Tree damage is expected to increase with more frequent extreme weather events, such as heavy rains, freezing rain and strong winds (Ligeti et al., 2007). Even without considering the frequency of extreme storms, which could destroy London's trees, variances in precipitation, pollution and temperatures alone will stress the trees, potentially leading to a die off or, at the least, suboptimal growth. Climate change vulnerability consists of three distinct parts: exposure to stress, sensitivity to stress and the ability to adapt to stress (Summers et al., 2012). Urban trees suffer greater exposure to stressors than rural trees. They "are beset by the heat reflecting off concrete and other hard surfaces, by restricted area for root growth, insufficient water, soil compaction, road salt, and mistreatment" (Ligeti et al, 2007, p. iii). Trees planted adjacent to buildings (which reflect heat onto the trees), alongside roads and parking lots, close to underground utilities (which raise soil temperatures) and in containers are more susceptible to heat stress (Ligeti et al., 2007).

These situations describe the situation of many of London's trees. Hotter, and even extreme, temperatures and altered precipitation patterns, most notably drought in the summer, can stress trees. With elevated temperatures, trees require more watering, particularly since high temperatures are frequently accompanied by drought. Trees require consistent watering in the first five years of their lives, but with droughts predicted, it is extremely likely that many seedlings and saplings will suffer and perhaps die due to lack of water. Moreover, with mild winters and irregular warm spells, trees may produce buds or blossoms prior to another freeze, which damages new growth (Ligeti et al., 2007). In 1996 the IPCC already concluded that forests are highly sensitive to climate change, and that since climate change is occurring at an unprecedented rate, trees struggle to adapt. Mature trees are already exhibiting signs of stress due to climate change (Cullington and Gye, 2010).

Hotter summers lead to higher concentrations of ground-level ozone, a known cause of disease and death in trees. Higher levels of ozone also damage leaves and slow down tree growth (Liegi et al., 2007). When trees become stressed they no are longer able to sequester carbon dioxide. This situation creates a negative feedback loop whereby the effects of rising carbon dioxide stress the trees, inhibiting their ability to remove that gas and other pollutants from the atmosphere, which thereby leads to elevated levels of the offending gases, and so the cycle deepens and worsens. Healthy, and particularly large, trees are better able to sequester carbon dioxide. Therefore, it vital that cities manage urban forests to survive climate change and to continue to remove carbon dioxide and other pollutants form the atmosphere (USDA Forest Service, 1999).

Rise in Invasive Species. **When trees and ecosystems are stressed, due to climate change and related disease and pest outbreaks, opportunistic invasive species can quickly overtake a region, especially if they are better suited to the new climatic conditions.** With climate change, a variety of species are expected to shift north, as migration patterns change. Not all non-native species that move into the region will necessarily be troublesome or invasive. Some species, however, will choke out native species and prevent the establishment of desirable species. Weedy species often possess high dispersal capabilities so they will prosper (Noss, 2001). When non-native species colonize a new region, almost every element of an ecosystem's composition and function is affected (Ellis, 2013). In some cases, these non-native species may lead to public health issues (perhaps from increased levels of pollen, or through transmission of disease), or may severely and harmfully disrupt ecosystems (Town of Oakville, 2014A). **The City of London must be prepared for the eventuality that species composition within the City's limits will be profoundly altered.** The City will have to clearly outline which species it defines as both non-native *and* invasive since "the distinction between native and non-native will become more blurred in the next decades" (Ligeti et al., 2007, p. 15).

Increase in Disease and Pests. Rich biodiversity within a landscape is known to be a key component in coping with climate change (Cullington and Gye, 2010). Greater heterogeneity in species composition improves ecosystem resilience, making it more able to weather change. When an area is simplified (homogenous species composition) and fragmented, that ecosystem is less likely to survive. By nature urban areas are both fragmented and simplified, with relatively few species of trees selected for city plantings for aesthetic, economic and/or practical reasons. Thus, cities are more vulnerable to a single pest or disease, which could wipe out a significant portion of their urban forests, as witnessed recently with the Emerald Ash Borer (Cullington and Gye, 2010).

The introduction of pests and disease will drastically alter the street tree population of London. With climate change, diseases and pests are likewise expected to migrate north. In addition, with warmer temperatures, diseases and pests may survive longer through each season thereby multiplying the amount of damage they can cause each year (Town of Oakville, 2014A). For example, scientists have attributed the rapid spread of the pine beetle in Western Canada to the warmer winters experienced in that region, which sustains the population by preventing a regular dieback. With more frost-free winters and earlier spring weather, insects will enjoy greater over-wintering survivability (Cullington and Gye, 2010). At the same time, warmer and wetter spring and autumn seasons will create ideal conditions for fungi, mildew and bacterial diseases to infest trees (Cullington and Gye, 2010).

Dis-synchrony. With climate change comes alterations to species phenologies, which can lead to problems with synchrony. Parmesan (2006) found in seven out of eleven cases used for a study interacting species reacted differently to global warming, which meant that some co-dependent species were more out of sync at the end of the study than at the beginning. For butterflies and their hosts, this dis-synchrony could lead to population crashes and extinctions.

Mortality and Local Extinctions. **Even modest projections of future warming trends represent a serious threat to global biodiversity (Schwartz, 2012).** Species' risk of extinction arises from a climate-related range shift or shrinkage; dispersal limitations (i.e. highly fragmented landscapes) that limit their ability to colonize new areas; and non-climatic extinction/mortality drivers, particularly habitat conversion (Schwartz, 2012). Since climate change is occurring at a rate faster than plants (particularly trees) can move, the result is loss of native biodiversity due to stress and death. If trees cannot adapt quickly enough (local) extinction will likely occur. Indeed, it is almost certain that "… because climate change is occurring faster than vegetation can migrate (MacIver, 2005), the change in climate is more likely to lead to stressed plants, vegetation dieback and a loss of native biodiversity" (Ligeti et al., 2007, p. 6).

Migration. Species' adaptation to climate change can occur through phenotypic plasticity (the ability of a species to alter its phenotype, or outward appearance, in response to a change in climate), evolution or migration (Noss, 2001). The latter is the common response for species experiencing a changing climate within their habitat. Climate is one of the principle determinants of plant distribution. Given past paleoecological records, the changing climate is likely to have a huge effect on suitable habitat for many tree species (Iverson et al., 2004). Unsurprisingly then, tree species would be expected to redistribute in response to climate change (Ordóñez et al., 2012). Fossil records reveal several examples of species migrating in response to past climate changes (Noss, 2001). Plants are more likely to migrate than to make evolutionary adaptations (Huntley, 1991). However, the rate of climate change currently occurring is ten to a hundred times more rapid than any previous rate of de-glacial warming (Huntley, 1991). Climate change analysis can predict potential "new" suitable habitats for trees, but there appears to be a lag between the availability of new habitat and the ability for species to expand into those areas (Iverson et al., 2004). Consequently, some scientists argue that "[u]nless steps are taken to facilitate the migratory response of organisms to the forecast changes, then widespread extinction is likely" (Huntley, 1991, p. 15; Spittlehouse, 2005). Ordóñez et al. recommend that since "climate is one of the main controllers of plant distribution around the world, urban forest responses to climate change should be appropriately included in its management" (Ordóñez et al., 2012, p. 2).

On the urban scale, local extinction is more likely to be the result of climate change. Species with poor mobility and which cannot overcome dispersal barriers will not succeed. Specifically, trees species currently native to London, may experience a die-off if warmer temperatures or associated ill effects (i.e. disease or pests) become too great a threat to continue their survival in the region. In that case, such as with the ash, a local extinction (but not a global extinction) may occur. On the other side, previously unknown tree species to the area may migrate north to occupy the gap left by the now absent trees. However, evidence exists that **there is a migratory lag with trees, compared with other forms of vegetation; they cannot move quick enough to keep pace with a rapidly changing climate (Huntley, 1991).** With climate change, a significant component of a species' chance for survival is its ability to disperse and colonize a new area. Given the highly fragmented landscape through which these tree species must move, this ability is severely crippled. It is questionable whether trees will be able to reach migration rates necessary to deal with forecasted climate change (Huntley, 1991). While some have predicted that more southerly species will move north, it remains unclear whether these species could survive the North's winter cold spells, which will likely still occur (Ligeti et al., 2007).

Migration will change the species composition of ecosystems, beyond simply the trees that will now inhabit the city. Invertebrates and vertebrates have demonstrated rapid range shifts in recent decades. For instance, of 35 non-migratory European butterflies sampled for a study, 63 percent shifted north by 35 to 240 kilometres this century (Parmesan et al., 1999 in Noss, 2001). What these shifts will mean for the fauna that depend on specific flora for food, reproductive or other needs is uncertain. Likewise, range shifts may harm certain species of trees which depend on other species for their dispersal. Various forms of fauna dependent on specific trees species will likely shift with their host trees. More likely, however, fauna will migrate north ahead of trees, which are known to lag in their dispersal rates, which could have consequences for pollination or other ecosystem services we do not fully understand. It is feared that "… all organisms will face demands to migrate across landscapes that may have been severely altered by human activities, and in which the habitats available to them will be limited in extent and fragmented" (Huntley, 1991, p. 19).

Past rapid migrations occurred on relatively fully forested landscapes, a situation no common today as "dispersal barriers", i.e. urban centres and intensive agriculture dot the landscape (Noss, 2001; Iverson, 2004). Many species will have to disperse quickly over highly fragmented and human dominated landscapes to match the rate of climate change (Dawson et al., 2011). Disturbance and hinder dispersal and reintroduction of species for over a century (Iverson et al., 2004). This problem will further hinder rates of migration. Since climate change will increase vulnerability and un-assisted migration will prove difficult, managers may need to facilitate the migration process (Summers et al., 2012).

Recently some evidence has surfaced of rapid, long-distance migration of some tree species (Clark, 1998 and Clark et al., 1998 in Noss, 2001). Rates of past migrations suggests that even rapid shifts in range limits are likely inadequate to "keep pace with" future climate change (Iverson et al., 2004). To date more evidence has surfaced of range expansion than contraction, but concerns that there may be an extinction lag persist (Dawson et al., 2011). The speed at which species can migrate is crucial, and if it cannot occur organically, urban forest managers may have to assist the process.

Phenotypic Plasticity and Evolution. If some species cannot migrate, due to dispersal barriers (i.e. urban spaces), they may either evolve in-situ or alter their phenologies. Most observations of alterations of species involved changes to their phenologies. Phenotypic plasticity signifies that a species changes its responses to climate without actually changing its genes. Previously scientists thought that climate change is occurring at a pace too fast for species to adapt. However, recent studies of species demonstrating remarkable resilience have surfaced (Marris, 2014). These reports demonstrate just how little we understand the planet's ability to cope with climate change. Parmesan for instance, discovered that the quino checkerpoint butterfly, which was believed to be blocked by Los Angeles, not only was able to move north to follow cooler temperatures, but also found a new host plant on which to lay its eggs (Marris, 2014).

Climate Change, Urban Forests and Human Health

Climate change has already begun to significantly affect human health, and this issue will become more apparent as global temperatures continue to rise. The Middlesex-London Health Unit has documented numerous risks to health from climate change across many communities in Ontario (Berry et al., 2014). Among these risks are high incidences of morbidity and mortality due to more frequent and severe weather events, higher levels of ambient and indoor air pollution, compromised recreational and drinking water quality, increased food contamination, spread and increase in numbers of pathogens and disease-carrying organisms, and greater exposure to harmful UV rays (Berry et al., 2014, p. 8). The citizens of London's exposure to these hazards is growing, threatening the population's health. **The baseline rate from 1981 to 2000 annual heat-related mortality in London was 4.3 deaths per 100,000. Due to climate changes rates are expected to increase to 9.3 per 100,000 from 2031-2050, 15.3/100,000, 2051 to 2070 and 23/100,000 from 2070 to 2090 (Martin et al, 2011 in Berry et al., 2014). Therefore, the Middlesex-London Health Unit believes that the City's decision-makers should make every effort to incorporate climate change issues into City planning going forward.**

Though Middlesex-London has witnessed some improvements in its air quality, with a 23 percent reduction in maximum ozone concentrations in London from 2000-2002 and from 2008-2010, climate change will intensify poor air quality in highly populated areas. Indeed, from 2000 to 2010 London experienced a 25 percent increase in average ozone concentrations (Berry et al., 2014). London also experienced twelve smog advisories in both 2005 and 2007. However, the number of advisories did go down between 2008 and 2011 (Berry et al., 2014). Warming temperatures increase aeroallergens, i.e. pollens from trees and grasses. Excessive heat is often tied with an increase in smog, which directly threatens those with respiratory illness. Climate change leads to greater incidents of asthma (Town of Oakville, 2014A). Already citizens of London experience high exposure to outdoor air pollution (smog, pollen) and this level of pollution is expected to increase with climate change (Berry et al., 2014). Ground-level ozone, which is a key component of smog, is especially expected to increase with rising temperatures. It already poses a serious health risk to Canadian communities (Berry et al., 2014). In addition, warmer and wetter weather may generate more weeds, molds and dust mites, all of which affect aggravate respiratory diseases (Berry et al., 2014). For instance, due to climate change, the ragweed season has become longer in North America. Moreover, high temperatures and periods of draught can lead to a greater number of forest fires, increasing peoples' exposure to particulate matter (Berry et al., 2014), and increasing risk of asthma attacks.

One of the greatest threats for those living within London's city limits is the Urban Heat Island (UHI) effect. The larger the community, the greater the UHI effect. During the day, a large city will experience temperatures 1-3 degrees Celsius higher than the surrounding environment, and up to 12 degrees Celsius higher during the evenings (Cullington and Gye, 2010, p. 18). Beyond the health effects, UHI increase energy demand within cities, as residents depend heavily on air-conditioning to cope with the extreme heat. This high-energy use, naturally, feeds back into the current climate change-energy use dilemma. **UHI contributes to higher energy costs, greater air pollution and greenhouse gas emissions, heat related illness (including respiratory distress) and mortality, as witnessed in a number of large cities recently.** Paris provides a prime example of the UHI threat when in 2003 over 3000 Parisians died due to an extreme heat wave. Cities, and London specifically, though not as large as Paris, should take seriously this threat of increased city temperatures and what that may mean for residents health and well-being, recognizing that cities are at a disadvantage to address climate change and extreme weather due to the UHI effect. **A study on the urban heat island effect in New York found that urban trees were one of the most effective ways to cool the air (Ligeti et al., 2007).**

Climate change-related tree mortality may likewise lead to distress in local residents who may experience a real sense of loss, and even depression as prized trees perish (Hull, 1992 in Novak and Dwyer, 2007). In British Columbia and Alaska, where the pine beetle has caused a mass die off of trees, on a unimaginable scale, citizens have felt despair and helplessness as familiar landscapes have been rapidly, and irreparably altered. Homeowners, understandably, grieved as the majority of the trees on their land succumbed to the beetle, and landscapes that were once dark green turned brown. Without preventative action, it is conceivable that climate change could cause the same massive die back within London, a disheartening prospect for those who work hard to manage the City's urban forest.

Policy Recommendations

Given the very real threats climate change poses to London's urban forest, and the ecological, social, economic and health costs that could result, climate change adaptation policies should feature prominently in urban planning. Regarding the urban forest, the City of London has a plan to "Plant more, protect more, maintain better" (City of London, 2014). **To achieve this objective, the city should look to projected climatic conditions for the city to make wise choices as to the trees planted going forward.** The City can look to the 2014 Provincial Policy Statement for guidance in this area. Article 1.7.1.j highlights the importance of "minimizing negative impacts from a changing climate and considering the ecological benefits provided by nature" (Ontario Provincial Policy Statement, 2014, p. 20). It also encourages Ontario decision-makers in 1.8.1.f.1 to "promote design and orientation which maximizes energy efficiency and conservation, and considers the mitigating effects of vegetation" (Ontario Provincial Policy Statement, 2014, p. 21). Other Ontario cities have already begun to recognize the importance of incorporating climate change adaptation in urban planning decisions. In 2005 the Oakville Town Council approved its first Environmental Strategic Plan (ESP) (updated in 2011). One of the plans objectives is to improve the town's ability to address and respond to climate related crises. As such, the town has mandated that both existing and new plans, policies and projects include mitigation and adaptation measures (Town of Oakville, 2014A). In addition, the ESP requires the town to consistently monitor their progress in this realm, and to make adjustments where necessary to keep pace with climate changes.

Clearly the province of Ontario understands that climate change cannot be ignored and that it is in the best interests of Ontario's citizens to undertake proactive adaptation measures. London could be a leader in this process. In particular, London could begin by managing its urban forest to reduce their risk of climate change-related damage or mortality. Healthy forests, after all, can directly mitigate some of the negative impacts of climate change (Bonan, 2008). By 'climate-proofing' London's urban forest, the City can protect its green infrastructure. Cullington and Gye warn that "[f]ailure to invest in re-structuring the urban forest to meet future climates could result in increased costs for cleanup after wind-or snow-storms, or unnecessary loss to wildfire or pests" (Cullington and Gye, 2010, p. 30).

London: Steppingstone for biodiversity. **When devising plans for London's green infrastructure, decision-makers may wish to view the city as part of a wider network of biodiversity, and account for the role it plays in providing ecosystem services for the region.** Habitat connectivity is important, even within an urban landscape, a proven through studies done on birds on wooded streets in urban centres (Goddard et al., 2009).

Therefore, urban forests cannot and should not be separated from the broader landscape. The City could strive to better connect London's green spaces to the wider ecosystem, creating a larger 'green infrastructure' (Crutzen and Schwägerl, 2011), as a collection of stepping stones for migratory and non-migratory species, thus building functional landscapes within the human-impacted environment (Poiani et al., 2000; Worboys et al., 2013). Through an intact matrix the City could seek to ensure the long-term survival of many floral and faunal species. Such an approach has been greatly touted in the United Kingdom with the publication of the Lawton Report (2010), which precisely called for a novel approach to biodiversity conservation, with a greater focus on including more areas into nature conservation through a system of steppingstones and corridors. Common practice has tended to look at nature as outside urban centres. However, as urbanization spreads across the globe, and as climate change alters global dynamics, cities should feature in our conception of nature. Once new ideals of nature are accepted, it becomes possible to enhance the role that cities can play in ameliorating environmental ills.

Human-assisted migration. **With certain species, humans could hasten their migration, should land fragmentation and dispersal barriers prove insurmountable to achieve**

natural migration and desirable rates (Iverson et al., 2004; Ladle and Whittaker, 2011). For instance, Iverson et al. (2004) noted that some species, like beech, have lost many of their animal dispersers. Human altered landscapes hinder the movement of species (Summers et al., 2012). An urban landscape provides an extreme example of an environment ill suited to self-propagation and migration. When species cannot overcome the barriers of human altered landscapes, they can become increasingly isolated, which increases their vulnerability to climate change (Summers et al., 2012). Huntley suggests that with climate change, "[a]rtificial dispersal of trees and other organisms of limited dispersal and/or migratory capacity, […] and the integration of wildlife habitat into human landscape utilization are all likely to be necessary" (Huntley, 1991, p. 15). Keeping this issue in mind, it may prove advisable to select continental species projected to migrate north into more suitable climate, but which may face immediate dispersal barriers within London.

Increasing resilience. **A top priority for urban forest management in a changing climate is to enhance trees resilience to change and crises. Options for improving resilience include: conserving natural areas, boosting species diversity, connecting ecosystems through corridors and steppingstones, careful species selection, and solid planting and maintenance practices (Cullington and Gye, 2010).** Large, healthy trees are estimated to remove 60-70 times more pollution than smaller trees because they have a greater leaf surface area (McPherson et al., 1997, 53). Therefore, "… sustaining the health and longevity of mature trees is critical to maximizing air quality benefits" (McPherson et al., 1997, 53). If disease or pests or heat and drought stress kill urban trees, the costs of removing and replanting them all will be huge (McPherson et al., 1997). Early mortality of trees must be prevented, since large trees can remove more pollutants than small ones (Ligeti et al., 2007).

Tree Choice. **The popular mantra in urban forestry is "right tree, right place", but this policy must take into consideration the changing climate, because what is right now, may not be right twenty years from now.** When an ill-suited tree species is selected, resources and energy are strained to ensure survival; "[t]rees that are not well-adapted will grow slowly, show symptoms of stress, or die at an early age" (USDA Forest Service, 1999, p. 4). Going forward the City of London should seek to determine the most appropriate tree species for this region given future climate projections (Cullington and Gye, 2010). No longer can future decisions on urban forests use the current climate as a baseline (Ordóñez et al., 2012). Considerations for climate change must be incorporated into all levels of urban forest management. Climate vulnerability assessments for London's urban trees should be conducted to tailor future decisions regarding the management of the urban forest. These analyses should include "climate impacts, sensitivity, adaptation capacity, non-climatic factors, drivers of vulnerability and adaptation strategies to climate change in an urban forest management context" (Ordóñez et al., 2012, p.1). London is advised to look at regions, which currently are experiencing this city's predicted climate for 2050, to ascertain what grows well (Cullington and Gye, 2010). For instance, planners should consider which species will thrive in a drier climate.

London needs to plant more native and drought resistant species, as these are less likely to suffer excessive stress due to higher temperatures and erratic precipitation patterns. If native species cannot tolerate higher temperatures and associated climatic changes, more climate appropriate species should be selected to guarantee the continuance of a vibrant and healthy urban forest (Ligeti et al., 2007). Native conifers usually do better than deciduous trees as they can limit photosynthesis during the dry season (Cullington and Gye 2010). Moreover, the City should consider planting trees, which have an above average ability to remove air pollutants (Ligeti et al., 2007). Those trees selected should likewise be able to sequester higher levels of carbon, such as Tilia species, blue spruce, Robust and Siouxland hybrids, all of which can sequester over 4.6 kg of carbon a year (Poaletti et al, 2003 in Ligeti et al., 2007).[1] Trees placed in the right setting can decrease summer heat and UV radiation and reduce the UHI effect (Cullington and Gye, 2010).

Novak and Dwyer warn that "… inappropriate landscape designs, tree selection, and tree maintenance can increase environmental costs, such as pollen production and chemical emissions from trees and maintenance activities that contribute to air pollution, and also increase building energy-use, waste disposal, infrastructure repair, and water consumption" (Novak and Dwyer, 2007, p. 27). When selecting trees, London could make

[1] See Appendix 1 for a list of the best and the worst tree species to enhance the City of London's urban forest.

use of the International Tree Failure Database (ITFD). This database provides information on tree failure in countries around the world. It helps tree managers and researchers understand tree failure patterns, and to predict tree failures. It allows for the creation of appropriate standards for species selection and maintenance, which thereby reduces the negative impacts from tree failures (Cullington and Gye, 2010).

Native v. Non-Native. For much of the 20th century, conservationists have accepted the notion of 'climax' communities, or the 'natural' state for an environment. Recently, though, scientists recognize that changing climates and changing vegetation patterns are common through Earth's history; everything shifts and changes through space and time (Manning et al. in Lorimer, 2012; Adams, 2003). In London, it is quite likely that the urban environment with which residents are currently familiar could be entirely foreign in fifty years. However, different does not necessarily mean worse. With climate change must come re-evaluation of what we consider native and non-native. Native species may not necessarily represent the most resilient choice. Native species may not thrive in London's changing climate, while species from further south may fair better; "[t]he distinction between 'native' and 'non-native' will become more blurred in the next decades as species distributions shift" (Cullington and Gye, 2010, p. 36). In the Anthropocene, we must approach biodiversity conservation through novel means (Lorimer, 2012), and clearly understand what our goals are in terms of preserving and creating a healthy and viable urban ecosystem. With climate change, we must accept that species composition will change, and perhaps even facilitate that change, while paying close attention to the species which we select and their effect on the local environment. New assemblages of species will occur over time; we may wish to influence the timing and the actual make-up of these assemblages. It is possible to "co-opt" novel ecosystems and "opportunistic biodiversity" to create a healthy ecosystem for the city (Kueffer and Kaiser-Bunbury, 2014). Cities should proceed with caution when selecting non-native species to prevent the release of invasive species which crowd out more desirable species, and reduce overall diversity (Cullington and Gye, 2010). That problematic non-native species (i.e. invasives) must be removed is largely a given. A safe choice is to select a species from nearby (not a different continent) and currently at the northern limit of its range (Cullington and Gye, 2010).

At the same time, we must be mindful that native species do fulfill a role within the wider ecosystem. A study of gardens in Pennsylvania found that native plants significantly increased the level of bird and butterfly diversity, compared to conventional non-native gardens (Goddard et al., 2009). The same results were found true in Australia. Other experiments found that exotic plants are used much less by native pollinating insects (Goddard et al., 2009). Consequently, continual monitoring to ensure that tree selection is not resulting in unforeseen outcomes for vertebrate and invertebrate populations may prove beneficial, and adjustments made as necessary.

Conclusion

The City of London has a vision of "a healthy, diverse, and extensive urban forest for today and in the future" (City of London, 2014). If appropriate actions are not taken now, climate change may threaten that vision. Consequently, it is important to adapt urban forests to deal with climate change so that they may continue to thrive even as they face new challenges. Healthy, resilient urban forests are a long-term investment. Communities that are proactive in dealing with climate change will be better prepared for its impacts (Cullington and Gye, 2010). Natural Resources Canada suggests that "[i]ntegrating climate change adaptation into decision-making is an opportunity to enhance resilience and reduce the long-term costs and impacts of climate change (Cullington and Gye, 2010, p. 3). Residents, with the right education and information sharing, are likely to get on board with a plan to build a climate resilient urban forest, and compliments the surrounding ecosystem. Moreover, if "[p]roperly designed and managed", urban forests serve as a "natural 'biotechnology', to reduce some of the adverse environmental and health effects associated with urbanization" (Novak, 2006, p. 93). It is important to identify new trees suitable for London's changing climate, and work to reduce the spread of insects and disease (Spittlehouse and Stewart, 2003).

The greatest challenge will be to allow uncertainty into decision-making (Schwartz, 2012). Uncertainty may push some to view taking action as a greater risk than doing nothing, or that adaptation is not feasible (Spittlehouse, 2005). In truth, poorly informed decisions can lead to unwanted results. However, uncertainty should not delay adaptive actions; decisions must be made on currently available information (Berry et al., 2014), since "adaptation to climate change in forest management requires a planned response well in advance of the impacts of climate change" (Spittlehouse and Stewart, 2003, p. 2). The Ontario Provincial Policy Statement declares that "[t]he long-term prosperity and social well-being of Ontario depends upon planning for strong, sustainable and resilient communities (…), a clean and healthy environment, and a strong and competitive economy" (Ontario Provincial Policy Statement, 2014, p. 4). It is hoped that by adopting the progressive urban forestry policies outlined above, London can move in that direction.

Glossary

Adaptation: In regards to climate change, the United Nations Framework Convention on Climate defines adaptation as the actions that a community or communities take in response to climate change. It refers also to the natural and human response to actual or perceived climate change to either reduce adverse effects, or to take advantage of possible benefits from an altered climate.

Aeroallergens: An airborne substance which triggers an allergic reaction, i.e. specific pollens.

Anthropocene: A term introduced by Paul Crutzen and Eugene Stoermer in the early 21st century to describe the present era where human activities now have the greatest impact on the Earth's geological processes and systems on a global level. Arguably, the Anthropocene began during the Industrial Revolution.

Assisted Migration: The deliberate act by humans to aid various flora and fauna inhabit new regions should their native climate become inhospitable due to climate change (or other factors).

Biodiversity: The variety of species (plant and animal) and ecosystems on Earth. This term is a contraction of "biological diversity".

Biodiversity Steppingstones: A series of small patches of habitat which a species can use for food and shelter to traverse an inhospitable region (due to land fragmentation).

Climax Communities: A term coined in the mid-20th century to describe an ecosystem which over time has reached a steady state, or an ecosystem seen to be in equilibrium. The concept of a "climax community" has recently come into question.

Corridors: Long, uninterrupted strips of hospitable land connecting larger areas of habitat. Species use these corridors to move through fragmented landscapes.

Dispersal Barriers: Anything that may prevent a species from migrating to a new area, or that may hinder its ability to propagate through movement. A common dispersal barrier is land fragmentation.

Dis-synchrony: A situation whereby species which are dependent on each others' lifecycles are no longer in sync. For instance, a plant which normally would flower at the time when an insect depends on the plant for reproduction, now blooms earlier due to changes in the climate.

Ecosystem Services: The benefits that humankind receives from the natural operation of a healthy and robust environment. Examples include flood control, water purification and decomposition.

Evapotranspiration: The evaporation from Earth's surface and the oceans, and the transpiration from plants into the atmosphere.

Extinction Lag: The lag in time between the destruction of a habitat and the extinction of a species.

Extreme Weather Events: Weather events that are outside the range of normal given historical weather patterns. These unusual and often severe events – drought, storms, floods, melting glaciers – are largely attributed to human-induced climate change.

Genetic Diversity: The variety of genes within a species.

Green Infrastructure: A network of natural and semi-natural features within a landscape, which provides a wide variety of ecosystem services within urban and rural environments (ex. an urban forest).

Invasive species: Flora, fauna or fungi introduced to an area of which it is not native, and then, having no natural predictors or other check, spreads rapidly and causes damage to the local environment, economy and/or human health.

Land Fragmentation: The separation of untouched pieces of land by developed landscapes; smaller natural areas having no connection to other small parcels of natural land in the immediate area. The loss of natural areas.

Mitigation: Efforts to reduce the emission of greenhouse gases in an effort to slow down climate change.

Morbidity: This term either describes the number of instances of a particular disease in a population in a geographical area, or the rate of death resulting from a particular disease.

Native species: A species which is indigenous to a particular region. This condition is confirmed through geological records.

No-Analog Climate: A climate for which there exist no previous records, thereby complicating the application of climate models to determine future climate realities.

Non-Native Species: A species which is not native to a particular region. This species may or may not be invasive (i.e. harmful) in its new location.

Paleoecological Record: The data retrieved from fossils to determine ecosystems of the past. This data can determine which species were previously found within a given region thereby providing concrete evidence regarding native and non-native species.

Phenology: Key seasonal changes in species from year to year, i.e. blossoming of trees or migration of animal species.

Phenotypic Plasticity: The ability of a species to alter its genes in response to environmental changes.

Resiliency: The amount of disturbance an ecosystem can withstand or the amount of environmental change a species can endure before it suffers damage and/or perishes.

Urban Forest: The tree coverage in a city setting, including densely wooded areas as well as trees on private land and boulevard trees.

Urban Heat Island Effect: An urban area with significantly higher temperatures than surrounding rural areas due to human activity, such as building structures and air pollution from transportation.

Vulnerability (species): Species which are at risk of becoming endangered or extinct due to a variety of environmental factors, including climate change and land fragmentation.

References

Adams, W. “When Nature won’t stay still: Conservation, equilibrium and control.” In W. Adams and M. Mulligan (eds.). *Decolonizing Nature: Strategies for Conservation in a Post-colonial era.* Earthscan: London, 2003.

Araújo, Miguel B., Diego Alagador, Mar Cabeza, David Nogués-Bravo and Wilfried Thuiller. “Climate change threatens European conservation areas.” *Ecology Letters* 14 (2011): 484-492.

Berry, Peter, Jaclyn Paterson and Chris Buse. “Assessment of the vulnerability to the health impacts of climate change in Middlesex-London.” *Middlesex-London Health Unit* 1 August 2014 <assessment-of-vulnerability-to-the-health-impacts-of-climate-change-in-Middlesex-London.pdf> (8 May 2015).

CCCSN.ca. “London, Ontario Climate Localizer Report.” 2013 <London_Ontario-Climate_Localizer_report_42.967500_-81.232500_0.pdf> (5 May 2015).

City of London. “The London Plan.” 2014 <thelondonplan.ca> (21 April 2015).

“City of London Urban Forest Strategy: Enhancing the Forest City.” June 2014 <https://www.london.ca/residents/Environment/Trees-Forests/Documents/London%20Urban%20Forestry%20Strategy%20Final.pdf> (21 April 2015).

City of London Urban Forestry, Upper Thames River Conservation Authority, USDA Forest Services and Bradwill Ecological Consulting. “An analysis of London’s urban forest using the Urban Forest Effects Model (UFORE).” May 2012 <UFORE-Final-May182012.pdf> (21 April 2015).

Crutzen, Paul J. “Geology of Mankind.” *Nature* 415 (2002): 23.

Crutzen, Paul J. and Christian Schwägerl. “Living in the Anthropocene: Toward a new global ethos.” *Environment 360* 2011 <http://e360.yale.edu/feature/living_in_the_anthropocene_toward_a_new_global_ethos/2363/> (5 May 2015).

Cullington, Judith and Jeremy Gye. “Urban forests: A climate adaptation guide.” July 2010 <www.retooling.ca?_Library/docs/Urban_Forests_Guide.pdf> (21 April 2015).

Dawson, Terence P., Stephen T. Jackson, Joanna I. House, Iain Colin Prentice, and Georgina M. Mace. “Beyond Predictions: Biodiversity conservation in a changing climate.” *Science* 332 (6025) 2011: 53-58.

Ellis, Erle C. “Sustaining biodiversity and people in the world’s anthropogenic biomes.” *Current Opinion in Environmental Sustainability* 5 (2013): 368-372.

García-López, Javier M., and Carmen Allué. "Modelling future no-analogue climate distributions. " *Global and Planetary Change* 101 (2013): 1-11.

Goddard, Mark A., Andrew J. Dougill and Tim G. Benton. "Scaling up from gardens: biodiversity conservation in urban environments." *Trends in Ecology and Evolution* 30 (10) 2009: 1-9.

Huntley, Brian. "How plants respond to climate change: Migration rates, individualism and the consequences for plant communities." *Annals of Botany* 67 (1991): 15-22.

Iverson, Louis R., M.W. Schwartz and Anantha M. Prasad. "Potential colonization of newly available tree-species habitat under climate change: An analysis for five eastern US species." *Landscape Ecology* 19 (2004): 787-799.

Kareiva, Peter and Michelle Marvier. "What is conservation science?" *BioScience* 62 (11) 2012: 962-969.

Kueffer, Christoph and Christopher Kaiser-Bunbury. "Reconciling conflicting perspectives for biodiversity conservation in the Anthropocene." *Frontiers in Ecology and the Environment* 12 (2014): 131-137.

Ladle, Richard J. and Whittaker, Robert J. (eds). *Conservation Biogeography.* Wiley-Blackwell: ????, 2011.

Lawton Report!!!

Ligeti, Eva et al. "Climate change adaptation options for Toronto's urban forest." 2007 <www.cleanairpartnership.org/pdf/climate_change_adaptation.pdf> (22 April 2015).

Lorimer, Jamie. "Multinatural geographies for the Anthropocene." *Progress in Human Geography* 36 (5) 2012: 593-612.

Marris, Emma. "How a few species are hacking climate change." *National Geographic* 2014 <http://news.nationalgeographic.com/news/2014/05/140506-climate-change-adaptation-evolution-coral-science-butterflies/> (4 May 2015).

Marris, Emma. *Rambunctious Garden: Saving Nature in a Post-Wild World.* Bloomsbury: USA, 2011.

McPherson, E. Gregory, David Novak, Gordon Heisler et al. "Quantifying urban forest structure, function and value: The Chicago Urban Forest Climate Project." *Urban Ecosystems* 1 (1997): 49-61.

Nikiforuk, Andrew. *Empire of the Beetle: How human folly and a tiny bug are killing North America's great forests.* Greystone Books: Canada, 2011.

Noss, Reed F. "Beyond Kyoto: Forest management in a time of rapid climate change." *Conservation Biology* 15 (3) 2001: 578-590.

Novak, David J. "Institutionalizing urban forestry as a 'biotechnology' to improve environmental quality." *Urban Forestry and Urban Greening* 5 (2006): 93-100.

Novak, David J. and John F. Dwyer. "Understanding the benefits and costs of urban forest ecosystems." In Kuser, J.E. (ed). *Urban and Community Forestry in the Northeast, 2nd ed.* Springer, USA: 2007.

Ordóñez, C., P.N. Duinker and M. Rostami. "Adapting urban forests to climate change." 2012 <OrdonezDuinkerRostami_AdaptUrbForto ClimChange_proceedings_.doc> (4 May 2015).

Parmesan, Camille. "Ecological and evolutionary responses to recent climate change." *Annual Review of Ecology, Evolution and Systematics* 37 (2006): 637-669.

Poiani, Karen A., Brian D. Richter, Mark g. Anderson and Holly E. Richter. "Biodiversity conservation at multiple scales: Functional sites, landscapes and networks. " *BioScience* 50 (2) 2000: 133-146.

Schwartz, Mark W. "Using niche models with climate projections to inform conservation management decisions." *Biological Conservation* 155 (2012): 149-156.

Solecki, William D. and Charles Olivieri. "Downscaling climate change scenarios in an urban land use change model." *Journal of Environmental Management* 72 (2004): 105-115.

Spittlehouse, David L. "Adaptation to climate change in forestry." 2005 <https://www.for.gov.bc.ca/hre/pubs/docs/Spittlehouse2005_Species@Risk.pdf> (5 May 2015).

Spittlehouse, David L. and Robert B. Stewart. "Adaptation to climate change in forest management. " *BC Journal of Ecosystems and Management* 4 (1) 2003: 1-11.

Summers, David M., Brett A. Bryan, Neville D. Crossman and Wayne S. Meyer. "Species vulnerability to climate change: impacts on spatial conservation priorities and species representation." *Global Change Biology* 18 (2012): 2335-2348.

Sutherland, Scott. “New and troubling carbon threshold passed, researchers say.” *The Weather Network* 8 May 2015 <http://www.theweathernetwork.com/news/articles/global-carbon-dioxide-reaches-record-high-not-seen-in-millions-of-years/50750/> (8 May 2015).

Town of Oakville. “Climate change primer.” 2014 <Use_of_Localizer_Report_by_Town_of_Oakville.pdf> (5 May 2015). (A)

Town of Oakville. “Climate change strategy – technical report.” September 2014 <http://www.oakville.ca/assets/general%20-%20environment/Version_1.1_FINAL_Climate_Change_Strategy.pdf> (5 May 2014). (B)

United States Department of Agriculture Forest Service. “Urban forests and climate change.” 1999 <www.fs.fed.us/psw/publications/documents/psw_gtr171/psw_gtr171_content.pdf> (20 April 2015).

Williamson, Craig E., Jasmine E. Saros, Warwick F. Vincent and John P. Smol. “Lakes and reservoirs as sentinels, integrators and regulators of climate change.” *Limnology and Oceanography* 54 (6) 2009: 2273-2282.