Ten-Year Results of the First Climate Change Experimental Site in Canada

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Abstract

This paper documents the collaborative contribution of community and inter-agency partnerships in a 10-year project involving community planting, monitoring and the establishment of a new Smithsonian Institution 1-hectare biodiversity site in Toronto, Canada.

Planned adaptation entails planting new species better suited to changing climatic conditions. Such measures were tested over a 10 year period at a climate-change experimental site at Humber Arboretum in northwest Toronto to evaluate the success of both native and new species in the context of an altered climate. Results suggest that additional risks with new forest species will require new management solutions. In the meantime, however, urgent action is needed now to implement aggressive insect, disease and browsing control, develop new policies to govern land-use changes and, above all, plant native and new forest species on a large scale.

Introduction

In 2002, the Association for Canadian Educational Resources (ACER), Humber Arboretum, Arborvitae (non-profit) and Atmospheric Science and Technology Directorate, Adaptation and Impacts Division (government), developed a climate-change experimental site in northwest Toronto.

The project involved the establishment and monitoring of a new biodiversity plot in the Humber Arboretum to assess ecological sustainability under a changing climate and the impacts of biological threats on urban forest biodiversity. Over a 10-year period, students and volunteers measured the survival, success and growth rate of different species of trees using scientific methods and tools developed by the Smithsonian Institution in Washington, D.C.

The site is still being maintained by Humber Arboretum in consultation with ACER and Arborvitae. Although ongoing measurements were not collected after 2009, some survival and growth measurements on a sub-set of trees were measured and recorded by ACER in 2010 and 2012.

The project had multiple objectives, including:

• Teaching communities to benchmark existing biodiversity according to international, scientific protocols;

• Training community members in the proper planting, measuring and monitoring of new urban forests;

•Providing demonstrations to communities on techniques to plant trees that will survive to age 40 and beyond, as well as tree planting protocols to encourage enhanced forest biodiversity;

• Investigating the benefits of forest planting design and the selection of species to optimize greater species biodiversity and ensure increased climatic resilience of species under current and changed climatic conditions, particularly for urban forests in the temperate zone;

• Monitoring the impacts of warmer temperatures on urban forest biodiversity;

• Documenting the response of biodiversity plots containing various combinations of native and new forest and herbaceous species more suited to a changed climate; and

• Developing new adaptive management practices, including the selection of the best species for the future.

The Toronto urban location proved particularly beneficial for study. The heart of Toronto, which is home to 2.5 million people, is characterized by a well-documented warming bias relative to surrounding areas. This "Toronto warming effect" of nearly 4.0°C higher minimum temperatures compared to nearby rural sites stems from thermal influences of the city's location on the shoreline of the Great Lakes as well as the urban heat island phenomena.

The degree of warming in the Toronto core relative to adjacent communities is consistent and within the range of anticipated future warming (MacIver and Karsh, 2010). It was hypothesized that this degree of temperature change in the city presented itself as a possible "living laboratory" and that observed differences in minimum temperatures might serve as an indicator to better assess the responses of vegetation to warming by comparison to rural sites outside of the city (MacIver et al., 2009).

The project garnered enthusiastic community involvement, with extremely large numbers of elementary, high school and university students participating as well as adult volunteers and interest groups. Results of the monitoring program have contributed to development, teaching and documentation of best monitoring practices, instilled community pride, and provided valuable data to educators and scientists.

Background

Climate change is predicted to have a greater than average impact on the biotas of the cold temperate and polar regions of the world. Southern Ontario, with its remnant Carolinian forest, lies within these regions and can expect significant climate warming. Globally, climate-change models project a warming of 1.4-5.8°C in mean annual temperatures by the end of the century, with warming of 2-5°C for average daily temperatures and minimum temperatures 1-2°C warmer than average daily temperatures for southern Ontario (Dallmeier et al., 2010).

Even without climate change, southern Ontario has been highly impacted as a result of extensive land clearing, intensive agricultural activity and growing urbanization pressures. Losses of native species have accompanied these transformations to the landscape. More than 30% of native biodiversity has been lost over the last 200 years. At this rate, a further 20% is predicted to be lost over the next 100 years due to land-use change, agricultural expansion, wetland drainage and insect/disease losses, as well as creeping climate change (Karsh and MacIver, 2010).

The climate of southern Ontario is already warmer and wetter, causing biodiversity to adjust. Some of the greatest changes have been observed in the Carolinian zone, where the study site is located. This narrow band extends along the north shores of Lake Erie and Western Lake Ontario and contains more rare and endangered species of plants and animals than any other part of Canada. More than 125 species have been declared at risk and over 400 others are considered rare. Forest cover has been reduced from 80 to 11% and in some places is less than 3%. Wetlands once covered 28% of the land but are now down to 5%. However, where remnant patches of existing Carolinian forest remain, this forest type contains some of the highest forest biodiversity in Canada (Karsh and MacIver, 2010).

The protected forests in the Carolinian zone should respond positively under climate change, based on climate-change biodiversity data. These indicate that the incremental warming of the climate system will create a favourable environment for a 25% increase in habitat biodiversity (native and new species) over the next 100 years (MacIver and Karsh, 2010). But this projected increase entails planting a combination of native and new species, with the latter depending entirely on well-planned and executed adaptation options. The key is proactive planting of new species better suited to changing climatic conditions, now and in the future. Thus, provided habitats are protected from land-use changes and other human stressors, climate change can not only help slow the rate of loss but also result in significant increases in biodiversity if planned adaptation options are implemented (MacIver and Karsh, 2010).

Methods

25 Site Description

The biophysical context of this site, the former Etobicoke Tree Nursery, is the urban forest (temperate zone). The soil is a rich loamy sand and growing conditions are excellent, provided there is adequate weed control and protection from browsing using brush blankets, mulch and tree guards. However, with no fencing around the perimeter of the site to prevent encroachment by deer, browsing proved to have a significant negative impact on tree survival and growth.

The Humber Arboretum is bounded by Finch Avenue, Highway 27, Rexdale Boulevard and Highway 427, enabling access to many community groups and schools. Its importance to the community has many facets. Citizens of the GTA look upon this area as an urban forest oasis and use the various gardens for picnics, wedding pictures and soothing walks. The forested and open area trails are particularly popular with hikers and cyclists. This area is also used by students from local elementary and secondary schools and Humber College. Annually, the arboretum attracts more than 10,000 visitors.

2. Plot Design, Tools and Monitoring Processes

Forest biodiversity benchmarking and monitoring activities followed the guidelines of the Smithsonian Institution Monitoring and Assessment of Biodiversity (SI/MAB) Program for establishing forest inventory plots in world biosphere reserves. The Smithsonian Institution initiated its global biodiversity observing program in 1992 and its network now numbers more than 500 sites in two dozen countries. Canada has 104 SI/MAB sites based largely in southern forest ecosystems where impacts on biodiversity are high, with southern Ontario home to at least 25 (MacIver et al., 2009).

All of the sites have standardized one-hectare plot sizes and measurement protocols for multi-taxa monitoring. Plots monitored using the SI/MAB protocols can be compared with measurements taken at other sites around the world to provide information on tree species' abundance and diversity, long-term trends in forest growth, mortality and regeneration, and impacts from forest disturbance. The globally agreed upon protocol requires that all trees above a certain diameter (10 cm dbh in the tropics and 4 cm dbh in southern Canada) are mapped, identified for species, and measured for diameter at breast height (dbh) and total height (m). Parameters such as tree health and understory vegetation are often monitored in the plots.

The Humber Arboretum plot is slightly larger, with 28 quadrats, but comparable to the standard one-hectare SI/MAB site size of 25 quadrats, each 20 m by 20 m. The use of a one-hectare plot gives a relatively large sample and has been shown to be robust enough to capture the biodiversity of a site in the tropics and in the most biologically diverse areas of the Carolinian zone (MacIver et al., 2009).

For the purposes of this study, the standard protocols for monitoring mature forests were adapted for new forest plantings. This included monitoring the performance of trees and shrubs for at least 10 years, since it generally takes between five to seven years to determine whether a planted tree will survive. Good growth rates during this establishment period can result in increased volume by 30-50%, which in turn has major consequences for carbon sequestration, ecosystem health, biodiversity, ecological footprint assessment and accumulated carbon debt calculation.

The conditions of seed-bed, ground cover and soil type were recorded prior to the planting of native and new species. Inventory of mature trees or shrubs already present on the site were gathered, along with weather conditions and date at time of planting. The site was rototilled to ensure planting success and both brush blankets and mulch were used to improve the odds of survival by reducing incidences of heavy competition. Tree guards were employed to protect trees from browsing and each tree had its own tag attached by wire to an implanted brick for long-term tracking by community volunteers.

Parameters monitored annually included root-collar diameter, total height, crown dimensions (average of two measurements) and dbh (if taller than 1.3m). Survival, browsing damage, health and condition were also recorded for each tree and shrub in the spring and fall.

3. Planting Design

Nearly 2,160 trees and shrubs were planted in 2002-03. During the life of the project, there was some mechanical damage to the plot, creating gaps with missing or dead trees. As a result, additional trees of similar species were planted in 2004, bringing the final number up to 2,230 as of 2009. There were more than 61 different species of trees and shrubs planted, an unprecedented number of species for a community planting project. Each quadrat had an average of 86 plants and the spacing was approximately 2.5 m between trees and slightly less between shrubs. As well as planting for biodiversity and climatic warming, the site was designed to bolster disease resistance: no more than 5 to 10% of any one species; no more than 20% of species of the same genus; and no more than 30% of the same family. Larger stock was planted to encourage good survival, along with plants that prefer direct sunlight and grow well together according to plant utilization principles and moisture gradients.

4. Landscape Design and Quadrat Comparisons

The landscape design consisted of four different species arrangements:

1. Forestry Quadrats (2 to 3 families);

2. Urban Street Tree Quadrats (3 to 4 families, trees that do well in the urban environment and tolerate high salt conditions, pollutants and pressures from human impact);

3. Biodiversity Quadrats (7 to 11 families, native species, same growing zone); and

4. Carolinian/Climate Change Quadrats (12 or more families, species that are expected to do well in warmer climates).

Further information on the composition and number of quadrats in each species arrangements is outlined below.

Forestry Quadrats (3): Q12, Q23, Q28

These three quadrats contained only White Pine, Red Oak and Paper Birch, each of which are highly valued for their forest products. The trees were planted in blocks and rows to simulate typical commercial planting designs.

Urban Street Tree Quadrats (4): Q4, Q11, Q18, Q25

Large numbers of Silver Maple (54%), Pussy Willow, Red Osier Dogwood and Staghorn Sumac were planted in these four quadrats, with shrubs interspersed with Silver Maple. Half of each quadrat was allocated for a path to allow access to heavy equipment for watering the site, which also simulated urban city street plantings and impacts from human development. The data from these four quadrats were aggregated to create the equivalent of one larger 20 m by 20 m quadrat. Thus, instead of 28 quadrats, the entire plot consisted of 25 equally sized quadrats to mirror the Smithsonian plot design (Diagram 1).

Biodiversity Quadrats (19): Q1, Q2, Q3, Q5, Q6, Q7, Q8, Q9, Q10, Q13, Q14, Q15, Q17, Q20, Q21, Q22, Q24, Q26, Q27

These 19 quadrats were further split into two sets: 1) mixedwood quadrats with both softwoods and hardwoods; and 2) hardwood quadrats with only hardwoods. Based on previous analysis of at least 37 SI/MAB sites across Canada, each set was then divided into categories of high (11-12 families), moderate (9-10 families), and low (7-8 families) biodiversity.

Quadrats of high biodversity in this study included Q5 and Q20 from the Mixedwood Biodiversity Quadrats as well as the two Carolinian warmer-species quadrats, Q16 and Q19. The high-biodiversity quadrats would be comparable to plots in Canada with the highest documented biodiversity (i.e., Long Point Biodiversity Reserve in southern Ontario).

a) Mixedwood Moderate Biodiversity Quadrats (4): Q7, Q22, Q24, Q27 plus Q1 (Low Biodiversity)

Both hardwoods and softwoods were planted in these seven quadrats, each with a little over half the number of tree families as found in the Carolinian Quadrats. The trees and shrubs were planted in clusters of approximately five to 15 individual plants per species in any one quadrat. The species chosen for these quadrats were ones known to do well in the planting zone that includes Humber Arboretum: American Basswood, American Beech, Green Ash, Red Oak, White Cedar, White Oak and Pin Cherry. Q1 was also in this group but would be considered low biodiversity.

b) Hardwood Moderate Biodiversity Quadrats (6): Q2, Q6, Q10, Q15, Q21, Q26

These six quadrats contained hardwoods and shrubs with fewer families of trees (a little over half) than in the Carolinian Quadrats. Trees were planted in clusters of five to 13 per quadrat.

c) Hardwood Low Biodiversity Quadrats (6): Q3, Q8, Q9, Q13, Q14, Q17

Less than half the number of families of the Carolinian Quadrats were planted in these six quadrats. The hardwoods and shrubs chosen were typical of species found growing around Humber Arboretum.

Carolinian Warmer Species High Diversity Quadrats (2): Q16, Q19

These two quadrats contained species associated with warmer temperatures located two zones to the south (e.g., Washington, D.C.) as well as Carolinian species commonly found in southern Ontario: Black Gum, Bladdernut, Ohio Buckeye, Spicebush, Sourwood, Tulip Tree, Chestnut Oak, Yellow Birch, Black Oak, Cucumber Tree, Pin Oak, Sassafras, Big Shellbark Hickory, Spicebush, Southern Arrowwood, Pumpkin Ash, Ohio Buckeye, Bitternut Hickory, Witch Hazel, Bladdernut and Persimmon.

The quadrats were composed of a mixture of hardwoods and shrubs, with 12 or more different families and a total of 19 varieties per quadrat. The trees and shrubs were clustered in groups of the same or compatible species, with a minimum number of five of any species and a maximum number of 24.

Analysis

Observations gathered at this site were intended to document the response of native and new forest and herbaceous species to climate change and to aid in the development of new planting protocols and adaptive management practices. The choice of species planted took into account climate-change projections as confirmed by scientifically reliable local field data on species vulnerability to impacts such as insect infestations, ice-storm damage and invasive species.

After initial analysis of all the trees, the database was stratified based on trees or shrubs that were marked as healthy in 2009. A minimum of five trees per species and a minimum of five measurements for each of the surviving and healthy trees per year was established as the threshold required to meaningfully track growth, given the extensive (more than 76%) browsed, damaged, dying, missing or dead trees.

Results

Climate warming in urban habitats is associated with increased frequency and outbreaks of pests, as well as the expansion of populations of deer and rabbits, which benefit from the warmer spring temperatures. Despite protecting the plants with tree collars, browsing impact in the site was considerable, with 27.5% damage to trees and shrubs in 2009 and 76.2% (range of 34.9-100%) mortality, breakage and loss of foliage associated with previous years of deer foraging. All of the trees still living, with the exception of White Spruce, showed signs of heavy or severe browsing annually that may affect future growth, survival, reproductive success and competitive ability.

1. Community Involvement

Approximately 2,051 people took part in planting, monitoring and measuring the newly planted trees and shrubs over a 10-year period. Of the 2,051 participants, 1,824 were students, 138 were teachers and 89 were supervisors from ACER and their partners in the non-profit and government sectors. There were fall and spring monitoring seasons throughout most of the nine years of data collection for a total of 14 opportunities for trained volunteers to participate. Forty-four educational institutions, comprised of 20 elementary schools, 22 secondary schools and two universities were involved in the project.

2. Deer Browsing

There was extensive evidence of persistent deer browsing, including signs of deer scat and impressions in the grass where deer had lain. A young faun was spotted in one of the quadrats and the trees showed annual damage from deer browsing such as bite marks, broken branches, girdling and chewed leaders.

3. Survival, Health Status and Growth Trends

The descriptions of results in this section correspond to the following graphs, figures and tables:

Table 1: Health and Status Report for Trees and Shrubs by Quadrat in 2009

Table 2: Healthy and Status Report for Trees and Shrubs by Quadrat in 2009 (Percentage Values)

Table 3: Health and Status Report for Trees and Shrubs in 2009 Within Biodiversity, Carolinian, Forestry and Street Tree Treatments

Table 4: Health and Status Report for Trees and Shrubs in 2009 Within Biodiversity, Carolinian, Forestry and Street Tree Treatments (Percentage Values)

Table 5: Health and Status Report for Trees and Shrubs in 2009 by Species

Table 6: Health and Status Report for Trees and Shrubs (Cumulated Values) by Total Number and Percentage Values

Table 7: Average Values for Crown Width, Root Collar Diameter, Total Height and DBH by Species for Trees and Shrubs

Table 8: Average Values for Crown Width, Root Collar Diameter, Total Height and DBH by Species for Healthy Trees and Shrubs as of 2009

Table 9: Average Values for Crown Width, Root Collar Diameter, Total Height and DBH by Species for Trees and Shrubs by Quadrat

Figure 1. Total Number of Trees (%) in Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian

Figure 2. Browsed and Bark Damaged Trees (%) in Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian 8

Figure 3. Dead and Dying Trees (%) in Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian

Figure 4. No Data or Missing Trees (%) in Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian

Figure 5. Healthy Trees (%) in Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian

Figure 6. Impacted Trees: Total Number of Trees – Healthy Trees (%) in Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian

Figure 7. Health Status of Trees and Shrubs (%) for Each Damage Category

Figure 8. Pie Chart of Healthy Trees and Shrubs (as of 2009) in Comparison to Impacted Trees (Browsed, Bark Damaged, Broken Branches, Dead, Dying, No Data, Missing)

Figure 9. Relative Percentage of Browsed, Dead, Missing, Healthy and Impacted Trees and Shrubs Within Each of the Four Treatment Categories: Forestry, Street Tree, Biodiversity and Carolinian

Figures 10-18; Figures 19-25 (Subset of Healthy Trees in 2009) – Change in Average Crown Width (cm): A Comparison Between Tree Species

Table 7 (Page 1); Table 8 (Page 1) – Change in Average Crown Width (cm): A Comparison Between Tree Species

Figures 26-34; Figures 35-41 (Subset of Healthy Trees in 2009) – Change in Average Root Collar Diameter (mm): A Comparison Between Tree Species

Table 7 (Page 2); Table 8 (Page 2) – Change in Average Root Collar Diameter (mm): A Comparison Between Tree Species

Figures 42-50; Figures 51-57 (Subset of Healthy Trees in 2009) – Change in Average Total Height (cm): A Comparison Between Tree Species

Table 7 (Page 3); Table 8 (Page 3) – Change in Average Total Height (cm): A Comparison Between Tree Species

Figures 58-60; Figure 61 (Subset of Healthy Trees in 2009) – Change in Average Diameter at Breast Height (mm): A Comparison Between Tree Species

Table 7 (Page 4); Table 8 (Page 4) – Change in Average Diameter at Breast Height (mm): A Comparison Between Tree Species

A. Treatment Effect: Health and Survival

There was no discernable treatment effect for the various species arrangements based on the health records in 2009 except that the Forestry, Street Tree and Carolinian Quadrats had the lowest number and percentage of browsed and bark damaged trees (14% or less on average) (see Tables 1 and 2). Q9 and Q26 also showed low values of browsed and bark-damaged trees, 12 and 9 8% respectively, which was not typical of the much higher values (range of 29-72%) observed in other biodiversity quadrats within their species arrangement and treatment category (Table 2). However, distinct differences were apparent when analyzing average values for the Forestry, Street Tree, Carolinian and Biodiversity Quadrats. For this reason, only four treatment comparisons are presented (Figures 1-6). The differences between high-, moderate- and low biodiversity quadrats were deemed inconclusive.

Based on the 2009 results, Eastern Cottonwood was the species most favoured for browsing by deer, followed by Balsam Poplar. Other species such as Bitternut Hickory, Canada Plum, American Basswood and Sweet Crabapple came third, followed by Staghorn Sumac, Peachleaf Willow, Hackberry, Eastern White Cedar, Paper Birch, Trembling Aspen, Red Oak, White Pine and Red Ash as the next group of trees most impacted by browsing (Table 1). White Spruce was the least browsed species.

The percentage of dead or dying trees (reflected as a percentage of all such trees) was more than 40% in the Biodiversity treatment, mid-range (26-32%) in the Forestry and Carolinian treatments and very low (<2%) in the Street Tree treatment. As shown in Figure 2, most of the dead or dying trees were in the biodiversity treatments.

The more numerous Biodiversity Quadrats were characterized by the largest percentage of missing trees or trees without any data collected (>69%). The remaining treatments (Forestry, Carolinian and Street Tree) had a more normative percentage of trees (10-11%) in this category. The quality of the data was impacted by gaps of these measurements in the early years of data collection.

The relative percentage of healthy trees was greatest in the Biodiversity treatment (>71%) compared to the Forestry and Carolinian treatments (10-13%) or the Street Tree treatments (<6%).

Subtracting the number of healthy trees from the total number of trees on the site provides an indication of how many trees were impacted by deer browsing or other causes of mortality. The impact was greatest (>68%) in the Biodiversity treatment, between 13-14% in the Forestry and Carolinian treatments, and 4% in the Street Tree treatment.

More than three-quarters of the trees and shrubs in the Biodiversity treatments were either browsed, bark-damaged, broken, dead, dying, or had missing data. However, the remaining treatments also had large percentages (69-81%) of such trees (Figure 9). This impact is well beyond normal loss of trees through attrition. Within species arrangements, the Street Tree Quadrats, as seen in Figure 9, had the lowest number of browsed, damaged, broken, dead or dying trees (just over 11%) but the highest number of trees that were missing or lacked data (47%). Browsing damage in 2009 was least in the Forestry treatment at 4.5%, mid-range in the Carolinian and Street Tree treatments (11-13%), and highest in the Biodiversity treatment (>41%).

It should be noted that the percentages within treatments in Figure 9 add up to 100% as the number of browsed trees within each treatment category was divided by the total number of trees within the same category. The preceding figures present a different perspective on the data with the number of browsed trees in each treatment category given as a percentage of the total number of browsed trees across all treatments. Thus, Figure 2 shows the greatest percentage of browsed trees are in the Biodiversity treatment and Figure 9 shows a relatively greater number of browsed trees in comparison to dead, no data/missing or healthy trees in the Biodiversity treatment.

B. Treatment Effect: Growth

There were insufficient comparisons to discern treatment effects between the Carolinian, Forestry, Biodiversity or Street Tree plantings due to lack of data: growth measurements for a minimum number of replications per treatments in any one year were not collected or there was not enough data per year or per growth measurement. As a result, the following analysis of results focus on growth comparisons between individual quadrats and tree species.

C. Change in Average Crown Width (cm): A Comparison Between Quadrats

Average crown width increased by four times for trees in Q1, far exceeding the doubling in size that occurred in Q11, Q2 and Q5 (quadrats are listed in order of growth). Measurements of crown width in the remaining quadrats were too variable from year to year or had insufficient measurements to discern patterns or trends.

D. Change in Average Crown Width (cm): A Comparison Between Tree Species (see Figures 10-18; Figures 19-25 [Subset of Healthy Trees in 2009]; Table 7 [Page 1] and Table 8 [Page 1]

The tree species with the strongest growth increments in average crown width, showing values increasing by approximately 2.5 times, were Sweet Crabapple, Balsam Poplar, White Pine, White Spruce and Silver Maple. Tamarack showed a similar trend but had an irregular drop in 2007 (Figures 10-18, Table 1 – CW). The greater crown growth in some of these species, particularly White Spruce, may reflect less relative browsing pressure from deer.

When the data was further analyzed for the subset of healthy trees in 2009, similar upward trends appeared for Silver Maple and White Spruce (Figures 19-25). This smaller subset showed higher average crown width values on a year-to-year basis and less impact from very high or very low values (compare Table 7 – CW to Table 8 – CW). For example, the high initial value for Green Ash in 2002 in the entire dataset is not present in the subset nor is the problematic drop in 2007 values for Tamarack. Growth also followed a more normal progression in the subset of healthy

trees (compare the last three years of growth in Silver Maple and White Spruce).

Species showing a slight steady increase while not quite a doubling in average crown width values were Pussy Willow, Red Osier Dogwood, Red Oak and Eastern White Cedar. By contrast, one species displaying a decreasing trend was American Basswood. Further analysis of healthy trees as of 2009 yielded insufficient data or excessively variable measurements (see data for Red Osier Dogwood) to observe any clear patterns in this group.

Of the remaining species planted, 22 had insufficient, discontinuous or excessively variable values, precluding any discernable trends from being observed in the data. Eleven species showed little or no increase in average crown width from 2002 to 2009.

E. Change in Average Root Collar Diameter (mm): A Comparison Between Quadrats

The trees in Q1, Q11, Q2, Q7, Q4 and Q8 were all characterized by greater average root collar diameter (mm). It more than doubled in Q1 and Q11 and increased by more than 1.5 times in Q2, Q7, Q4 and Q8. Data measurements in the other quadrats were insufficient or showed no change over the period of monitoring.

F. Change in Average Root Collar Diameter (RCD) (mm): A Comparison Between Tree Species (see Figures 26-34; Figures 35-41 [Subset of Healthy Trees in 2009]; Table 7 [Page 2]; Table 8 [Page 2])

The conifers, in particular White Spruce and White Pine, had the greatest increase in average root collar diameter, with values doubling from 2002 to 2009. Most of the remaining trees species, such as Speckled Alder, Sweet Crabapple, Pin Cherry, Canada Plum, White Cedar, Tamarack, Balsam Poplar, Bur Oak, Red Oak, Black Walnut, Peachleaf Willow and Elderberry, experienced more of a steady slow advancement while others displayed little change. Among the latter group were Hackberry, Green Ash, Eastern Cottonwood, Trembling Aspen, Pussy Willow and American Basswood.

An examination of the subset of healthy trees in 2009 showed consistently higher values in this same measurement parameter for Silver Maple, White Spruce, Pin Cherry and White Pine. The problematic values for Bur Oak (low 2009 value) or Trembling Aspen (high 2007 value) are not reproduced in the subset of healthy trees (compare Table 7 – Page 2 and Table 8 – Page 2).

G. Change in Average Total Height (cm): A Comparison Between Quadrats

Average total height (cm) declined, as evidenced by the data for 12 of the quadrats. Height decreased by up to 1.4 times for Q8, Q5, Q6, Q7, Q9, Q19 and Q26. Total height went down by 1.6-1.8 times for Q4, Q3 and Q18 and by 50% for Q25. For Q2, it dropped by almost one-third. It is assumed that this height loss was a result of intense browsing by deer. Measurements in the remaining 16 quadrats were too variable on a year-to-year basis or insufficient to discern trends in the data.

H. Change in Average Total Height (cm): A Comparison Between Tree Species (see Figures 42-50; Figures 51-57 [Subset of Healthy Trees in 2009]; Table 7 [Page 3]; Table 8 [Page 3])

An analysis of trends in average total height revealed a decrease in values from 2002 to 2009 for nearly all of the tree and shrub species, with the exception of White Spruce and Red Osier Dogwood. Average total height was the most variable measurement monitored from year to year.

I. Change in Average Diameter at Breast Height (mm): A Comparison Between Quadrats

Trees in 11 quadrats showed an increase in average dbh over the lifetime of the project: 1.5-2.0 times in Q11, Q17, Q2, Q8, Q10 and Q18; 2.3-2.5 in Q7 and Q21; 2.7-2.8 times in Q4 and Q6; and by 3.3 times in Q9. The remaining quadrats had insufficient or too widely variable data for trend analysis.

J. Change in Average Diameter at Breast Height (mm): A Comparison between Tree Species (see Figures 58-60; Figure 61 [Subset of Healthy Trees in 2009]; Table 7 [Page 4]; Table 8 [Page 4])

Very few of the trees planted in 2002 reached breast height (1.3 m) by the end of the project. It is only at this height that DBH is measured. The exceptions were Silver Maple, Sweet Crabapple and Balsam Poplar. Some of the other trees attained the minimum height but lacked sufficient measurements for trend analysis. The latter included Red Osier Dogwood, Tamarack, White Spruce, Eastern Cottonwood, Bur Oak and Sandbar Willow.

The only species with sufficient measurements in the subset of healthy trees were Silver Maple, Balsam Poplar and White Spruce (Table 8 – Page 4). All of these trees showed marked growth in average dbh, with values more than doubling from 2002 to 2009. A comparison of dbh values for Silver Maple among the entire dataset (Table 7 – Page 4) and the subset of healthy trees (Table 8 – Page 4) indicated consistently annual higher values in the subset of healthy trees. Further observation of trends in dbh would require the collection of measurements well beyond 10 years.

Summary of Growth Results:

• Average crown width (cm) doubled or quadrupled in some quadrats.
• The species showing the most crown expansion were White Spruce and Silver Maple.
• Average root collar diameter (mm) increased by 1.5 to 2.0 times in half the quadrats, less or nill in the remaining ones.
• White Spruce and White Pine doubled in average root collar diameter (mm) while the remaining trees and shrubs showed evidence of a slower steady rate of growth.
• A drop in total height (cm) was apparent in half the quadrats with reductions of up to 50%.
• White Spruce and Red Osier Dogwood had the least decrease in height; it was also noted that White Spruce was one of the only species not extensively browsed by deer.
• Average DBH (mm) was greater for trees in some quadrats by 1.5 to 3 times.
•Silver Maple, Balsam Poplar and White Spruce doubled in average DBH (mm), indicating that these trees still increased in volume growth despite reductions in crown width and leader length.

Lessons Learned and Recommendations

The Humber Arboretum Climate-Change Experimental Site provides a compelling case study in biodiversity conservation and climate-change adaptation and mitigation. One of the most valuable

lessons learned was the importance of community volunteers and their participation in benchmarking monitoring activities. The project proved that with training by educators and scientists, communities can maintain a long-term interest in their urban forests and be better informed and proactive about potential changes in climate and its effects on local landscapes.

Another achievement was to show that communities can learn to plant trees that will survive to age 40 and beyond and, with assistance, can pool their knowledge to proactively plant for the future. Volunteers were taught how to choose tree species and design urban forested areas in order to maximize biodiversity and ensure tree survival under current and future climatic conditions. For example, if planting for the greatest increase in canopy growth, the community could plant White Spruce or White Pine from among the conifers or Sweet Crabapple, Balsam Poplar or Silver Maple from among the hardwoods. Or, if the objective was to maximize root collar diameter, they could plant White Spruce or White Pine instead.

One unexpected development was that browsing proved to be more of a problem than originally anticipated. The take-home message for managers is to plant larger-sized trees and trees more resilient to deer in the urban landscape and, above all, to protect the planted stock with adequate fencing.

The project also demonstrated that community efforts are the main driving force behind requirements for planting, measuring and monitoring for the future, at least in urban environments. By transferring the required knowledge, communities can help safeguard the health of future urban forests by planting trees now, planning in anticipation of projected climatic 13 changes and tracking these new trees' survival, health and growth. Community involvement during the first seven years is critical since trees that can survive the initial establishment period and start producing advanced growth have an increased likelihood to survive to maturity (MacIver et al., 2009).

By taking advantage of the Toronto warming effect in its location, the project had the added advantage of an anecdotal indication of the impact of warming on tree growth and response through comparison with cooler conditions in surrounding rural areas. Choosing consistent SI/MAB protocols to monitor the site's biodiversity further allowed its measurements to be compared to other forest biodiversity monitoring sites in southern Ontario. The final results from the Humber Arboretum study can now provide much-needed data for the development of guidelines for the selection of adaptive vegetative species for changing climatic conditions.

Summary of Lessons Learned

Title of Project	**Key Features**	**Main Lessons Learned**	**Tools & Monitoring Pocesses**	**Relevance to Biodiversity Programs**
Benchmarking Biodiversity and Planning Future Forests in Urban Impacted	The case study investigated the benefits of forest planting design and the selection of species to optimize	Trained community volunteers planting under appropriate conditions can substantially improve	SI/MAB forest biodiversity monitoring protocols; urban	Selection of tree species and planting

Areas	greater species biodiversity and to ensure increased resilience of species under current and changed climatic conditions, particularly for urban forests.	early survival rates. Trained community volunteers increase their interest and participation in planting projects proportional to the number of species planted and the ability to track the growth of trees over time.	warming site allowed comparison with biodiversity conditions at cooler rural sites	

Conclusion

Forested areas in urban environments provide irreplaceable ecosystem services ranging from reducing soil erosion to decreasing the incidence of air-quality-related illnesses to creating green spaces that enhance mental and emotional well-being. Major watersheds in the GTA such as the Humber provide refuge areas for wildlife, including corridors for their migration.

As the climate changes, the twin challenges for communities will be to revitalize their landscapes for the conservation of biodiversity and to capitalize on the enhanced ecological services that these landscapes can provide. Many of the factors that have the most impact on biodiversity are areas that communities can influence using proactive measures – namely land-use regulation and sustainable practices. This is crucial, since the opportunity exists under climate change to reverse some of the rates of loss to Canada's biodiversity that are linked to human settlement and development.

Urban communities need to benchmark their current state of forest biodiversity. Rates of change likewise have to be well documented in order to make intelligent planning decisions for the future. Communities need to be proactive in their planning to assess the current state of knowledge, monitor past and potential planting sites and develop guidelines to design urban forests for a variety of purposes, including biodiversity conservation.

Research conducted at the Humber Arboretum has also shown that the urban climate and the accompanying warming of southern Ontario will create new opportunities to support the growth of more southern tree species (e.g., species currently grown in Washington, D.C.) and subsequently expand the possible varieties of food (e.g., nuts, fruits) and commercial and flowering trees. More southerly latitudes have up to four times the number of species per tree family than the same families in southern Ontario, offering valuable insights into potential increases in future habitat biodiversity. The majority of these species provide numerous beneficial and often edible uses for both wildlife and humans. Many are high-quality ornamental trees used in handicrafts, woodworking, outdoor applications and lumber, as well as in medicines. Some have additional uses for shelterbelts in energy conservation, pulpwood, soil reclamation and fuel. Moreover, these species also create habitats for a range of wildlife, further increasing biodiversity (MacIver and Karsh, 2010).

The Humber Arboretum study suggests the time to carefully implement planned adaptation options is now if levels of habitat biodiversity are to be re-attained to pre-settlement levels by 2020 and beyond. The already-changing climate presents cities, towns and rural areas with an opportunity to plant species never before grown in Ontario – including forest species that can better adapt to warmer temperatures – as well as to conserve native biodiversity.

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