ECOSYSTEM SERVICE VALUES OF THE CITY OF TORONTO RAVINE SYSTEM

Prepared for the City of Toronto and Toronto and Region Conservation Authority

FINAL REPORT

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Executive Summary

Toronto's ravine system provides many benefits to the people of the Canada's most populated city, including improved air quality from the filtering effects of trees, recreation and active transportation opportunities, aesthetic benefits from natural landscapes, and cultural and spiritual benefits. To support informed decision-making about the management and use of the city's ravine system, the value of these *ecosystem services* can be measured, monitored and wisely managed along with other services provided by more traditional assets (e.g. financial and infrastructure assets).

Green Analytics was commissioned by the City of Toronto and Toronto and Region Conservation Authority (TRCA) to provide an assessment of ecosystem service values provided by the natural capital within the ravine system. Natural capital can be defined as the stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people. These benefits are termed ecosystem services.

This analysis follows from direction outlined in the Toronto Ravine Strategy, which provides guidance for ravine management, use, enhancement and protection. The study area for the assessment is the City of Toronto's Ravine and Natural Feature Protection Bylaw area, referred to as Toronto's ravine system. The assessment relied on the most current economic and ecological condition data, as well as the most up-to-date valuation approaches. Thirteen ecosystem services provided by natural capital in the ravine system were considered, and monetized benefit estimates were derived for eight of the thirteen services. Ecosystem services for which monetized estimates were derived include:

- Recreation
- Physical health
- Mental health
- Gas regulation (e.g. air quality)
- Carbon sequestration
- Food provision
- Aesthetic appreciation
- Habitat and refugia

For each ecosystem service noted above, a description of the service is provided, along with details on how the values were estimated. Depending on the service, the valuation approach varied. Services that were considered, but not assigned a monetary value, include:

- Disturbance regulation (e.g. flood mitigation)
- Temperature regulation
- Noise regulation
- Active transport
- Education and research benefits

Based on the monetized benefits, the total annual value of the ravine system's ecosystem services is estimated to be $822 million. Table 1 provides a summary of the values by ecosystem service. The values presented here should be considered conservative as we only included benefits with an existing body of supporting evidence.

Table ES-1: Ecosystem service physical flows and monetary benefits for the City of Toronto ravine system

Ecosystem service physical flows and monetary benefits for the City of Toronto ravine system						
Ecosystem Service	**Indicator**	**Unit**	**Physical flow 2017**	**Indicator**	**Unit**	**Monetary flow benefit 2017 ($ Millions)**
Recreation	Users of ravines for cycling and biking	# of users	398,240	Value of welfare benefit received by biking in ravines	$ per year	**$111**
	Users of ravines for walking and hiking	# of users	924,486	Value of welfare benefit received by walking and biking in ravines	$ per year	**$473**
Physical health	Population meeting physiscal health guidelines by accessing greenspace	# of people	753,812	Value of physical activity supported (avoided health care costs of dealing with ill health due to inactivity)	$ per year	**$217**
Mental health	Reduced number of people experiencing depression	# of people	5,297	Value of improved mental health, avoided foregone GDP due to depression	$ per year	**$5**
Gas regulation (air quality)	Air pollution removed (CO, NO_x, O_3, PM_{10}, SO_2)	metric tonnes	CO=3.2; NOx=94.3; O3=374.4; PM10=113.0; SO2=19.8	Value of cleaner air (avoided health care costs of visits to hospital for respiratory and other related health issues)	$ per year	**$7**
Carbon sequestration	CO2e sequestered	metric tonnes	14,542	Value of carbon sequestered (avoided social damages that are anticipated to result from climate change)	$ per year	**$2**
Food provision, urban agriculture	Fruit and vegetable production occuring in ravine area	metric tonnes	34.7	Value of food from urban agriculture sites in ravines (replacement cost of equivalent produce)	$ per year	**$0.04**
Aesthetic appreciation	Area of natural cover	hectares	6,000	Value people place on the aesthetic enjoyment of the area	$ per year	**$2.67**
Habitat and refugia	Area of natural cover	hectares	6,000	Value people place on knowing natural areas exist	$ per year	**$2.47**
						$822

The values presented above can inform the potential implications of land use change and resource management policy decisions in Toronto. As with all critical assets that support health and wellbeing, the natural assets of the ravine system should be protected or enhanced to ensure the flow of ecosystem services can be sustained for current and future residents of the watershed.

1 Introduction

Toronto's ravine system provides many benefits to the people of the Canada's most populated city, including improved air quality from the filtering effects of trees, recreation and active transportation opportunities, aesthetic benefits from natural landscapes, and cultural and spiritual benefits. These *ecosystem services* provided by the natural capital of the ravine are significant contributors to the health and wellbeing of the residents of Toronto and its surrounding regions. Thus, it is imperative that they be taken into consideration when making land-use and resource development decisions. To support informed decision-making about the management and use of the city's ravine system, the value of these *ecosystem services* can be measured, monitored and wisely managed along with other services provided by more traditional assets (e.g. financial and infrastructure assets). Thus, Green Analytics was commissioned by the City of Toronto and Toronto and Region Conservation Authority (TRCA) to provide an assessment of ecosystem service values provided by the natural capital resources within the ravine system, a recommended action included in the 2017 Toronto Ravine Strategy. The assessment relied on the most current economic and ecological conditions as well as the most up-to-date data and valuation approaches.

The results of the ecosystem service assessment of the City of Toronto ravine system are contained in this report, which is structured as follows:

- Section 2 contains background information on the ravine system, natural capital and ecosystem services.
- Section 3 presents values for each of the ecosystem services provided by the ravine system.
- Section 4 summarizes the ecosystem service values for the ravine system.
- Section 5 presents recommendations and concludes the report.
- Appendix A provides an overview of the state of ecosystem service science in an urban context.
- A reference list is provided at the end of the report.

2 Background

The importance of healthy, functioning ecosystems and the ecosystem services that they provide is increasingly being recognized within Canada and around the world. The result is a growing trend towards the assessment and valuation of such services. Decision-makers at various levels of government (municipal, regional, provincial, federal) are pursuing the assessment and valuation of ecosystem services to:

1. Better communicate the importance of green space to residents,
2. Inform policy decisions related to natural resource consumption, management and conservation,
3. Measure and track progress towards policy goals and objectives, and
4. Complement and incorporate ecosystem service estimates into measures of wellbeing, which tend to focus on traditional economic-oriented indicators (such as gross domestic product).

Commensurate with the increased interest in recognizing the value of ecosystem services, is the trend towards improved analytical approaches for identifying, quantifying, assessing and valuing such services. This section of the report defines natural capital and ecosystem services.

2.1 Natural Capital and Ecosystem Services Defined

Natural capital refers to the stock of natural "assets" in a region. It is typically characterized by common ecosystem land cover types such as water, forests, wetlands, and grasslands, but also includes air, soil, and the assemblage of flora and fauna that make up these ecosystems. Similar to other forms of capital, these stocks produce a flow of valuable goods and services over time. For instance, a wetland (the stock) can absorb flood water, providing flood protection (the flow) to people and property downstream. These flows are referred to as ecosystem services. Ecosystem services are typically defined as the benefits people obtain from nature. They are measurable and result in improvements to human wellbeing. In the case of flood protection, for example, the benefit that can be measured is avoided flood damages. Figure 1 illustrates the pathway from ecosystem structure to economic value.[1]

[1] For an alternative, and more detailed representation of this pathway please see the ecosystem services cascade model used by the Common International Classification for Ecosystem Services: https://cices.eu/supporting-functions/

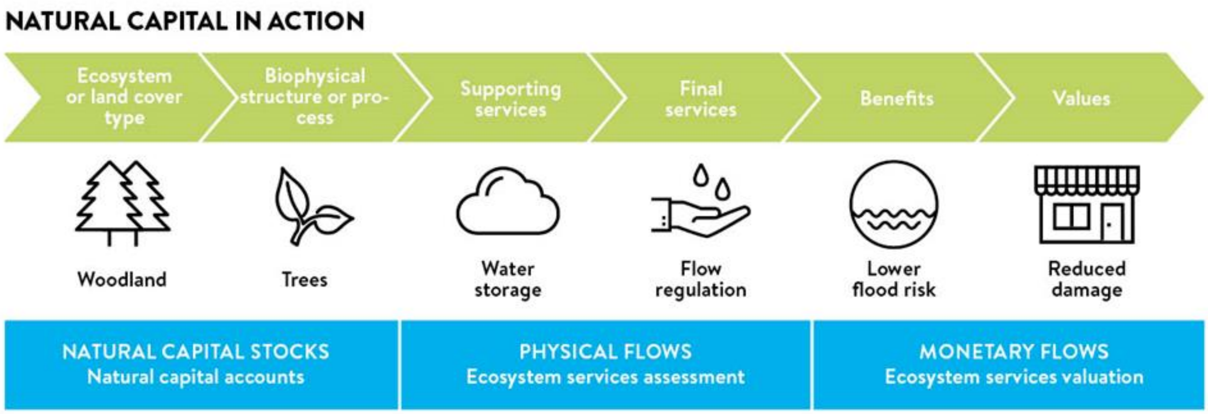


Figure 1. The pathway from ecosystem structure to economic value[2]

On the left side of Figure 1, the stock of natural capital is defined by biophysical structure, function and processes, usually organized by land cover classifications. When biophysical structures, processes and functions occur in proximity to human populations, they can provide a physical flow of ecosystem services (e.g. water storage and flow regulations), which in turn produce measurable benefits (e.g. lower flood risk) that can be translated into measures of economic value (e.g. the value of avoided flood damages).

Because the concept of natural capital is focused on the benefits nature provides to humans, the value we place on it is dependent on who benefits, and where beneficiaries are located relative to the spatial distribution of ecosystem service flows. As a result, natural areas near large populations tend to have high associated values. For instance, a wetland or forest on an urban fringe can provide quick, easy access for recreation, and if urban development is downstream, those same features can provide flood protection benefits. An ecologically identical wetland or forest located 100 kilometers downstream of the nearest human habitation is not likely to be providing the same level of direct benefits to people.

Since 2008, there has been an evolution in how ecosystem services are defined and categorized. The Economics of Ecosystems and Biodiversity (TEEB) reports propose the following framework for categorizing ecosystem services (TEEB 2010):

- Provisioning services – the material outputs from ecosystems (e.g. wild foods, crops, fresh water and plant-derived medicines)
- Regulating services – services ecosystems provide by acting as regulators (e.g. filtration of pollutants by wetlands, climate regulation through carbon storage, water cycling, pollination and protection from disasters)
- Cultural services – the non-material benefits people obtain from contact with ecosystems (e.g. recreation, spiritual and aesthetic values, and education)
- Supporting services – refer to specific ecological characteristics that in one way or another underpin the output of a 'final' ecosystem service (e.g. soil formation, photosynthesis and nutrient cycling).

[2] Source of Figure: https://www.raconteur.net/sponsored/success-water-industry-much-financial-capital

2.2 Why is Natural Capital Important?

The concept of natural capital recognizes that the natural environment is a fundamental asset on which our social and economic systems depend. By conceptualizing nature as an asset, we can codify, measure, and track the ways in which we depend on and impact the environment. Business and economic activity depends on natural capital assets to provide important inputs, such as clean water, minerals, and timber. Natural capital also provides better air quality, water quality, flood protection, and climate stability, which are well established as important determinants of social wellbeing. In addition, natural capital provides other important indirect functions that support human health. Urban greenspaces, parks, wetlands and protected areas, for example, provide important recreation spaces and buffer the effect of extreme heat in urban settings, thereby reducing the prevalence of respiratory infections and heat related illnesses. While the physical health benefits of nature contact are well documented, recent scientific research highlights the mental health benefits (Hartig et al., 2014; Keniger et al., 2013; Bratman et al., 2012). Maller, a leading authority on the health benefits of nature, contends that increasing access and exposure to greenspace and natural areas may be the most effective population wide strategy for promoting mental health (Maller et al., 2006). However, if we do not manage our natural assets responsibly, their value will depreciate and their ability to provide benefits diminish. Like any asset, natural assets need to be carefully managed to ensure a sustainable supply of services. Figure 2 depicts the roles of governance and institutions in the decision-making process, as well as the functions of built, human and social capital in transforming ecosystem services into goods and benefits for people.

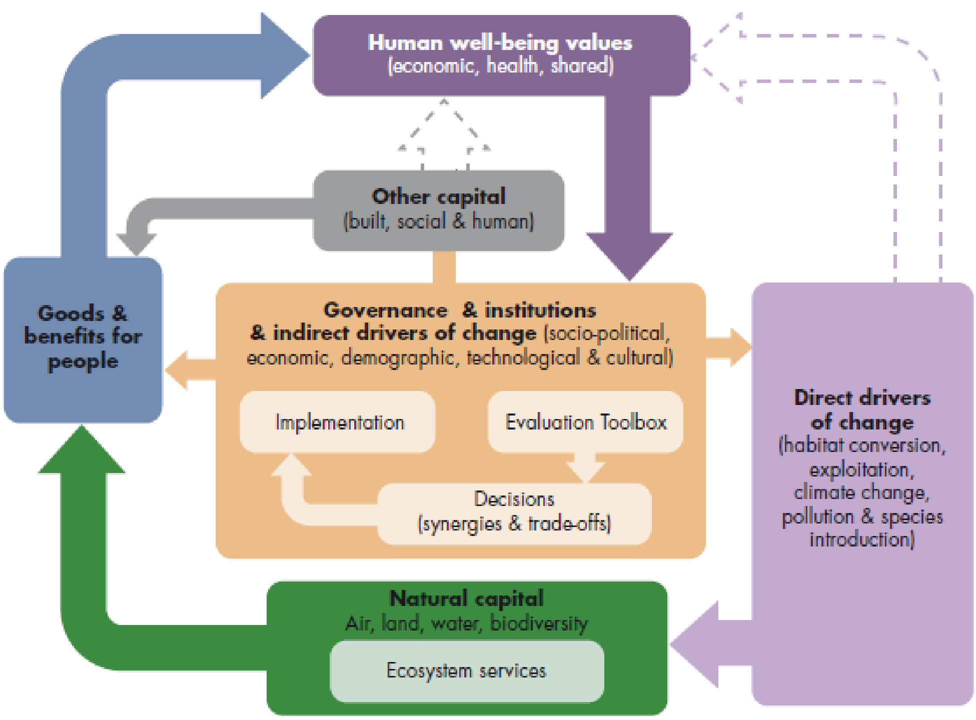


Figure 2. The UK NEAFO Ecosystem Services Conceptual Framework [3]

[3] Source of Figure: UK National Ecosystem Assessment Follow-on. 2014. The UK National Ecosystem Assessment Follow-on: Synthesis of the Key Findings. UNEP-WCMC, LWEC, UK.

When natural capital is destroyed, or its ability to provide an ecosystem service is impaired or lost, the service must be replaced for people to continue to derive the benefits that were provided by the natural system. Engineering the replacement of a service nature provides often requires expensive new infrastructure with significant operational and maintenance costs. In the long run, the protection of natural capital and the services it provides is often the most cost-effective option. This realization is now being incorporated into many municipal initiatives that consider natural capital assets as “green infrastructure.” The Green Infrastructure Ontario Coalition defines green infrastructure as the natural vegetative systems and green technologies that collectively provide society with a multitude of economic, environmental and social benefits.[4] While the emphasis has been on preserving existing natural capital assets, increasingly municipalities and agencies are looking to restore and enhance natural capital assets as well.

[4] This includes: urban forests and woodlots; bioswales, engineered wetlands and stormwater ponds; wetlands, ravines, waterways and riparian zones; meadows and agricultural lands; green roofs and green walls; urban agriculture; parks, gardens, turf, and landscaped areas. See Green Infrastructure Ontario Coalition, greeninfrastructureontario.org.

3 The Value of Natural Capital in Toronto's Ravine System

This section of the report describes the study area and contains the results of the ecosystem service assessment. The assessment considered thirteen ecosystem services provided by natural capital in the ravine system. A monetized benefit was estimated for eight of the thirteen services. Table 1 identifies the ecosystem services that were considered in this assessment. Services assigned a monetized value are highlighted in green.

Table 1: Ecosystem service provided by the Toronto ravine system

Ecosystem Services	
Monetized value	**Non-monetized value**
Recreation	Disturbance regulation (e.g. flood mitigation)
Physical health	Temperature regulation
Mental health	Noise regulation
Gas regulation (e.g. air quality)	Active transport corridors
Carbon sequestration	Education and research benefits
Food provision	
Aesthetic appreciation	
Habitat and refugia	

For the services that were provided a monetized value estimate, Table 2 summarizes the measurable benefits that were valued.

Table 2. Key ecosystem services and associated measurable benefits

Ecosystem Service	Measurable Benefit to Human Wellbeing
Recreation	Value of recreational activity
Physical health	Value of health benefits associated with living in proximity to nature and avoided health care costs of dealing with ill health due to inactivity
Mental health	Avoided health care costs and forgone GDP due to depression
Gas regulation (air quality)	Value of human health care costs avoided from reduced air pollution
Carbon sequestration	Avoided social costs of climate change[5]
Food provision	Value of food from community gardens, fruit trees, and urban agriculture
Aesthetic appreciation	Value people place on the aesthetic enjoyment of the area
Habitat and refugia	Value people place on knowing natural areas exist

The study area for the assessment is the City of Toronto's Ravine and Natural Feature Protection Bylaw area, referred to as Toronto's ravine system. Figure 3 shows the geographic boundaries of the ravine bylaw area (shaded in green).

[5] The social costs of climate change refer to damages anticipated to occur over the coming decades, such as increased damages from more frequent and more severe extreme weather events.

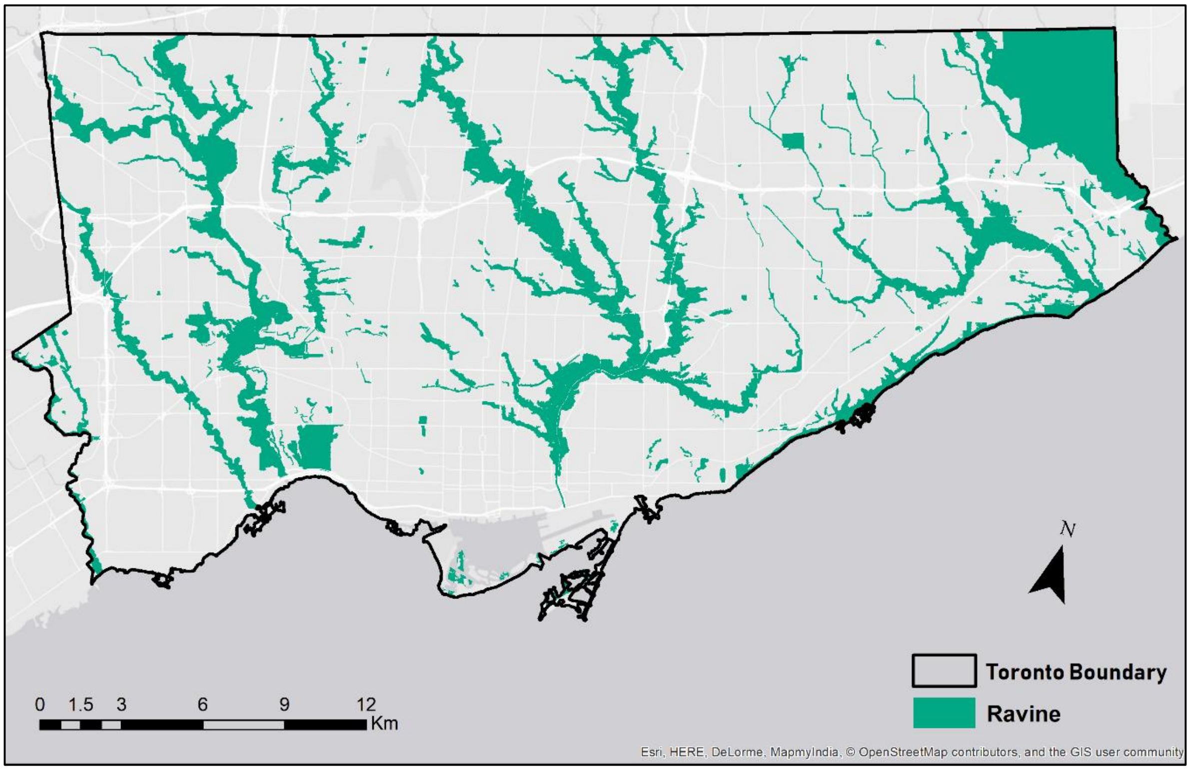


Figure 3. Map of the Toronto Ravine and Nature Feature Protection Bylaw Area.

Land cover data for Toronto's ravine system was used to estimate the monetary value of the services provided. Table 3 provides a breakdown of the natural land cover categories within the study area.

Table 3. Land cover types in the Toronto Ravine System

Natural Cover Types	Area (ha)
Beach / Bluff	83
Forest	4431
Meadow	748
Successional	526
Wetland	209
Open Water	3
Total Natural Area of Ravine*	6000
Other**	5,009
Total Area of the Ravine By-law	11,009

* Based on Natural Cover 2013 dataset from TRCA open data
** Other covers include a range of developed or modified surfaces such roads, buildings, and cemeteries.

In the sections that follow, for each ecosystem service under consideration, a description of the service is provided, along with details on how the values were estimated. Depending on the service, the valuation approach varied. All values are presented in 2017 Canadian dollars (unless otherwise stated).

3.1 Recreation

Nature recreation is one of the most tangible ways in which people derive benefit from natural capital. Toronto's system of ravines represents the city's most significant concentration of natural areas and urban greenspace. It is heavily used for recreational activity. Recreation activities that take place within the ravine system include walking/hiking, biking, picnicking and birding. For the purpose of this study, we focused on two recreational categories, walking/hiking and biking for pleasure (not as a form of active transportation). For each recreational category, we estimate the value of wellbeing derived from the activity.

Calculation

To estimate the welfare value of walking/hiking and biking using an expenditure approach based on reported spending on "nature-based recreation" in Ontario as per the 2012 Canadian Nature Survey (2014) (adjusted to 2017 dollars), the following steps were undertaken:

1. Estimate the number of users by activity (walking/hiking and biking)
2. Estimate the value per user/trip
3. Estimate the total value by multiplying the number of users by activity by the value per user.

Recreation benefit

The total annual value derived from recreational activities in the ravine system is $584 million. Table 4 provides a summary of the value by recreational activity type.

Table 4. Recreation annual values

	# of users	Average # of days per year	$ per person/ per day	Estimated value ($ Millions)
Walking/hiking	924,486	66	$7.75	$472.9
Biking	398,240	36	$7.75	$111.1
Total				**$584.0**

3.2 Physical Health

Access to nature and greenspace contributes to positive physical health outcomes. Studies have found that increased greenspace is associated with lower blood pressure and reduced rates of cardiovascular disease, asthma, and respiratory illness (Donovan et al, 2013; Lovasi et al, 2008). Karden et al (2015) in a study of Toronto found that people who live in neighbourhoods with a higher density of trees on their streets report significantly higher health perception and significantly less cardiometabolic conditions. Studies also document the physical benefits of stress reduction attributed to nature contact, such as reduced headaches and increased energy levels (Hansmann 2007). Numerous studies have also shown that greenspace and park access increases physical activity in a population (Astell et al. 2014, Lee et al. 2013, McCormack et al. 2010, Hartig et al. 2003). Table 5 lists physical wellbeing benefits resulting from interacting with nature.

Table 5: Examples, physical wellbeing experience and associated benefits of interacting with nature

Experience	Benefit
Lower blood pressure	Reduced rates of cardiovascular disease and death
Ability to breath more clearly	Reduced asthma attacks and lower rates of asthma and respiratory illness
Faster healing and recovery times	Reduced impact of illness and injury
Increased sense of perceived health	Reduced occurrence of illness and improved overall health

For this assessment, we estimate the physical health benefits derived from exercising in the ravine system. While only counting the physical activity benefits underestimates the value of physical health benefits, we are cautious to avoid double counting benefits captured by other benefit categories, for example, improved air quality, aesthetic appreciation and recreation.

Access to greenspace is associated with increased levels of physical activity resulting in avoided costs of ill health due to inactivity. We estimate avoided ill health costs due to inactivity based on the number of ravine users that meet weekly recommended physical health requirements (150 minutes of moderate to vigorous activity per week, or portion thereof) multiplied by the direct and indirect costs of inactivity. This approach is proposed in the United Kingdom, Urban Natural Capital Accounts framework and applied in the Corporate Natural Capital Accounting (CNCA) framework (eftec 2017, Jon Sheaff and Associates 2017).

The direct and indirect health care costs of physical inactivity in Canadian adults is estimated to be $6,757,000,000 or $253 per adult (in 2009 CDN) or $288.29 per adult in 2017 (Janssen 2012). A challenge, however, is determining the number of users meeting the weekly exercise standard in the ravines. To establish this number, we estimate the number of ravine users engaged in physical activity based on park use. The percent of park users engaged in moderate to vigorous activity is estimated to range from a high of 53% in three urban Ontario parks to a low of 13% in a study of five US cities (Hamilton et al. 2017, Holliday et al. 2017). A study focused on urban parks in Los Angeles found that 34% of users engaged in moderate to vigorous activity (Cohen et al. 2007).

The Urban Natural Capital Accounts framework was applied in the London Borough of Barnett. For that study, instead of estimating number of park users, the authors assumed that half of those who meet the weekly exercise standard in the Borough did so using greenspaces, although the study does not defend the assumption with any supporting data. Using this approach, we would assume half of the Toronto adult population that were at least moderately active or higher (46.4% in 2014)[6] were physically active in a ravine space.

Calculation

The following steps were taken:

1. Estimate the number of people meeting recommended physical health activity requirements of 150 minutes of moderate to vigorous exercise per week who are physically active in the ravines. We determined the number of users meeting their weekly exercise standard in the ravines using two different set of assumptions:
    a. Approach A establishes the number of ravine users and multiples that by the percentage that were at least moderately active or higher based on the park use study of three Ontario urban parks (noted above).
    b. Approach B assumes half of adults that were at least moderately active or higher were physically active in the ravine based on the approach used in London Borough of Barnett study.

[6] Toronto Public Health. 2017. Health Surveillance Indicator: Physical Activity.

2. Multiply the number of people meeting recommended physical health activity requirements using the ravine (results of approach A and B above) by $288.29 (the direct and indirect costs of inactivity per adult).

Physical health value of physical activity

The annual value of physical activity occurring in the ravine ranges from $140 million (Table 7) to $217 million (Table 6).

Table 6: Health value of physical activity

Population meeting physical health activity requirement using ravines	Direct and indirect health care costs of physical inactivity per adult	Value of increased physical activity annually ($ Millions)
Approach A: 753,812	$288.29	$217.3
Approach B: 478,218	$288.29	$137.9

We recommend the use of assumption A as it is based on assumptions derived from research on Ontario urban parks.

3.3 Mental Health

Maller, a leading authority on the health benefits of nature, contends that increasing access and exposure to greenspace and natural areas may be the most effective population wide strategy for promoting mental health (Maller et al. 2006). Maller's recommendation reflects over 30 years of research demonstrating that contact with nature reduces stress and increases sense of personal wellbeing (Shanahan et al. 2016, Hartig et al. 2014). Empirical studies have shown that being in nature reduces cortisol levels and blood pressure (Van de Berg and Custers 2011, Hartig et al. 2003). While explanatory pathways are not well understood, studies consistently find that people feel better in nature. Contact with nature is positively associated with increased self-esteem, higher life satisfaction, cognitive function and better job performance (White et al. 2013, Bratman et al. 2012, Bowler et al. 2010, Kaplan and Kaplan 1989). Table 7 provides examples of mental health benefits of interacting with nature.

Table 7: Examples, mental wellbeing experience and associated benefits of interacting with nature

Experience	Benefit
Lower stress/ faster recovery from stress	Reduced rates of stress and anxiety related illness
Increased self-esteem and sense of well being	Reduced rates of depression
Lower aggression, anger, frustration	Reduced rates of crime and destructive behaviour
Improved cognitive function	Improved educational outcomes and job performance
Increased productivity	Improved job performance

To estimate the mental health benefits derived from Toronto's ravine system, we adopt a cautious approach and only estimate a monetary benefit associated with reduced rates of depression. A study by Shanahan and colleagues found that 30 minutes per week in greenspace reduces the population prevalence of depression by 7% (Shanahan et al. 2016). The direct health care costs and forgone gross domestic product (GDP) due to lost productivity resulting from depression are estimated to be $1.5 billion ($2009) and 32.3 billion ($2012), respectively (Smetanin et al. 2011, Conference Board of Canada 2016). Using Statistics Canada population estimates[7], the average costs per person are estimated to be $50.82 ($2017) and $982.90 ($2017), respectively.

Calculation

To calculate the mental health value associated with reduced rates of depression, the following steps were taken:

1. Estimate the number of people spending on average 30 minutes or more per week in the ravines
2. Establish the prevalence rate of depression
3. Estimate the reduced prevalence rate of depression resulting from spending time in the ravines (item 2, corrected for item 1)
4. Multiply the reduced rate of depression by the direct health care costs and forgone GDP due to lost productivity resulting from depression per person

Mental health value of spending time in Toronto's ravine system

The total mental health value associated with reduced rates of depression resulting from spending time in the ravine system is $5.5 million (Table 8).

[7] Statistics Canada. *Table 051-0001 - Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual (persons unless otherwise noted),* CANSIM (database). Accessed April 2018.

Table 8: Mental health benefit value

Reduced prevalence of depression (# of people)	Mental health benefit per person (2017)	Mental health benefit value ($ Millions)
5,297	$1,033.72	$5.5

3.4 Gas Regulation (Air Quality)

Forested areas and trees can regulate atmospheric gases and maintain air quality by removing airborne pollutants. This results from the collection of particulate matter on the surface area of leaves and by the absorption of gaseous pollutants into leaves. Improved air quality can result in significant benefits to the surrounding population, who are likely to experience fewer visits to the hospital for respiratory and other illnesses (Nowak et al. 2015). The City of Toronto has already conducted a robust research project on understanding the value of urban forests (Nowak et al. 2013). Across the City of Toronto, it was estimated that trees and shrubs remove 1,430 metric tonnes of air pollution (CO, NO_2, O_3, PM10, SO_2).

Calculation

To estimate the value of clean air provided by Toronto's ravines system, we weighted the results of the city-wide estimates by the ratio of canopy cover in the ravine area to the total Toronto canopy cover. In other words, about 36% of Toronto's canopy cover occurs within the ravine area and this number was used to estimate the portion of the city-wide benefits attributable to the ravine system.

Improved air quality value provided by the ravine area

Based on the research conducted in 2009 for the City of Toronto, the avoided health care costs provided by the ravine area is approximately $7.4 million per year (Table 9).

Table 9. Summary of air quality improvement and avoided annual health care costs

Variable	Toronto-Wide Estimate ($M)	Ravine Area Estimate ($M)
Pollutant removal rate (tonnes per year)		
- Carbon monoxide (CO)	10	4
- Nitrogen oxides (NOx)	297	107
- Ozone (O_3)	1180	427
- Particulate matter (PM)	357	129
- Sulphur dioxide (SO_2)	62	22
Total removal rate (tonnes per year)	1906	689
Avoided health care costs (dollars per year)	**$20.4 M**	**$7.4 M**

The valuation approach employed in the city-wide study accounts for health-care expenses (i.e. cost of illness and willingness to pay to avoid illness), productivity losses associated with specific adverse health events, and the value of a statistical life in the case of mortality.

3.5 Carbon Sequestration

Forests, woodlands, wetlands, grasslands, and non-intensive agriculture play an important role in mitigating climate change through the sequestration and storage of carbon dioxide and other greenhouse gases. The mitigation of climate change is likely to have a wide range of benefits to humans in the form of avoided severe weather events. Here, only sequestration is valued, as it represents the annual service flow.[8]

Calculation

The first step in estimating the value of carbon sequestration is to establish the rate of sequestration. Two approaches were used in this analysis:

1. Like the approach used to estimate gas regulation, the total carbon sequestration rate for forests across Toronto was adjusted to reflect only the forests located within the ravine area.
2. For grasslands, non-intensive agriculture and wetlands, estimates were obtained for the rate of sequestration for each of the ecosystem types (i.e. tonnes of carbon sequestered per ha per year of ecosystem type) present in the ravine system.

Once the average rate of sequestration was determined, a price per tonne of carbon was applied to the sequestration estimates. For this purpose, Environment Canada's recommended social cost of carbon was used, which is currently $44.67 per tonne of CO_2e (i.e. CO_2 equivalents).[9] The social cost of carbon quantifies the marginal value of avoided social damages that are anticipated to result from climate change. In other words, it is a measure of the incremental avoided damages from a decrease in CO_2 emissions. Note that this price per tonne is different than the price used by Nowak et al. (2013).

Since the social cost of carbon is measured in tonnes of CO_2e, and sequestration is measured in tonnes of carbon, it was necessary to convert the values to comparable units. The conversion was based on the relative atomic weights. That is, 1 tonne of carbon sequestered translates into 3.667 tonnes of CO_2 removed from the atmosphere.

Existing research on Toronto's urban forest has calculated the gross carbon sequestration by trees in Toronto to be 46,700 metric tonnes of carbon per year and net carbon sequestration to be 36,500 metric tonnes (Nowak et al. 2013). Based on the fact that 36% of Toronto's tree canopy occurs in the ravine area, carbon sequestration for this area is assumed to be 13,194 tonnes per year. The social cost of carbon was then applied to the sequestration for the trees within the study area to calculate the value of carbon sequestration from the forested area in Toronto's ravine system.

Drawing on recent literature examining the role of wetlands in sequestering carbon, a series of sequestration rates were identified for different wetlands. A weighted average sequestration rate for different wetland types was calculated and then applied to the area of wetlands within the study area. Data for carbon sequestration rates were drawn from Mitsch et al. (2013) and Bernal and Mitsch (2012). The weighted average for wetlands was estimated at 3.4 tonnes per hectare per year. The social cost of carbon was then applied to the sequestration for the wetlands within the study area to calculate the value of carbon sequestration from wetlands in Toronto's ravine system.

[8] The carbon storage can also be valued. However, it represents the accumulated stock of carbon that has been sequestered in all previous years. As a result, it is not included as the annual service value.
[9] http://www.ec.gc.ca/cc/default.asp?lang=En&n=BE705779-1

Similarly, existing literature was used to establish sequestration rates for grasslands. Unfortunately, limited research was found related to grasslands, particularly in an Ontario context. Previous valuation reports for areas in southern Ontario drew on a study that estimated an average of 0.5 tonnes of carbon per ha per year (Smith et al. 2001). More recent research suggests that temperate grasslands can sequester anywhere from 0 to 8 tonnes of carbon per ha per year (Jones and Donnelly 2004). In western Canada, sequestration by grasslands averages about 0.19 tonnes of carbon per ha per year (Wang et al. 2014). Given the uncertainty in the rate of sequestration and lack of data for Southern Ontario systems, for this report, 0.5 tonnes per ha per year is assumed.

Carbon sequestration value provided by the ravine area

The total carbon sequestration value provided by the ravine area is $2.4 million per year. Carbon sequestration values by land cover type are summarized in Table 10.

Table 10. Carbon sequestration, annual values by land cover type

Land cover type	Area (ha)	Carbon sequestration Rate (tonnes)	CO2e (tonnes)	Social value ($ per tonne)	Estimated Value ($ Millions)
Forest	4,431	13,194	48,382	$44.67	$2.16
Wetlands	209	711	2,606	$44.67	$0.12
Meadow	748	374	1,371	$44.67	$0.06
Successional	526	263	964	$44.67	$0.04
Total	**5,914**	**14,542**	**53,324**	**$44.67**	**$2.38**

3.6 Food Provision

Urban agriculture and community gardens provide benefits to participants. Studies show that gardening and participating in a community garden provide mental and physical health benefits, contribute to an increased sense of community belonging and are an important source of nutritional food (Toronto Public Health 2015). Case studies examining the relationship between community gardens, including urban agriculture and health have found that people who use community gardens report (Castro et al 2013, Comstock et al. 2010, Wakefield et al. 2007, Zick et al. 2013):

- Improved access to food
- Better nutrition
- Increased physical activity
- Improved mental health
- Enhanced social health and community cohesion

Growing your own food also leads to avoided food transport costs and lower food waste.

To avoid double counting, for this analysis we only consider the value of benefits derived from avoided food purchases based on the market value of produce derived from established urban agriculture sites within the ravine system. Currently, there is one site, Black Creek Community Farm.

Calculation

To calculate the value of food grown in the ravine area, the following steps were undertaken:

1. Estimate the hectares of growing space in the ravine area
2. Multiply the area of growing space by estimated food production per hectare
3. Multiply the food production per hectare by the market value of food grown

Metric tonnes of food production were estimated based on a yield figure of 10.7 metric tonnes per hectare.[10] Market value of urban agriculture food production per tonne in the Toronto region is estimated to be $1,033.72 based on the market value equivalent of a similar basket of locally grown food.[11]

Food provision value

The total food provision value of urban agriculture in the ravine area is $36,000, annually (Table 11).

Table 11. Value of food provision

Hectares of growing space	Food production (metric tonnes)	Market value of food per tonne (2017)	Value of food provision
3.24	34.70	$1,033.72	$35,837

3.7 Aesthetic Appreciation

Aesthetic appreciation is the benefit people obtain from the beauty of natural vistas. Many aesthetic benefits result from recreational activities and some such value would be accounted for in the recreational estimates above. However, the aesthetic values experienced by those simply viewing the ravine, from a road way or sidewalk, or from a nearby house or balcony overlooking the ravine have not been captured in the recreation estimates. Numerous studies show that properties adjacent to, or near natural areas, such as an urban ravine, command higher selling or rental prices (Brander and Koetse 2011). The value of aesthetic appreciation is location-specific depending not only on the aesthetic quality of an area, but also on the local real estate market. However, it is not possible to clearly determine if this market differential captures only aesthetic appreciation values. In fact, it likely also captures other values associated with attributes such as ease of access to the ravine or social status symbol.

Calculation

As a first step toward calculating this value, a meta-analysis was utilized to transfer existing values to the City of Toronto (Brander and Koetse 2011). The meta-analysis was based on 20 studies providing 73 value estimates associated with key services provided by urban greenspace. The approach systematically holds constant three services provided by urban greenspace: recreation, preservation, and aesthetic appreciation. By holding these variables constant, and focusing on aesthetic appreciation values, the risk

[10] Garnett, T. ND. City Harvest: The Feasibility of Growing More Food in London. Sustain: The Alliance for Better Food and Farming. Available online: http://www.fcrn.org.uk/sites/default/files/CityHarvest/.
[11] Dihr, S. 2018. Personal communication. Senior Project Manager, Humber Watershed Services and Urban Agriculture Program. June 2018.

of double counting recreation is avoided. By parameterizing this equation to the City of Toronto, the aesthetic value of the ravine system was estimated to be $445 per ha per year.

Aesthetic value

The total aesthetic value provided by the ravine area is $2.7 million per year (Table 12).

Table 12. Aesthetic value

Area of natural cover within the ravine area	Aesthetic value per hectare (2017)	Aesthetic value ($ Millions)
6,000 hectares	$445	$2.7

3.8 Habitat and Refugia

The value of habitat and refugia (referred to as existence and bequest values, or preservation values) is derived from the knowledge that the diversity of individual species of flora and fauna – as well as their assemblage into connected ecosystems and habitats – is protected for current and future generations.

Not surprisingly, the majority (87%) of Toronto's environmentally significant areas (ESA) are found in the ravine system (City of Toronto, 2017). Within Toronto's ESA's there are 369 significant plant species, 175 species of birds and 16 species of reptiles and amphibians (City of Toronto, 2017).

It is important to note that biodiversity itself is not an ecosystem service. However, existence and bequest values implicitly account for biodiversity and these values can be held for a wide range of environmental features (Green Analytics 2016). For instance, there is a considerable volume of research that examines the value of endangered species (Richardson and Loomis 2009), while others examine the value of protected areas (Adamowicz et al. 1998). There is also considerable debate on whether valuation techniques can adequately capture the different levels of disaggregation resulting from how individuals perceive such values. An entire body of literature exists that examines the sensitivity of these values to the scope of the environmental good being studied.[12] To avoid these complex issues and uncertainties, a meta-analysis function was used to transfer the preservation value (i.e. the value residents place on knowing an area is protected or preserved) of urban habitat to Toronto (Brander and Koetse 2011).

Calculation

By parameterizing the meta-analysis function to the City of Toronto, the existence value of the ravine system was estimated to be $412 per ha per year.

The total existence value of the ravine system is $2.5 million per year (Table 13).

Table 13. Habitat and refugia value

Natural area within ravine area	Existence value per hectare	Existence Value ($ Millions)
6,000 hectares	$412	$2.5

[12] For example, see: Boyle et al. (1994)

3.9 Ecosystem Services Not Accounted For

This section notes and provides brief descriptions of other benefits that are relevant to the ravine system but have not been accounted for above due to a lack of data, allocation challenges related to assigning a benefit to the ravine system, or lack of scientific knowledge.

3.9.1 Disturbance Regulation

Wetlands and other natural areas can play an important role in protecting human property by regulating flood waters and erosion. Ideally, these values would be determined by carefully assessing the hydrology of relevant subwatersheds and quantifying the level of anticipated flooding with and without flood regulating land covers. Such flood and erosion profiles can be correlated with the number of properties and other built infrastructure located within flood zones downstream of regulated land covers. For example, Moudrak et al. (2017) modelled flooding and the impact wetlands have on flooding in two southern Ontario pilot sites: one urban and one rural. At the urban site, if wetlands were maintained relative to being replaced by agriculture, flood damages were estimated to be $51.1 million (or 38%) lower. This modelled scenario examined the loss of 540 ha of wetlands in Laurel Creek watershed for an average of roughly $94,600 per ha in avoided damages. At the rural site, flood damages were estimated to be $3.5 million (or 29%) lower. This modelled scenario examined the loss of 72.9 ha of wetlands in the Credit River Watershed, for an average of roughly $48,000 per ha in avoided damages. Nowak et al (2012) investigated the effects and values of Toronto's urban forests, including the impact of urban forests on stormwater run-off. Simulations conducted as part of that study indicate that a doubling of the tree canopy in the Don watershed would decrease overall water flow by 2.5% (Nowak et al. 2012).

While the hydrologic modelling required to estimate the value of disturbance regulation for Toronto's ravine system was not within the scope of this study, the above examples illustrate the potential impact that wetlands and forest cover can have in regulating water flows in Southern Ontario. The Toronto Region Conservation Authority is currently in the process of conducting a flood risk assessment. The results of this research may provide some insight to the value of disturbance regulation provided by the ravines.

3.9.2 Temperature Regulation

Toronto's urban forest is estimated to reduce energy use from heating and cooling of residential buildings by 41,200 MWH ($9.7million/year). Trees also provide an additional $483,000 in value per year by reducing the amount of carbon released by fossil-fuel based power plants, representing a reduction of 17,000 metric tonnes of carbon emissions (City of Toronto Urban Forestry, 2017).

A pro-rated approach similar to that used for carbon sequestration could be used to quantify the value of street trees in the ravine. However, in the case of temperature regulation, the value also depends on the position of street trees relative to residential buildings. Therefore, any pro-rated approach should ideally consider the number of trees in the right spatial configuration relative to a residential building to provide the energy savings. The effort required to do this was outside the scope of this project. As a result, this value is left this unaccounted. In future urban forest modelling work, exploring a way to tag the specific trees that are providing this value could make this assessment a simple matter of extracting the correct information from the urban forest database.

3.9.3 Noise Regulation

The United Kingdom has developed urban natural capital accounts that include benefits derived from noise regulation (eftec 2017). Lower noise levels contribute to improved health outcomes and greater productivity in the workplace.

In their approach, patches of tree cover greater than a threshold area of 200 m^2 are assumed to provide a noise mitigation service. To estimate the noise reduction benefit resulting from natural capital, the number of buildings located within patches of trees that meet the 200 m^2 threshold is quantified along with the amount of road noise and the reduction in noise due to the presence of trees. A benefit is assigned based on number of buildings where road noise levels are mitigated by 2 dB (decibels).

The UK natural capital accounts were used to derive a monetary benefit value for noise mitigation for Greater Manchester. The analysis found that 429,000 buildings receive some noise mitigation by urban trees. In total, noise mitigation from natural capital is estimated at £59m per year. For comparison purposes, the study estimates the value of CO_2e sequestered by Greater Manchester's urban woodland at £2m per year and avoided direct and indirect health costs of inactivity of nearly £40 m per year.

3.9.4 Active Transportation

Ravine trails and pathways are well used to travel by active transportation to work. In addition to physical health benefits, active transport replaces commuting by car or public transit reducing CO_2 emissions. In Toronto, 6.9% of the working population commute to their usual place of work by active transport (5.2% cycling, 1.4% walking).[13] Depending on the neighbourhood, commuting to work by bike or walking are as high as 34% in Cabbagetown and 33% in Bloor-Spadina.

The benefits derived from an active commute to work include physical and mental health benefits (see Sections 3.2 and 3.3) as well as environmental benefits. The main environmental benefit is avoided CO_2 emissions. Avoided emissions can be estimated by subtracting the emissions associated with kilometers travelled by active transportation from emissions that would have occurred if those trips had been made by car or bus. Avoided life cycle emissions, including caloric intake, are estimated at 250 g CO_2 /km for travel by car and 80 g CO_2 /km for travel by bus.[14]

3.9.5 Information, Science, Education, and Research Benefits

Natural areas can provide significant cultural benefits in the form of provision of information, and opportunities to conduct science, education and research. Quantifying such benefits is difficult due to data limitations. To derive an estimate for such benefits would first require an understanding of who is deriving value from the ravine system for these purposes. This could be determined through a survey of primary, secondary, and post-secondary education institutions and research centres. The second step would be to establish a price for these activities. This is much more difficult. Few approaches exist to quantify these values (Phillips et al. 2008). One approach that has been used relies on the social value of research. One estimate measures this proxy value as $12,000 per article per year,[15] measured by achievement of knowledge that leads to additional economic growth (Loomis and Richardson 2000). To

[13] Statistics Canada. 2016. Census of Population.
[14] CO2 emissions per kilometer traveled per passenger: cycling 21g/km; bus 101 g/km; car 271 g/km
[15] Note this value is reported in USD currency for the year 2000.

use this approach, an estimate of the annual number of scientific studies published from research done within the ravine system would be needed.

4 Summary of City of Toronto Ravine System Values

Table 14 summarizes the physical and monetary flow accounts for key ecosystem service values for the City of Toronto ravine system. This study makes use of many advances in concepts, data, and valuation techniques to provide the most up-to-date values possible. For each ecosystem service, the measurable benefit that was used to determine the value is described. This is provided to clearly demonstrate what has been measured and what has not. Data gaps limit the ability to provide estimates for all final services. As noted in section 3, several benefits were not accounted for in this study, including disturbance regulation, temperature regulation, noise regulation, active transportation corridors, and information, science, education and research benefits. Based on the monetized benefits, the total annual value of the ravine system's ecosystem services is estimated to be $822 million. The values presented here should be considered conservative estimates of the values provided by the ravine system.

Table 14: Ecosystem service physical flows and monetary benefits for the City of Toronto ravine system

Ecosystem service physical flows and monetary benefits for the City of Toronto ravine system							
Ecosystem Service	**Indicator**	**Unit**	**Physical flow 2017**		**Indicator**	**Unit**	**Monetary flow benefit 2017 ($ Millions)**
Recreation	Users of ravines for cycling and biking	# of users	398,240		Value of welfare benefit received by biking in ravines	$ per year	**$111**
	Users of ravines for walking and hiking	# of users	924,486		Value of welfare benefit received by walking and biking in ravines	$ per year	**$473**
Physical health	Population meeting physiscal health guidelines by accessing greenspace	# of people	753,812		Value of physical activity supported (avoided health care costs of dealing with ill health due to inactivity)	$ per year	**$217**
Mental health	Reduced number of people experiencing depression	# of people	5,297		Value of improved mental health, avoided foregone GDP due to depression	$ per year	**$5**
Gas regulation (air quality)	Air pollution removed (CO, NO_x, O_3, PM_{10}, SO_2)	metric tonnes	CO=3.2; NOx=94.3; O3=374.4; PM10=113.0; SO2=19.8		Value of cleaner air (avoided health care costs of visits to hospital for respiratory and other related health issues)	$ per year	**$7**
Carbon sequestration	CO2e sequestered	metric tonnes	14,542		Value of carbon sequestered (avoided social damages that are anticipated to result from climate change)	$ per year	**$2**
Food provision, urban agriculture	Fruit and vegetable production occuring in ravine area	metric tonnes	34.7		Value of food from urban agriculture sites in ravines (replacement cost of equivalent produce)	$ per year	**$0.04**
Aesthetic appreciation	Area of natural cover	hectares	6,000		Value people place on the aesthetic enjoyment of the area	$ per year	**$2.67**
Habitat and refugia	Area of natural cover	hectares	6,000		Value people place on knowing natural areas exist	$ per year	**$2.47**
							$822

5 Recommendations and Conclusions

This report presents the results of an assessment of ecosystem service values derived from the City of Toronto ravine system. The values can inform the potential implications of land use and resource management policy decisions in the region. Tracking and measuring the ways in which local populations benefit from natural capital is essential to their long-term management. As with all assets, the natural assets of the ravine system should be protected and conserved to ensure the flow of ecosystem services can be sustained for current and future residents of the watershed.

This assessment of natural capital in the City of Toronto ravine system represents the next step in advancing towards standardized accounting and valuation of the many benefits provided by the watershed. Towards that end, a number of key actions can be taken:

1. Formally establish the ravine system as an asset, similar to other built assets in Toronto, and incorporate it the municipal asset management process. Key next steps toward this recommendation would include:
    a. Build an asset inventory of the ravine system and organize it in an asset registry.
    b. Conduct a condition assessment of the ravine asset. This could largely draw on and build off the existing data and ecological assessments done by the City of Toronto and TRCA.
2. Establish sampling protocols and use trail counters to gain a more accurate understanding of the actual public use of the ravine system.
3. Continue to update and advance the urban forestry program and modelling. The existing work provides excellent input into the carbon sequestration and air quality services. For future modelling work, consider making a distinction between trees in the ravine versus other areas of Toronto. This would better facilitate the use of that information as an input in monitoring the ravine as an asset. Consider distinguishing in the model key subcomponents of the urban forest:
    a. Street trees / canopy
    b. Ravine trees / canopy
    c. Trees / canopy in other parks and open spaces
4. Coordinate with TRCA water resources staff to explore how current hydrologic modelling could be incorporated into this assessment to fill the gap associated with the role the ravine system plays in flood and erosion control (i.e. disturbance regulation).

Appendix A – The State of Ecosystem Service Science in an Urban Context

This appendix summarizes the state of ecosystem service science in an urban context. The review targets the most current economic and ecological studies as well as the most up-to-date data and valuation approaches. Specifically, this appendix presents:

1. A review of frameworks and accounting processes
2. Examples of ecosystem services modelling and assessment tools
3. Application considerations in an urban setting
4. Urban case studies

Ecosystem Service Accounting and Classification Frameworks

This section briefly describes leading frameworks and guidance documents for classifying ecosystem services and establishing natural capital accounts with an emphasis on urban and local scale frameworks. The following frameworks are discussed in this section:

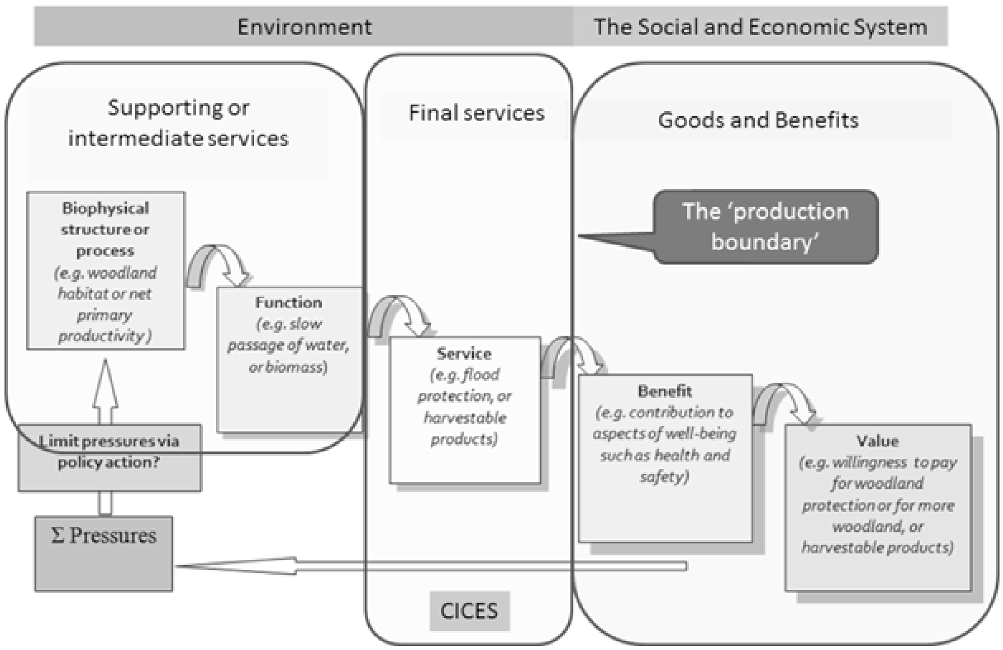
- The United Nations System of Environmental-Economic Accounting, National
- The Common International Classification of Ecosystem Services, National
- National Ecosystem Services Classification System, National (United States)
- Principles of Natural Capital Accounting, National (United Kingdom)
- Urban Natural Capital Accounts, City (United Kingdom)
- Corporate Natural Capital Account Framework, Local (United Kingdom)
- Mapping and Assessment of Ecosystem Services Urban Pilot, City (European Union)

The United Nations System of Environmental-Economic Accounting

There has been substantial international effort to develop standardized frameworks for classifying ecosystem services and establishing natural capital accounts. The United Nations (UN) System of Environmental-Economic Accounting (SEEA) is a key source of technical guidance for integrating environmental accounting into national accounting frameworks. In 2014, the UN released the SEEA Experimental Ecosystem Accounting framework for organizing biophysical data, measuring ecosystem services, and tracking changes in ecosystem assets. The SEEA Experimental Ecosystem Accounting framework provides a structure to integrate ecosystem services and ecosystem conditions in both physical and monetary terms into national accounting frameworks (2014). The guidance document supports countries looking to integrate natural capital and ecosystem services into national accounting systems.

The Common International Classification of Ecosystem Services

The Common International Classification of Ecosystem Services (CICES) was developed by the European Environment Agency as part of their contribution to SEEA. CICES is a classification system designed to help measure, account for, and assess ecosystem services. The system builds on earlier classification typologies introduced in the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010). Version 5.1 was released in January 2018 (Haines-Young & Potschin, 2018). CICES seeks to classify final ecosystem services which are defined as the contributions that ecosystems make to human wellbeing (p.3). The classification scheme is grouped at the highest level into provisioning services, regulation and maintenance services and cultural services which are respectively subcategorized into detailed divisions, groups and classes. The cascade model (figure below) provides the conceptual framework underlying CICES (Haines-Young & Potschin, 2018 from Potschin & Haines-Young, 2016).



Cascade Model, Potschin and Haines-Young, 2016

In addition to being used at the national level, CICES is the basis of the mapping, assessment and accounting work advanced in support of Action 5 of the EU Biodiversity Strategy to 2020 under the Mapping and Assessment of Ecosystem Services (MAES) initiative (urban framework discussed below).

National Ecosystem Services Classification System, United States

The National Ecosystem Services Classification System (NESCS) developed by the United States Environmental Protection Agency (2015) is designed to support comprehensive and systematic accounting of changes in ecosystem services. NESCS focuses on flows of final ecosystem services (FFES), which it defines as the direct contributions made by nature to human production processes or to human wellbeing. FFES are identified by linking the ecological systems that supply final ecosystem services with the human systems that demand them. To uniquely identify and classify FFES, the NESCS structure consists of four classification groups:

1. Environmental classes, which are spatial units, with similar biophysical characteristics, that are located on or near the Earth's surface and that contain or produce "end-products" (e.g., aquatic, terrestrial, atmospheric).
2. Classes of ecological end-products, which are the biophysical components of nature directly used or appreciated by humans.
3. Classes of direct human uses (extractive or in situ) or non-use appreciation of end-products.

4. Classes of direct human users of end-products (EPA, 2015).

A defining characteristic of NESCS when compared to other classification nomenclatures is the emphasis on final ecosystem services which occurs at the point of hand-off between natural systems (ecosystems) and human systems (producers and households) (EPA, 2015).

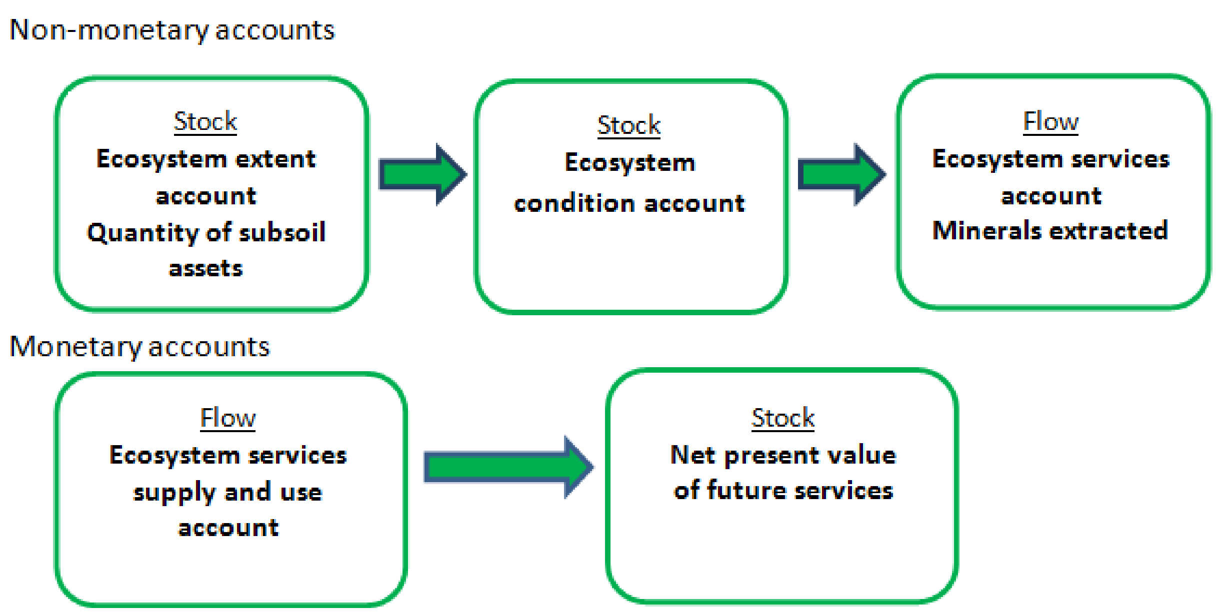
Principles of Natural Capital Accounting, United Kingdom

In the United Kingdom (UK), the Department for Environment, Food and Rural Affairs (DEFRA) and the Office of National Statistics (ONS) have coordinated efforts to formalize natural capital accounts into the UK Environmental Accounts by the year 2020 including the development of natural capital accounting principles and a natural capital accounting framework schedule (DEFRA/ONS, 2017).

The framework proposes five principle accounts (figure below):

1. Physical account of natural capital extent (stock account)
2. Physical account of natural capital condition (stock account)
3. Physical account of ecosystem service provision and use (flow account)
4. Monetary account of annual provision of ecosystem service (flow account)
5. Monetary account of future provision of ecosystem service (stock account)

Tracking the proposed accounts over time allows for the assessments of changes in the extent and condition of natural assets, in addition to changes in the provision of ecosystem services. An account would report the opening and closing value of a stock of natural capital assets as well as the reconciliation of these stocks by recording intervening (net) changes to assets over the accounting period (DEFRA/ONS, 2017).



DEFRA/ONS framework of national natural capital accounting

Urban Natural Capital Accounts, United Kingdom

Based on the cumulative work advancing natural capital accounting led by DEFRA/ONS, Eftec (2017) was consulted to test how urban natural capital accounts might be developed in the UK. The scoping study provided initial monetary value estimates for the following ecosystem services: physical health, local climate regulation, noise regulation, air quality regulation, food provision, and global climate regulation. Other ecosystem services were excluded on the basis of low/no provision or lack of data/methods for analysis. Consistent with other studies, Eftec (2017) noted methodological challenges around converting physical flows into monetary benefits and lack of data limiting more robust analysis. The study also highlighted other challenges for consideration in the urban context such as how to report on the condition of the natural capital stocks, how to quantify benefits of climate regulation and treatment of transboundary effects. Treatment of transboundary effects refer to how to consider the influence on residents of natural capital assets on the edge of urban areas which fall outside the urban boundaries excluding them from analysis (Eftec, 2017). The scoping study provides a useful example of process, linking natural capital extent and condition to ecosystem services, and connecting physical flows to monetary flows.

Scope of UK Urban Natural Capital Account (Eftec 2017, p. 23)

Natural capital benefits	**Physical flow account**	**Monetary flow account**
Food	✓	✓
Freshwater	X	x
Air quality regulation	✓	✓
Noise regulation	✓	✓
Climate regulation - local	✓	✓
Climate regulation – global (carbon)	✓	✓
Natural hazard regulation (incl. flood)	X	x
Water quality regulation	x	x
Pollination	x	x
Cultural heritage	x	x
Aesthetic value	n/a	◊
Recreation and tourism	◊	◊
Property values	n/a	◊
Physical health from outdoor recreation	✓	✓
Key benefits included in original account: ✓: high priority ✓: low priority ◊: existing figures/under development x: not included		

Corporate Natural Capital Account Framework, London Borough of Barnett

The UK national efforts have been adapted to a local level. The Corporate Natural Capital Account (CNCA) framework developed to capture the value of green infrastructure in the London Borough of Barnett (LB Barnett) is a leading demonstration of natural capital assets accounting at a municipal scale (Jon Sheaff and Associates, 2017). The CNCA framework provides a balance sheet that shows the benefits provided by natural capital against the cost of maintaining it and is designed to accompany physical infrastructure asset management plans. The framework puts forward a structure for accounting and valuing natural capital assets starting with the development of an asset inventory. The inventory is used to derive a physical flow account. In the case of LB Barnett, they included four benefit categories: recreation, physical health benefits, property value uplift, and carbon sequestration. Benefits chosen were expected to be amongst the most significant and were categories for which data were available. The physical flow account informs a monetary flow account by assigning economic value to benefits from natural capital that accrue to the organisation that manages the assets (private benefits) and those that accrue to others (external benefits). To develop the natural capital balance sheet, the monetary benefits are compared against the cost of maintaining the natural capital. The final output, or natural capital balance sheet, reports the benefits of natural capital as 'Assets' and the maintenance costs as 'Liabilities' in present value (PV) terms (Jon Sheaff and Associates, 2017).

An ongoing challenge of natural capital accounting is assigning monetary values to the benefit categories with confidence. The methodologies need to be robust and transparent. In the case of LB Barnett, the asset values were estimated where possible using third party established valuation methodologies and local datasets. The recreation benefit value was estimated using the Outdoor Recreation Valuation Tool (ORVal) developed by the University of Exeter for Defra. The physical health benefit was the avoided costs of dealing with ill health due to inactivity based on locally collected physical health data and visits to greenspace data. The property value uplift was determined through analysis of case studies. The carbon regulation benefit was determined by multiplying the UK carbon sequestration rate by habitat type by the DECC non-traded carbon value (Jon Sheaff and Associates, 2017).

Mapping and Assessment of Ecosystem Services Urban Pilot, European Union

The Mapping and Assessment of Ecosystem Services (MAES) Urban Pilot is a collaboration between the European Commission, the European Environment Agency, volunteering Member States and cities, and stakeholders. The fourth MAES report proposed a framework for urban ecosystem services piloted in ten communities. The framework provides a standardized template to assess the condition and contribution of ecosystem services across Europe (European Commission, 2016). The framework includes a set of key indicators that can be used for mapping and assessment at regional, metropolitan and urban scales based on CICES ecosystem services relevant to cities. Indicators are organized by CICES section: provisioning services, regulating and maintenance services, and cultural services (see tables below). Each indicator is marked as a capacity indicator or demand indicator and by relevant spatial extent: Regional (R), Metropolitan (M), Urban (U) (European Commission).

Indicators frame for provisioning, regulating, maintenance and cultural services (European Commission, 2016)

CICES Division - Group					
Nutrition - Biomass					
Class	**Class type (urban ecosystem service)**	**Indicator (unit)**	**Relevant spatial extent**		
			R	**M**	**U**
Cultivated crops	Vegetables produced by urban allotments and in and the commuting zone	● Production of food (ton ha^{-1} $year^{-1}$)	•	•	
		● Surface of community gardens /small plots for self-consumption (ha)		•	•
Nutrition - Water					
Surface/ground water for drinking		● Drinking water provision (m^3 ha^{-1} $year^{-1}$)	•	•	
		● Drinking water consumption (m^3 $year^{-1}$)	•	•	•
Materials - Water					
Surface/ground water for non-drinking		● Water provision (m^3 ha^{-1} $year^{-1}$)	•	•	
		● Water consumption per sector (m^3 $year^{-1}$)	•	•	•

CICES Division - Group					
Mediation of waste, toxics and other nuisances - Mediation by ecosystems					
Class	**Class type (urban ecosystem service)**	**Indicator (unit)**	**Relevant spatial extent**		
			R	**M**	**U**
Filtration/ sequestration/storage/ accumulation by ecosystems	Regulation of air quality by urban trees and forests	● Pollutants removed by vegetation (in leaves, stems and roots) (kg ha^{-1} year-1)		●	●
		● Dry deposition velocity (mm s^{-1})		●	●
		● Population exposed to high concentrations of pollutants (% on surface area)		●	●
Mediation of smell/noise/visual	Noise mitigated by urban vegetation	● Leaf Area Index + distance to roads (m)		●	●
		● Noise reduction rates applied to UGI within a defined road buffer dB(A) m^{-2} vegetation unit (Derkzen et al. 2015)		●	●
Mediation flows-Liquid flows					
Hydrological cycle and water flow maintenance	Water flow regulation and run off mitigation	● Soil water storage capacity (mm)	●	●	●
		● Soil water infiltration capacity (cm)	●	●	●
		● Water retention capacity by vegetation and soil (ton km^{-2})	●	●	●
		● Intercepted rainfall (m^3 $year^{-1}$)	●	●	●
		● Surface runoff (mm)	●	●	●
Flood protection	Flood protection by appropriate land coverage	● Share of green areas in zones in danger of floods (%)		●	●
		● Population exposed to flood risk (% per unit area)		●	●
		● Areas exposed to flooding (ha)		●	●
Maintenance of physical chemical biological conditions - Lifecycle maintenance, habitat and gene pool protection					
Pollination and seed dispersal	Insect pollination	● Capacity of ecosystems to sustain insect pollinators activity (dimensionless) (Zulian et al. 2013)	●	●	
		● Relative abundance (number over area or over a length)	●	●	
Maintenance of physical, chemical, biological conditions - Atmospheric composition and climate regulation					
Global climate regulation by reduction of greenhouse gas concentrations	Climate regulation by reduction of CO_2	● Carbon storage in soil (ton C ha^{-1})	●	●	
		● Carbon sequestration (ton ha^{-1} $year^{-1}$)	●	●	

Micro and regional climate regulation	Urban temperature regulation	● Leaf Area Index		●	●
		● Temperature decrease by tree cover (°C m^{-2})		●	●
		● Cooling capacity of UGI (Zardo et al.)		●	●
		● Cooling capacity of UGI (Derkzen et al. 2015)		●	●
		● Cooling capacity of UGI (Grêt-Regamey et al. 2014)		●	●
		● Population exposed to high temperatures (% per unit area)		●	●

CICES Division - Group					
Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings] – Physical and experiential interactions					
Class	**Class type (urban ecosystem service)**	**Indicator (unit)**	**Relevant spatial extent**		
			R	**M**	**U**
Physical use of land-/seascapes in different environmental settings	Nature-based recreation	● Accessibility[15] to public parks, gardens and play-grounds (more than 50 ha) - (inhabitants within 10 km from a park)	●	●	●
		● Accessibility to public parks gardens and play-grounds (between 10 ha and 50 ha) - (inhabitants within 1 km from a park)	●	●	●
		● Accessibility to public parks gardens and play-grounds (between 2.5 ha and 10 ha) - (inhabitants within 500 m from a park)		●	●
		● Accessibility to public parks gardens and play-ground (between 0.75 ha and 2.5 ha or smaller but important green spaces) - (inhabitants within 250 m from a park).			●
		● Weighted recreation opportunities provided by Urban Green Infrastructure (Derkzen et al. 2015)			●
		● Nature based recreation opportunities (includes Natura 2000; includes bathing water quality) (dimensionless) (Zulian et al. 2013)	●	●	
		● Proximity of green infrastructure to green travel routes (km)	●	●	●
		● Green related social service provided to population (dimensionless) (Secco and Zulian 2008)			●
		● Regression models on georeferenced data (i.e. pictures or geo tagged locations) (Tenerelli et al. 2016)	●		
Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings] – Intellectual and representative interactions					
Educational	Nature-based education	● Accessibility of parks from schools (number of public parks and gardens within a defined distance from a school)		●	●
Scientific					
Heritage, cultural		● Cultural and natural heritage sites[16] (e.g., UNESCO world heritage sites) (number per unit area, % per unit area)	●	●	●

Ecosystem Service Modelling and Assessment Tools

Numerous tools and models have been developed to identify, assess, model, and place a monetary value on ecosystem services with little consistency and standardization across approaches. This section provides a high level overview state of ecosystem services assessment.

The assessment and quantification of ecosystem services typically involves 4 steps:

(1) Identify/inventory the location of ecosystems (i.e. natural capital) providing the service.
(2) Identify the human demand for the service, which can be either:
    a. Rival, where use of a service leaves less of it available for other users (e.g., consumptive water use), or
    b. Nonrival, where its use does not prevent others from enjoying it (e.g., recreational water use or scenic views).
(3) Identify spatial flow paths for the service (e.g., hydrologic flows, lines of sight, or transportation networks).
(4) Assess the biophysical and anthropogenic landscape features that deplete or alter that spatial flow (Bagstad et al., 2014).

While the general steps are similar, how assessments have been carried differ especially in regards to economic valuation techniques employed, the spatial and temporal representation of services, the effects of management practices and trade-offs, the incorporation of existing biophysical models, and the sensitivity analysis (Grêt-Regamey et al., 2017; Bagstad et al., 2013; de Groot et al., 2010). Bagstad and colleagues (2013) reviewed 17 modelling tools designed to measure and quantify ecosystem services and assessed them based on 8 criteria. The authors found that most tools seek to quantify services and their trade-offs at a landscape scale in order to support scenario analysis using simplified underlying biophysical models. However, they differ in their modelling approaches, level of complexity, generalizability, and proprietary nature (p.g.28).

An important conclusion from the Bagstad and colleagues (2013) review is that that there is still no standard modelling approach or tool. Grêt-Regamey and colleagues (2017) similarly conclude that despite the vast increase in ES studies in recent years, ES assessment approaches need to be further developed to improve standardization, site specific relevance, and use in decision making contexts. The authors found some sector specific tools, such as for agriculture or forestry to be more advanced and better suited to support the integration of nature's benefits into policy and planning processes.

An important consideration in ecosystem services assessment is determining the right degree of model complexity. Assessments based on proxy information such as land cover have been shown to sacrifice accuracy and limit site specific policy recommendations (Grêt-Regamey et al., 2017). Highly complex models, however, may restrict wider use and do not necessarily add value to decision making (Seppelt et al., 2011). Context and purpose of the ecosystem service assessment clearly matter. Another important consideration is the underlying value dimensions and world views. Grêt-Regamey and colleagues (2017) conducted a literature review of 68 tools for integrating ecosystem services into decision making; they noted substantial differences in study outcomes depending on the value systems that were applied.

Based on the conclusions from recent research, the best path forward may be to focus less on developing a singular standardized tool, and more on a system of data sharing (especially for spatial data), ecological studies to parameterize models, and economic valuation techniques (Bagstad et al., 2013). Clear assumptions and transparency in motivations and world view are also critical to understand where and in what context model replicability is suitable.

Application Considerations in an Urban Context

Natural areas in urban contexts have unique ecosystem service considerations given their small size, unbalanced composition and fragmentation. Within urban areas, ecosystems services can vary greatly depending on the surrounding environmental and socio-economic characteristics. Bolund and Hunhammar (1999) proposed the first classifications of ecosystem services for an urban context arguing the focus should be on direct and locally generated services. They identified seven urban ecosystem types: street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea, and streams. For the respective ecosystem types, Bolund and Hunhammar assessed ecosystem service values of air filtration, micro climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreation and cultural value. Building on Bolund and Hunmammar's pioneering work, Gómez-Baggethun and Barton (2013) developed an expanded list of ecosystem service categories for inclusion in urban ecosystem valuation assessments, which is the current standard. They suggested: food supply, water flow regulation and runoff mitigation, temperature regulation, noise reduction, air purification, moderation of environmental extremes, waste treatment, climate regulation, pollination and seed dispersal, recreation and cognitive development, and animal sighting.

When assessing urban ecosystem services, identifying the most appropriate study boundaries is not a simple task. From a budgetary and authority perspective, municipal boundaries make the most sense. Cities, however, derive substantial ecosystem services from outside jurisdictional boundaries. Depietri and colleagues (2013) suggest using watersheds as boundaries, recognizing the link between urban life and healthy watershed ecosystems.

Numerous studies have attempted to assign a monetary value to urban ecosystem services. Elmqvist and colleagues (2015) reviewed 25 peer reviewed studies in the literature focusing on five ecosystem services: local pollution removal, carbon sequestration and storage, regulating water flows, climate regulation/cooling effects, and aesthetics, recreation and other amenities. The authors conclude that the monetary benefits are substantial. Based on the studies analyzed, benefits range from US$ 3,212 to $17,772 in constant dollars per ha per year, justifying, the authors contend, the need for ecosystem restoration and green infrastructure investment. Elmqvist and colleagues (2015) single out the contribution of urban green infrastructure to enhancing the capacity of cities to respond and adapt to a changing climate, 'insurance value', as a neglected variable in most analyzes.

In respect to specific urban ecosystem types, substantial research has looked specifically at the ecosystem service values provided by urban forests (Nesbitt et al., 2017; Willis & Petrokofsky, 2017; Livesley et al., 2016; Haavardsholm, 2015). The US Forest Service developed the i-Tree suite of tools, which have been widely applied at a municipal level across Canada with several examples in Southern Ontario including Toronto, Brampton, Mississauga, Waterloo, Oakville, and Hamilton (Steenberg, 2017). The i-Tree Eco tool, for example, estimates urban forest canopy cover and benefits associated with carbon storage, carbon sequestration, air pollutants removal, and energy conservation (Novak et al., 2013). While the focus of assessments is usually on benefits, Escobedo and colleagues (2011) introduced the concept of ecosystem disservices in the context of urban forests. Examples of disservices associated with the urban forest include: tree growth that block views; wind pollinated plants dispersing allergens, and damage to infrastructure from root growth. The concept has been extended more broadly to other ecosystem services as well (Gómez-Baggethun & Gren, 2013).

Assessing urban ecosystem services has brought attention to the importance of management practices. Livesley and colleagues (2016) show that urban forest management practices can improve energy conservation, carbon storage, reduce storm-water runoff, improve air quality, and enhance human health and wellbeing. Tratalos and colleagues (2009) in a study of biodiversity potential and ecosystem services in five UK cities found there is substantial scope for improving ecological performance based on management of urban form. Using spatial analysis, Holt and colleagues (2015) identify hotspots of production potential in cities where multi-functionality of greenspace can be increased. What emerges from their respective research is that we clearly need to manage urban greenspaces to maximize multiple ecosystem services.

The concept of ecosystem services is increasingly part of urban planning discourse. The cities of Stockholm New York, Seattle and Berlin in particular, have widely integrated the concept into urban planning policy and strategy documents largely in respect to promoting cultural services and habitat provision (Hansen et al., 2015). Seeing natural capital as a vital part of the urban landscape will help increase the resiliency of our cities to environmental impacts and improve health, and quality of life of residents (Gomez-Baggethun and Gren, 2013).

Best Practice, Urban Biodiversity and Ecosystem Services Research Project

The Urban Biodiversity and Ecosystem Services (URBES) project, which concluded in 2015, assessed urban ecosystem services and biodiversity in seven cities in Europe and the United States. The project aimed to bridge the knowledge gaps related to the contribution of urban biodiversity and ecosystem services to human wellbeing. The effort resulted in over 50 published papers. Based on the collective experience, researchers and practitioners identified key insights to guide future urban ecosystem services research. The insights summarized below are discussed in more detail in Kremer et al. (2016).

1. Using existing land-cover and land-use based indicators to estimate ES benefits in urban areas is problematic as conversion factors are often based on non-urban empirical data. The ecosystem performance and functionality between urban and non-urban areas will differ substantially. Even extended conversion factors between cities is problematic given different conditions.

2. Understanding urban ES supply and demand dynamics requires cross-scale and cross-boundary considerations. Administrative boundaries are often not sufficient to delimit an area of analysis because ES supply and demand dynamics do not align with administrative boundaries. The authors suggest conducting analysis at three scales, the core city within administrative boundaries, the hinterland, and the combined core city and hinterland.

3. Ecosystem services and benefits derived from them depend on non-ecological elements, including physical infrastructure, technology, social practices, and the cultural contexts in which people experience human-environment relations. Studies must consider these factors when estimating the human benefits of ecosystem services or advising on management of services.

4. Cultural ecosystem services are difficult to quantify and value, however, they are among the most important services in urban areas because people hold spiritual, educational, aesthetic, place-based, and other nonmaterial values toward the urban environment that contribute substantially to human wellbeing. These values will differ based on culture, experience, social norms, and economic status.

5. Links between biodiversity and ecosystem services in an urban setting remain unclear. Understanding and managing for that relationship could potentially enhance biodiversity and ecosystem services simultaneously.

6. Implementing ES concepts in planning and policies requires addressing the “science-policy gap”, developing methods and tools that planners can use to assess ES, and communicating concepts in language that economists, architects and engineers grasp.

Examples of Greater Toronto Area focused research

There are few examples of published attempts to identify, measure and value the benefits of ecosystem services specific to Toronto. Existing studies have been primarily in the realm of public health and not necessarily framed around ecosystem benefits. For example, looking at the increased health benefits of active transportation or more walkable cities (Toronto Public Health, 2012) which reference trails and parks or the relationship between increased physical activity and public green spaces (Koohsari et al., 2015).

Healthy Toronto by Design Series

The Healthy Toronto by Design series includes two literature review studies on the benefits of greenspace. The studies focus on the impact of greenspaces on heat island mitigation and reducing air pollution (Zupancic et al., 2015), and on physical health, mental health and wellbeing (Toronto Public Health, 2015). The respective studies do not explicitly link greenspaces in Toronto to specific benefit values, however, they do document evidence of the ecosystem service benefits provided by greenspaces in an urban context and offer important information to carry out more detailed analysis. What is clear from the respective studies is that the benefits provided by greenspaces are large and positively impact the liveability of cities.

Urban Forest

The study, *Every Tree Counts, A Portrait of Toronto’s Urban Forest* provides a detailed analysis of trees in Toronto (City of Toronto, 2013). The assessment used the iTree suite of tools to estimate that Toronto has about 10.2 million trees with a canopy cover of approximately 26.6 percent of the city. The summary of ecosystem services provided by the urban forest canopy includes:

- Storage of approximately 1.1 million tonnes of carbon valued at CAD$25.0 million.
- Sequestration of about 46,700 tonnes of carbon per year (CAD$1.1 million per year)
- Removal of about 1,905 tonnes of air pollution per year (CAD$16.9 million per year).
- Reduce annual residential energy costs by CAD$9.7 million per year.

The information on the structure and functions of the urban forest, as measured in this type of study, can be used to improve support for urban forest management programs. If updated on a regular basis, the results can be used to track progress toward urban forest management goals and well as broader city-wide goals to improve environmental quality.

Taking a different approach, Karden et al. (2015) conducted a statistical analysis correlating the presence of urban forest and greenspace with self-reports of general health, cardio-metabolic conditions and mental illnesses. Controlling for socio-economic and demographic factors, their results suggest that people who live in neighborhoods with a higher density of trees report significantly higher health perception and significantly less cardio-metabolic conditions. Statistically, the results suggest having 10 more trees in a city block improves health perception that is comparable to an increase in annual personal income of $10,000. Similarly, having 11 more trees on a city block decreases cardio-metabolic conditions that is comparable to an increase in annual personal income of $20,000. Urban trees have also been linked to improved educational outcomes. A recent study examining potential effects of tree cover, diversity, and species composition on academic performance of grade three and six students in the Toronto District School Board found that proportion of tree cover was a significant positive predictor of student performance (Sivarajah et al., 2018).

Wellbeing and Your Watershed, Credit River Ecosystem Services WebMap

Bunch (2016) created a web based mapping tool that tracks and measures ecosystem services benefiting the residents, community and stakeholders of the Credit River watershed, and informs them about these benefits. The tool communicates the wellbeing benefits associated with ecosystem services documented in the literature; it does not attempt to specifically quantify or value the ecosystem services benefits associated with the Credit River Watershed.

Urban Case Studies

Ultimately, what is measured, and the approach used to measure it, depends on the intended use of the results. Types of uses at a municipal or regional level include:

Education and Building Awareness

Ecosystem service valuation is frequently used to increase citizen and corporate understanding and awareness of the value provided by nature. By estimating the monetary value of nature's contribution to wellbeing, people have a greater appreciation for the importance of nature and are able to asses that value on equal footing with other monetized goods and services.

Case Study Example: At nearly 2 million acres, Ontario's Greenbelt stretches from Niagara to Northumberland protecting vital agricultural land and greenspace in the Greater Golden Horseshoe. Implemented in 2005, the Greenbelt Plan protects this natural capital by preventing new urban development in greenfield areas within its boundaries. Green Analytics and Sustainable Prosperity were commissioned by the Friends of the Greenbelt to provide an updated estimate of the value of natural capital in Ontario's Greenbelt, building on an assessment that was first carried out in 2008. The assessment used the National Ecosystem Services Classification methodology to identify a series of ecosystem service accounts that directly benefit residents (e.g. recreation, flood protection, and clean air to breath). This study determined that the Greenbelt accounts were valued at $3.2 Billion per year.

Tracking, Monitoring, and Managing Natural Assets

There is a growing trend towards the use of ecosystem service assessment and valuation by municipalities to track, monitory and manage the natural assets within their boundaries.

Case Study Example: In July 2014, the Town of Gibsons, British Columbia, became the first municipality in North America to pass a municipal asset management policy that explicitly defines and recognizes natural assets as an asset class and creates specific obligations to operate, maintain and replace natural assets alongside traditional capital assets, including the development of natural asset management strategies. The Town recognized that if natural assets are degraded or destroyed, the services previously provided for free have to be replaced. From an economic perspective, maintaining healthy ecosystems ensures continuity of essential services at a fraction of replacement and maintenance costs of engineered alternatives. The municipal asset management policy means that in addition to reporting physical assets like roads and storm sewers, Town planners will track natural assets such as forests, aquifers, creeks, wetlands and foreshores that provide essential services, such as flood prevention, provision of drinking water and rain water management. Currently the only natural capital asset tracked is the Town aquifer. [16]

According to the Town's eco-asset plan, natural asset management plans require:

- assessing the asset conditions from a biophysical perspective to determine their properties, and the civil services they provide;
- determining the asset worth and substitution or replacement cost so that the municipality understands the risk and exposure in the event that the asset deteriorates and needs to be replaced with an engineered alternative;
- determining the impact of increased demands on the asset;
- determining objectives for the asset which could range from maintaining it at the lowest possible cost to being protected in perpetuity;
- developing an operations and maintenance plan; and,
- developing a financial management plan (Municipal Natural Asset Initiative, 2017).

Changing how we track and value natural assets brings attention to the important ecological services that ecosystems provide and the incredible economic and social value that previously went unaccounted.

Land Use Planning

Ecosystem service assessment and valuation can also play an important role in supporting land use planning within municipal settings. Natural capital can be spatially allocated, and the implications of alternative land use decisions modelled and mapped to identify areas well suited to development and regions for ecological protection. Trade-offs resulting from different land uses can also be informed by ecosystem service assessment and valuation.

[16] Town of Gibsons, *Towards and Eco-Asset Strategy for the Town of Gibsons*, Gibsons, BC: Town of Gibsons.

Case Study Example: The University of Michigan developed the Green Infrastructure Spatial Planning Model (GISP) for identifying priority areas (census tracts) for green infrastructure development in Detroit. As a post-industrial city –there is extensive vacant land for urban transformation. Detroit has ambitious policies to develop green infrastructure to enhance sustainability and resiliency. GISP tool was design to help planners best site future green infrastructure to maximize different ecosystem benefits and to distribute these benefits fairly across neighborhoods. The tool provide a rational approach to justify green development locations. Newell one of developers argued that current siting decisions are largely political and focus predominately on storm water management neglecting other ecosystem service benefits.

The tool is made up of six GIS layers corresponding to six green infrastructure or ecosystem service benefits: stormwater management, social vulnerability, access to green space, air quality, the urban heat island effect, and landscape connectivity. To compare priority sites versus current sites, tool developers used multi criteria analysis to weigh different ecosystem service benefits based on expert engagement. The tool includes social vulnerability recognizing that critical ecosystem service benefits of green infrastructure investment are largely localized.

Case Study Example: In United Kingdom, Bateman and colleagues (2013) show that making land use decisions based solely on the market value of agricultural production can contribute to significant economic losses. The authors use spatially explicit models in conjunction with valuation methods to estimate comparable economic values of land use decisions that consider a wide range of ecosystem services. Ecosystem services considered in the analysis include: agricultural production, greenhouse gas sequestration, recreation, urban greenspace amenity, and wild bird species diversity. Looking out to 2060, they demonstrate that making land use decision based on a comprehensive suite of ecosystem service values can generate 19.6 billion of £s per annum (£2010) (equivalent to 35.6 billion $CAN) compared to 892 million of £s per annum (£2010) (equivalent to 1.6 billion $CAN) when considering market prices for agricultural production alone.

Monitoring Progress Towards Policy Goals/Objectives

Municipal governments can use ecosystem service assessment and valuation to measure progress towards policy objectives and goals. This could be in relation to protecting a specified percent of land, or achieving an objective such as no net loss or biodiversity targets.

Case Study Example: The City of Birmingham estimated the stock of natural capital assets and flow of ecosystem services at a city-wide level as basis to establish targets for increasing greenspace as part of the City's Green Living Spaces Plan and to inform a 25-year Natural Capital Plan. The Green Living Spaces Plan assessment includes indicative monetary values in annual terms and asset values (over 100 years) based on value transfer. The city also adopted the Natural Capital Planning Tool (NCPT) to inform planning and policy for sustainable land use. The NCPT is qualitative based on 'expert opinion' translating indicators into impact scores, without any quantification or monetisation of physical impacts. Ecosystem services measured by the City's Green Living Spaces Plan include: harvested products, biodiversity, aesthetic values, recreation, water quality regulation, flood risk regulation, air quality regulation, local and global climate regulation and soil contamination (Eftec, 2017). The City of Birmingham is at the forefront of natural capital accounting and exploring opportunities to ensure natural capital is integrated into land use and planning decisions as exemplified by the City's Natural Capital Plan, Natural Capital Planning Tool, and becoming a designated biophilic city.

Case Study Example: Halifax Regional Municipality (HRM) has implemented a progressive Urban Forest Master Plan that includes forest management plans for 111 unique urban forest neighbourhoods. Adopting a Neighbourhood level management approach increases citizen participation in urban forest stewardship fostering a sense of local ownership and social cohesion. The Master Plan promotes location-specific forest health to maximize the ecosystem service benefits across the municipality. The city used the i-Tree method to determine canopy coverage and estimate ecosystem value benefits provided by the urban forest. HRM estimated benefits of carbon sequestration, shading, and reduction in air pollutants by forest neighbourhood. For the municipality as a whole, the urban forest sequesters over 18,500 tonnes of carbon annually and directly reduces energy demand through heating and cooling by 1.7 million dollars. In addition, the trees remove over 550,000 kg of pollutants from the air annually.

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