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The Evolving Role of Botanical Gardens and Natural Areas: A Floristic Case Study from Royal Botanical Gardens, Canada

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Abstract: As leaders calling for the conservation of the world's plants, botanical gardens protect plants within living collections. Many also study, manage and restore plants in natural habitats. Royal Botanical Gardens (Ontario, Canada) has integrated both horticultural and natural heritage in its mission for decades. Envisioned by municipal leaders in the 1920s as a combination of nature sanctuaries and civic gardens, RBG now includes forests, wetlands and other habitats, gardens and built spaces. Today RBG is Canada's largest botanical garden on the basis of area. In the 1950s RBG began to inventory plant diversity. The checklist of spontaneous vascular plants now exceeds 1 170 species, of which 752 are native. This is 37% of Ontario's native vascular plants and 19% of the native vascular flora of Canada. The RBG nature sanctuaries are among the richest locations in Canada for species-level diversity. We examine the history of floristic exploration within RBG and compare plant species-area relationships among protected natural areas in Ontario. This comparison supports the contention that the nature sanctuaries, and in particular Cootes Paradise, could be considered an important area for plants in Canada, and relative to the nation's flora, a biodiversity hotspot. The fact that a candidate vascular plant hotspot for Canada lies within a major botanical garden presents opportunities for raising public awareness of the importance of plant diversity, as well as focusing attention on the scientific and conservation biology needs of communities and individual species in this area.

Key words: Botanical garden; Ontario; Natural areas; Biodiversity; Species-area curve; Species richness

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Botanical gardens originated as teaching collections and as places of botanical research. Today their mandates are more inclusive, ranging from conservation to providing visitor attractions to supplying botanical expertise and educational programs to a diversity of users. The development of botanical gardens varies greatly, influenced by planning decisions, economic development and the natural and cultural resources at hand. Some were established as municipal or public parks, encompassing landscapes that are entirely artificial. They are often considered *ex situ* institutions, conserving biological diversity outside of its original context. Some botanical gardens, however, have been developed to include natural areas, and others now also place an increased emphasis on conserving of plants and plant communities *in situ*. In Canada, approximately 75% of botanical gardens and arboreta own or are associated with natural areas (Garcia-Dominguez and Kennedy, 2003).

Conservation biologists and planners sometimes label natural areas of high biological diversity as "hotspots". Protecting such hotspots is an effective way to conserve large numbers of species as well as their ecological associations (Myers *et al.*, 2000). At the global level, biodiversity hotspots are usually identified in megadiverse countries and may include

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large numbers of endemic species. At the regional or national levels, important areas for species diversity may also be considered as hotspots regardless of their level of endemism, especially for the important objective of raising public awareness (Plantlife, 2010).

Within Canada, two regions are generally recognized as holding the richest botanical diversity: southern British Columbia and southern Ontario (Argus and Pryer, 1990; CESCC, 2006). Both of these regions are rich in spontaneously occurring plant species because they represent patchworks or mosaics of many different kinds of habitats, transitions and plant communities, and because of favorable climate. Both the southern British Columbia and southern Ontario high-diversity regions are heavily affected by contemporary human society.

In southern Ontario the northern extent of the Deciduous Forest Region meets the Great Lakes-St. Lawrence Forest Region. The landscapes of this region include some remnant savannahs and prairies, and rare habitats such as sand dunes, alvars and cliff-faces. Settlement and development of this area has introduced many exotic species, including animals and plants related to horticulture, agriculture and landscaping as well as accidental introductions. It is a rapidly growing economy as well. The region surrounding Toronto, for example, is among the highest-density urban zones in North America (United Nations, 2009).

Some of Canada's richest landscapes for species diversity are within the Greater Toronto Area. About 60 kilometers west of Toronto lies the Dundas Valley, which cuts deeply into the Niagara Escarpment at the western tip, or "head" of Lake Ontario. The importance of Cootes Paradise Marsh, a wetland within this valley, and the ecological productivity of the area, were recognized when the wetland was designated as a fish sanctuary in the 19th century and a game sanctuary in the early 20th. The concept of a major public park system in this area combining large open lands, natural areas and horticultural displays originated in the late 1920s. By 1932, the first garden area opened to the public. Royal Botanical Gardens was formed as an agency of the Province of Ontario in 1941, with the objectives of developing horticulture appropriate for the region, displaying gardens, undertaking botanical research and protecting natural areas for recreational and ecological purposes (Laking, 2006). Since the early 1950s, dozens of person-years have been invested in the botanical exploration of the RBG natural lands, resulting in tens of thousands of herbarium specimens, and checklists of the spontaneous vascular flora published in 1969 (Pringle, 1969), and updated in 2003 (Smith, 2003).

Here we present preliminary evidence that these lands present the highest vascular plant species richness in the landscape of Ontario, and possibly in Canada, on the basis of species-area relationships among comparable protected areas. We discuss the importance of natural areas associated with botanical gardens as opportunities for conservation and interpretation.

Materials and Methods

Geographic Setting and Floristic Inventories

Royal Botanical Gardens consists of approximately 760 hectares of nature sanctuaries and another 200 + hectares of built gardens and other facilities, within the present boundaries of the cities of Hamilton and Burlington, Ontario, Canada. These lands are arrayed in several disjoint properties (headquarters at 43°17. 412′ N 79°52. 536′ W). Four of these are major nature sanctuaries, including Cootes Paradise Marsh and the surrounding terrestrial habitats situated in and around the Dundas Valley and the near-by Grindstone Creek to the east.

Early lists of plants found in the Hamilton area were published in 1854, 1861, and 1874 (Pringle, 1995). The most intensive survey of RBG's spontaneous flora was made by Aleksander Tamsalu, an RBG staff member who had studied plant ecology in his native Estonia. From 1954 through 1958 Tamsalu collected about 10 000 specimens from RBG's Cootes Paradise and Hendrie Valley properties, re-

presenting approximately 800 species and botanical varieties (Lord, 1980). Subsequent additions to RBG's properties were surveyed in the 1960s by Robert M. Johns, a student at McMaster, and James S. Pringle, RBG's plant taxonomist. The first checklist of the spontaneous flora of these sanctuaries was published in 1969, and included 937 species (Pringle, 1969). John B. Lord, a student at the University of Guelph, surveyed the aquatic and marsh vegetation of Cootes Paradise in 1971–1972, comparing his list of species observed with those compiled in previous studies. Subsequently, RBG field botanists Justus Benckhuysen, Jeremy Lundholm, Tyler Smith, Carl Rothfels, Natalie Iwanycki and other staff members have discovered additional species, including rare native species as well as many naturalized exotics. In 2003, RBG field botanist Tyler Smith revised the list of the spontaneous flora on RBG properties (Smith, 2003). Subsequent studies have added to the checklist (Rothfels, 2003, 2004, 2005a,b, 2006a,b, 2007; Rothfels *et al.*, 2004; Smith *et al.*, 2001).

The continuing efforts to document the diversity and distribution of plants at Royal Botanical Gardens include collection and identification of plants across the various properties, and searches for previously recorded species that have not been reported in recent years (some of which have been rediscovered). For this study, species recorded in the current database were considered to be the *Spontaneous Flora* and were classified as either native (likely present in the local area prior to European settlement in the 18th Century) or introduced (arrived in the area since European colonization). Plant species richness was individually summarized for three of the major natural lands properties at RBG: those in the Cootes Paradise Nature Sanctuary (541 hectares), Hendrie Valley Nature Sanctuary (114 hectares), and Rock Chapel Nature Sanctuary (74 hectares), and for the RBG nature sanctuaries as a whole.

Species Richness at Other Parks and Protected Areas

Observations of plant species richness, or checklists from which richness could be derived, were requested from agencies maintaining natural areas in Ontario, including conservation authorities, Ontario Nature (formerly the Federation of Ontario Naturalists), Parks Canada, Ontario Parks, and the Ontario Ministry of Natural Resources. Where possible, species richness datasets for individual protected areas were developed to include total species richness, richness of native and of introduced species, using the same definition as used for the RBG properties. The geographic areas of individual parks were also requested from the contacted agencies and were confirmed using the Ontario Natural Heritage Information Centre's (NHIC) database (NHIC, 2010). Latitude and longitude for each park were obtained either using the NHIC database or by locating the parks using the online service Google Maps®.

Analysis

In order to control for effects of different plant communities within different ecozones, latitude, and other geographic variables, our analysis was limited to parks in the Mixed Wood Plains Ecozone in the Province of Ontario, of which RBG is a part.

To investigate the relationship between the size of natural areas and species richness, and to assess if the nature sanctuaries at RBG contain a greater number of species than expected, three different analyses were conducted. Firstly, a regression analysis was performed, using log (area) as the explanatory variable, and species richness as the dependent variable.

Since the natural lands at RBG are composed of distinct nature sanctuaries, a second analysis was performed, in which three individual RBG areas were included (Cootes Paradise, Hendrie Valley and Rock Chapel). To understand the contributions of native and introduced plants to overall species richness, two separate linear regressions were conducted. For these two analyses, only parks which had introduced and native species data available could be included.

In order to compare the species richness seen at

RBG with what one would expect based on data from other natural areas, a vascular plant species-area relationship for the sample of parks in Ontario was estimated by linear regression of species richness versus log (area), calculated without the RBG sanctuaries. The resulting regression equation was then used to calculate the expected number of species that should be present within each of the focal individual RBG nature sanctuaries as well as for RBG as a whole. All analyses were performed using SYSTAT 13® (SYSTAT Software, 2009).

Results

The most recent assessment of species richness of spontaneous vascular plants within the RBG nature sanctuaries and associated parklands includes 1 171 species in 126 families. Within the nature sanctuaries themselves (excluding highly disturbed areas such as roadsides) 1 037 species have been documented, of which 300 are introduced (29% of the recorded flora).

Species richness data were obtained for 55 parks and protected areas located in Ontario's Mixed Wood Plains Ecozone (Table 1; Fig. 1). The majority of parks (70%) are located in the counties of Hastings and Northumberland, east of Toronto. Park areas ranged from 5 hectares to 27 844 hectares, and species richness ranged from 91 to 891 species. Forty-five parks provided separate species richness data for native and introduced vascular plants. A strong, statistically significant relationship was observed between total vascular plant species richness and protected area size among the parks for total species richness, richness of native species and richness of introduced species (Fig. 2).

The total species richness within each of the three focal RBG nature sanctuaries was much greater than expected based on the observed relationship between species richness and log (area) among the examined protected areas in Ontario (Fig. 3: A). Furthermore, both the native plant species richness and introduced plant species richness was higher than expected in RBG on the basis of forty-five parks for which separate species richness data for native and introduced plants was available (Fig. 3: B, C).

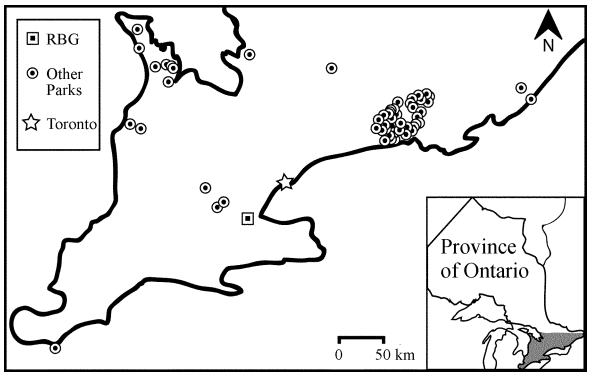

Fig. 1 Locations of parks and other protected areas in the Province of Ontario, Canada, for which vascular plant checklists could be obtained

Table 1 Summary of protected areas within Ontario's Mixed Wood Plains Ecozone for which plant species richness data was found

Name	Latitude	Longitude	Area (ha)	Native species	Introduced species	Total vascular plant species
Alderville Woods SNA	44 °9.599′ N	78 °2.370′ W	116	279	67	346
Altberg Wildlife Sanctuary Nature Reserve	44°44.1′ N	78°2.394′ W	204	125	8	133
Barry Lake Wetland Complex Conservation Area	44°18.42′ N	78°44.57′ W	101	296	38	334
Batawa SNA	44°9.779′ N	77°36.13′ W	329	318	65	383
Big Apple Headwater SNA	44°0.840′ N	77°54.76′ W	73	241	48	289
Bruce Peninsula National Park	44°11.93′ N	81°31.30′ W	27 844	—	—	891
Burnley-Carmel Headwater SNA	44°7.559′ N	78°1.199′ W	1 203	415	78	493
Carman Headwater SNA	44°7.680′ N	77°43.99′ W	127	206	47	253
Cold Creek Complex SNA	44°6.720′ N	77°49.79′ W	1 211	457	80	537
RBG-Cootes Paradise	43°16.67′ N	79°54.90′ W	541	683	246	929
Cramahe Hill SNA	44°10.49′ N	77°49.37′ W	200	263	66	329

continue table 1

Name	Latitude	Longitude	Area (ha)	Native species	Introduced species	Total vascular plant species
Cranberry Lake Wetland Conservation Area	44°0.480′ N	78°1.854′ W	58	200	20	220
Crookston Forest SNA	44°26.7′ N	77°26.63′ W	290	326	40	366
Dartford Pond-O'Reilly Lake Wetland Conservation Area	44°13.55′ N	77°56.21′ W	162	162	10	172
Dumfries Conservation Area	43°23.22′ N	80°19.60′ W	75	51	12	63
Georgian Bay Islands National Park	44°52.78′ N	79°52.39′ W	1 218	—	—	880
Godolphin Esker Wetland Conservation Area	44°18.71′ N	77°53.90′ W	79	227	36	263
Greenock Swamp Conservation Area ANSI	44°9.359′ N	81°22.5′ W	8 300	—	—	692
Harwood Plains SNA	44°8.040′ N	78°8.675′ W	69	146	58	204
RBG-Hendrie Valley	43°17.58′ N	79°52.5′ W	114	410	145	555
Hickory Island Conservation Area	44°12.90′ N	78°6.563′ W	5	91	13	104
Hoards Creek Flats Wetland Conservation Area	44°19.79′ N	77°38.00′ W	97	274	49	323
Johnstown Drumlin SNA	44°10.20′ N	77°34.06′ W	162	258	41	299
Kemble Mountain Conservation Area	44°45′ N	80°55.92′ W	140	—	—	205
Killoran Lake Wetland Conservation Area	44°17.21′ N	77°56.85′ W	59	131	9	140
Laurel Creek Conservation Area	43°34.61′ N	80°28.98′ W	288	142	28	170
Lost Bay Nature Reserve	44°28.19′ N	76°6.209′ W	47	106	19	125
Lyal Island Nature Reserve	44°57.00′ N	81°24.48′ W	305	278	3	281
Mayhew Creek Headwater SNA	44°5.759′ N	77°41.13′ W	432	356	92	448
Moreland Lake Complex SNA	44°25.13′ N	77°24.68′ W	1 269	391	70	461
Morrow Bay Woods Conservation Area	44°15.41′ N	78°2.303′ W	80	137	18	155
Murray Hills Headwater SNA	44°7.139′ N	77°39.47′ W	383	379	69	448
Nappan Island SNA	44°23.52′ N	77°49.09′ W	93	159	16	175
Northumberland County Forest SNA	44°6.599′ N	78°4.248′ W	783	282	90	372
Oak Lake SNA	44°16.44′ N	77°31.47′ W	274	335	86	421
O'Melia-Lamey Lakes Wetland Conservation Area	44°16.08′ N	77°57.91′ W	60	307	54	361
Pancake Hill SNA	44°22.68′ N	77°25.33′ W	92	33	58	91
Point Pelee National Park	41°57.47′ N	82°30.85′ W	1 550	—	—	838
Puslinch Tract Conservation Area	43°25.98′ N	80°14.76′ W	107	163	72	235
Rawdon Marsh Conservation Area	44°24.41′ N	77°31.81′ W	67	107	7	114
Rawdon Wetland and Alvar Complex SNA	44°26.28′ N	77°32.72′ W	697	368	67	435
RBG-Rock Chapel	43°17.58′ N	79°52.55′ W	74	220	94	315
RBG-Summed Nature Sanctuaries	43°16.38′ N	79°54.91′ W	772	735	302	1 037
Rubberweed Nature Reserve	45°7.860′ N	81°26.16′ W	67	—	—	206
Rylstone Wetland Conservation Area	44°21.78′ N	77°40.51′ W	145	302	42	344
Salt Creek Valley SNA	44°9.060′ N	77°55.54′ W	607	383	76	459
Skinner Bluff Conservation Area	44°47.16′ N	81°1.884′ W	1 052	—	—	198
Slaughter Island Conservation Area	44°22.91′ N	77°50.65′ W	9	117	9	126
Spirit Rock Conservation Area	44°45.72′ N	81°10.78′ W	86	—	—	222
Spring Valley Headwater SNA	44°3.960′ N	77°44.95′ W	104	232	49	281
Squire Creek Headwater SNA	44°24.30′ N	77°38.59′ W	904	375	45	420
St. Lawrence Islands National Park	44°21.00′ N	75°58.69′ W	527	—	—	814
Stirling Slope Complex SNA	44°14.1′ N	77°34.22′ W	200	251	33	284
The Glen Conservation Area	44°36.90′ N	80°59.98′ W	1 168	—	—	298
Trout Creek Wetland Conservation Area	44°15.84′ N	77°52.64′ W	121	258	28	286
Tubbs Corners Headwater SNA	44°3.179′ N	77°56.59′ W	181	284	48	332
Vernonville Headwater SNA	44°3.780′ N	77°58.72′ W	67	225	32	257
Wicklow Creek Headwater SNA	44°1.319′ N	77°58.15′ W	83	229	38	267

ANSI = Area of Natural and Scientific Interest; RBG = Royal Botanical Gardens; SNA = Significant Natural Area

The regression analysis excluding RBG provided a means of comparing expected and observed species richness. All observed values were much higher than expected values (Table 2). The observed species richness for all of RBG was 223% greater than the expected richness, and for the three sanctuaries, observed richness ranged from 140% to 217% greater than expected.

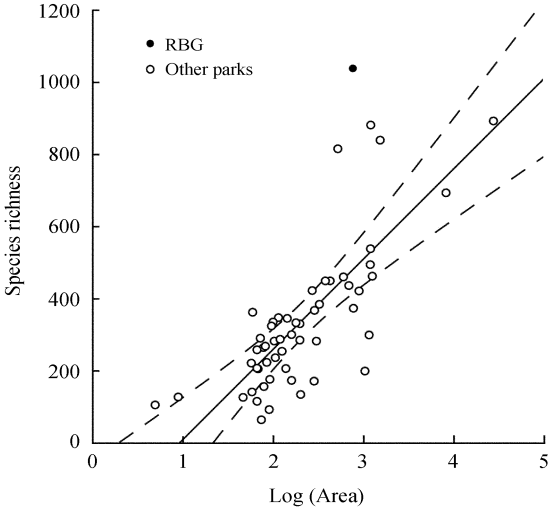

Fig. 2 Relationship between the total number of species and the $\log_{10}$ area of parks found in Ontario. The solid line represents the estimated linear regression; the dashed lines are the 95% confidence interval on the regression equation ($r^2 = 0.525$, $P < 0.0001$)

Table 2 Observed and expected species richness of vascular plants RBG nature sanctuaries. Expected species richness was calculated in each case using the observed relationship between species richness and log (area) for Ontario parks, excluding the same RBG properties, as calculated by linear regression

Area	Area (ha)	Observed species richness	Expected species richness	Observed as % of expected
Cootes Paradise Nature Sanctuary	541	929	428	217
Hendrie Valley Nature Sanctuary	114	555	269	206
Rock Chapel Nature Sanctuary	74	315	225	140
Royal Botanical Gardens (combined natural areas)	759[1]	1037[2]	465	223

Notes: 1—The total combined natural areas of Royal Botanical Gardens listed here is less than the total area of the property owned by the institution, as other areas include gardens and other land uses.

2—The total combined species richness is less than the sum of the richness in individual areas because many species were found in more than one area

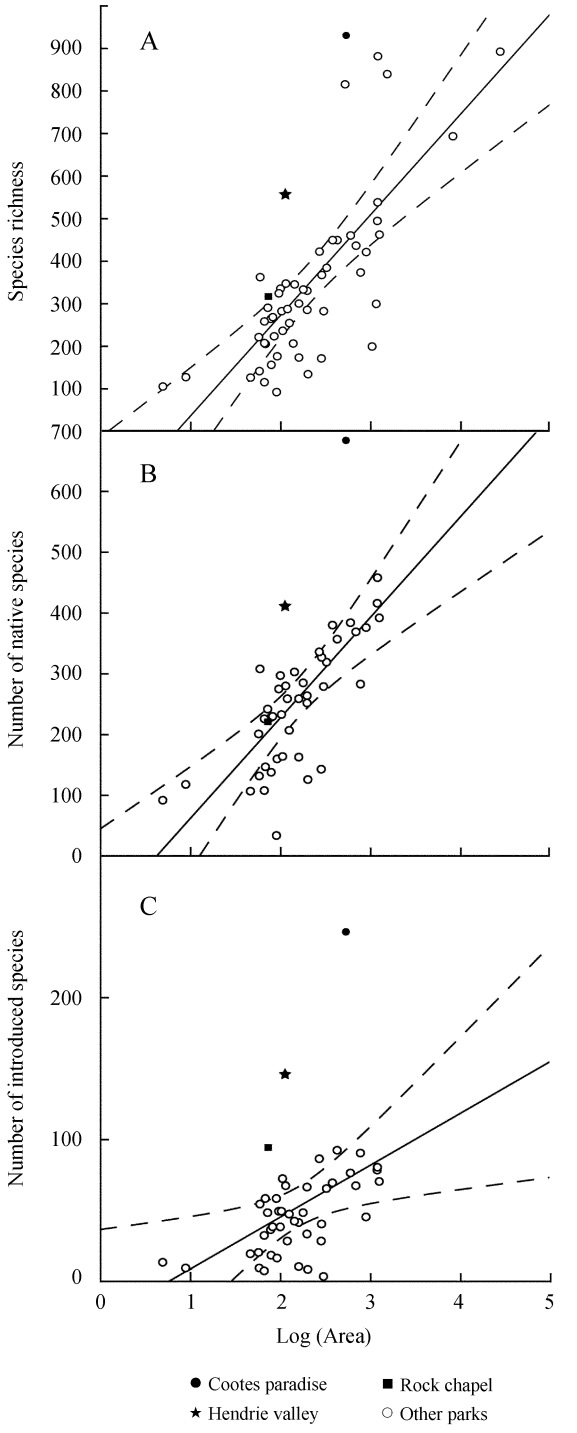

Fig. 3 Relationships between species richness and the area ($\log_{10}$) of parks found in Ontario. A: all vascular plants ($r^2 = 0.514$, $P < 0.0001$). B: native vascular plant species ($r^2 = 0.479$, $P < 0.0001$). C: introduced vascular plant species ($r^2 = 0.192$, $P = 0.001$). The solid lines represent estimated linear regressions; dashed lines are the 95% confidence interval on the regression equations

Discussion

Variation in the number of species found in different geographic areas has been a fundamental focus in ecology (Connor and McCoy, 1979). Two established biogeographic patterns are the species-area relationship and the latitudinal diversity gradient. The species-area relationship refers to the tendency of species richness to increase with increasing area, while the latitudinal diversity gradient describes a decrease in species richness as distance from the equator increases (Qian *et al.*, 2007). These relationships are consistent among different taxonomic groups and geographic areas (Lomolino, 2000; Lyons and Willig, 2002; Hillebrand, 2004).

The nature sanctuaries at Royal Botanical Gardens display greater total vascular species richness, native species richness, and introduced species richness, than expected on the basis of their area. There are several possible explanations for these results, including factors that drive diversity, as well as factors that artificially inflate the relative species richness.

These nature sanctuaries lie at the transition zone between the Deciduous Forest Region and the Great Lakes-St. Lawrence Forest Regions, which may contribute to the high species richness in the area. Due to the topography of the landscape and proximity to Lake Ontario, a wide array of vegetation communities and soil types exist on RBG properties. Habitats such as Carolinian forest, coastal wetland, remnant oak prairie and savannah, cliff and talus slopes are all found at RBG.

Observations of species richness are a function of the habitats sampled and intensity of sampling effort. In addition to the biological and geographic factors influencing RBG's richness, it is quite probable that RBG's nature sanctuaries have been sampled more intensely than the other parks included in this analysis. RBG's Spontaneous Flora is a result of six decades of floristic inventories undertaken by staff botanists and is supported by herbarium vouchers. The frequency and intensity of botanical inventories, as well as the level of botanical skill, likely varied for all other parks. It is likely that most parks considered in this study do not have a full-time botanist on staff.

Species that were found historically within individual protected areas but that may now be locally extinct ("extirpated") were included in this analysis, as there is no practical means of checking the floristic inventories for extirpated species. As a result, relative species richness could be inflated for those areas where extirpation has taken place. It is also difficult to compare total numbers of plants across checklists without examining all of the lists for nomenclatural consistency. The level of botanical expertise employed in floristic inventories, and/or the year that the inventories were conducted could both affect the species reported for a given area.

The sample of parks for which data were available to this study may not be an ideal representation of the diversity in size, shape, and location of protected areas within the Mixed Wood Plain Ecozone. For example, the high concentration of analyzed parks in just two counties (Fig. 1) may have introduced a confounding geographic effect into the species area relationship. In addition, we were unable to attain species checklists or information on species richness for Provincial Parks, and no data could be obtained from parks in close proximity to RBG. A more complete analysis of the relationship of plant species diversity and the areas of protected parks is clearly warranted. Furthermore, more work to document plant species diversity within protected areas is needed to understand these relationships, and guide park development and management. Three of the other parks similar in size to RBG included in the present study (Georgian Bay Islands National Park, Point Pelee National Park and St. Lawrence Islands National Park) also presented higher than expected species richness. At present, Canada does not have a formal process for designating important plant areas, a tool used to raise awareness and promote conservation in some jurisdictions (Plantlife, 2010).

Further research on plant species richness will be important to such efforts.

Introduced plants within RBG's nature sanctuaries account for 29% of the total species richness (36% if all natural land holdings are considered), which is slightly lower than the proportion for the Province of Ontario (33%) (CESCC, 2006). Although introduced species contribute to the overall richness at RBG, they are not the sole cause for RBG presenting the extraordinary species richness demonstrated in the present study. Introduced species richness has been correlated with native species richness, and both are correlated with human settlement and population density (Stohlgren *et al.*, 2006; Pautasso and McKinney, 2007). The diverse land uses that surround RBG's nature sanctuaries may have facilitated plant introduction, particularly given the extensive cultivated gardens managed by RBG.

From our preliminary analysis of species richness-area relationships, it is clear that the more we look, the more we find. New species are still being added to the RBG checklist after decades of intensive botanical research. If the intensity of expert surveys at RBG has yet to produce a comprehensive checklist, the "single season, single botanist checklists" typical for many other reserves have likely overlooked a substantial portion of their floras. Unfortunately, we do not have access to objective quantification of the search effort for most natural areas. However, our experience suggests that the species-effort curve may be as important as the species-area curve in understanding botanical diversity.

Urban botanical gardens, and urban nature reserves generally, can effectively serve as public recreation areas and at the same time protect natural heritage. However, conserving plants in both *in situ* and *ex situ* circumstances within a single institution can be challenging (Galbraith, 2003). Royal Botanical Gardens is located within the economic and population center of Canada. Despite growing pressures to develop new recreation trails and overwhelming demand on existing infrastructure, RBG sanctuaries continue to provide high-quality habitat for dozens of rare and endangered species. Furthermore, ongoing monitoring of the sanctuaries will provide scientists with the data necessary to assess the success of this mission in future.

Botanical gardens such as RBG provide a rare example of high-quality natural habitats that are protected from development and that are also supported by long-term, expert staff capable of documenting year-to-year changes in the flora. As human population increases, climate change accelerates, and introduced plants and animals become more pervasive, this combination of nature preserves and human expertise will be increasingly valuable in monitoring and managing our changing environment.

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Appendix: Checklist of the Spontaneous Flora of Royal Botanical Gardens, Ontario, Canada

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