



*Severity of invasion by invasive plant indicators at Terrestrial
Volunteer Monitoring Program sites 2009 - 2011*

Watershed Monitoring and Reporting Section

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Report prepared by: Theresa McKenzie, Terrestrial Volunteer Coordinator

Reviewed by: Scott Jarvie, Manager, Watershed Monitoring & Reporting Section

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Executive Summary

Alien invasive plant species are an identified threat to the biodiversity and ecological integrity of terrestrial ecosystems in the Toronto region. Ontario-wide, conservation authorities and other agencies have developed lists of invasive species (both flora and fauna) of concern in their regions, and are working on strategies to prioritize activities and methods for reducing their impact. Sharing of information on invasive plants occurs through various agency communication methods, including the Ontario Invasive Plant Council, in which the Toronto and Region Conservation Authority (TRCA) participates. Locally, knowledge of the current distribution and severity of invasion of these plants is needed to inform this work.

Since 2002, the TRCA Terrestrial Volunteer Monitoring Program (TVMP) has operated to collect data on native indicator species at fixed ten-hectare sample sites in natural areas throughout the Toronto region. The program's five-year report (TRCA 2008a) evaluated the condition of the region's terrestrial ecosystem on the basis of native indicator species richness score, and documented the differences found between the urban and rural zones within the region. Native indicator species richness appeared to provide a very good index for ecosystem condition. A gap analysis further determined that the need for regional monitoring of invasive plants could be addressed cost-effectively through the addition of a new set of protocols under the TVMP. Eight high priority invasive plant indicator species were selected, protocols developed, training conducted and monitoring implemented effective summer 2009.

This document summarizes the methods used to objectively score the predicted invasiveness of each indicator, to quantify the severity of invasion by species, and to score overall severity by site. It further reports on results for the 2009 - 2011 period for the region, and its urbanization zones.

The eight invasive species monitored encompass a range of predicted invasiveness from mild (or poorly understood) through extreme. Listed in decreasing order of invasiveness score they are: common buckthorn (*Rhamnus cathartica*), common reed (*Phragmites australis australis*), European frog-bit (*Hydrocharis morsus-ranae*), dog-strangling vine (*Cynanchum rossicum/C. nigrum*), garlic mustard (*Alliaria petiolata*), glossy buckthorn (*Rhamnus frangula*), Himalayan balsam (*Impatiens glandulifera*), and periwinkle (*Vinca minor*).

The survey protocol and subsequent data compilation used a count of the number of occurrences of the species on a site combined with the size of the largest occurrence (patch) to arrive at a severity of invasion score for that species. The scores for all species found on an individual site were then summed and the resulting site severity of

invasion expressed as a percentage of the maximum possible (i.e. were all species to found, with the highest severity of invasion score on the site).

Of the 53 sites surveyed during the period, just one had none of the invasive indicators found. One had 6 of the 8, and the majority of sites (68%) had 3 or 4 represented. Common buckthorn was present on the highest proportion of sites at 92%, and it displayed the highest mean and maximum severity of invasion. Garlic mustard and dog-strangling vine were found at well over one-half of sites, with the distribution of dog-strangling vine being higher in the eastern half of the jurisdiction. Common reed had a similar eastern weighting and was present on one-third of sites. Glossy buckthorn and Himalayan balsam were found at fewer sites and in all cases at lower levels of invasion. Periwinkle, found at seven sites, had severely invaded one. European frog-bit was not present on any site, but was found just outside the boundary of a site in Duffin's marsh at the eastern edge of the region. Appendix C shows the distribution of species and severity scores on a series of maps.

Site severity of invasion was higher in the urban zone than the rural, and also higher in the eastern half of the jurisdiction over the western half. Severity of invasion was lower on sites located in larger patches of natural cover and those in natural cover patches that had a higher habitat quality score under the TRCA's Terrestrial Natural Heritage System Strategy model (TRCA 2007c). Sites located on lands with public access, not surprisingly, exhibited a higher severity of invasion.

An expectation that native indicator species richness would decrease with increasing severity of invasion score was only partially supported by the analysis, being the case in the urbanizing zone, but not the urban or rural zone. The observed east to west differences, which may reflect the path of invasion for at least some of the invasive species, may obscure an urbanization effect. The urbanization zones are oriented primarily south-north from the heavily urban downtown City of Toronto through suburban and urbanizing areas to rural and agricultural lands becoming more prominent northward, particularly close to the northern boundary of the region on the Oak Ridges Moraine, as illustrated on the maps contained in Appendix C.

Interestingly, native species richness actually increased with increasing site severity of invasion in the urban zone of the Don watershed, contrary to the expectation. While it is not possible to conclude as to the cause of this result, it is worthwhile to consider whether there are activities that might result in both higher diversity of native species, and higher severity of invasion, with restoration efforts coming to mind as a possibility. This idea drives a recommendation that management best practices be followed during restoration activities to reduce the likelihood of people inadvertently transporting seeds or plant material of invaders from one location to others. A similar precaution needs to be followed during monitoring work, particularly where the same individuals are visiting multiple sites during the course of their work.

A further activity of concern is the use of members of the public in invasive plant control activities. An event operated to pull garlic mustard, for example, may simply provide disturbed space ideal for germination of the garlic mustard seeds already present in the seed bank, while also causing the spread of seeds as volunteers access, move through and exit the site. Participants are likely to further spread seeds carried on boots and clothing to any additional natural areas they subsequently visit. Improper transport and disposal of the removed plants can further defeat the objective of the exercise.

Public education, directed towards groups that visit multiple natural areas during the course of recreational activities, may also be helpful in reducing the rate at which some of these invaders are spreading, particularly in the interim until effective control methods such as biological agents are in place. Groups such as birders, naturalist clubs, and hiking clubs are generally unaware of individual actions they can and should take to avoid spreading seeds from one natural area to others.

In view of the lack of invasive species monitoring in Southern Ontario, it is recommended that other organizations with a need to inform invasive species management consider a similar monitoring approach to the method herein. The protocols followed under the current program may well be applicable, whether applied to the same invasive indicators or species of higher priority in the region of interest. If similar protocols were followed it would provide an opportunity for comparison between jurisdictions, enhancing the interpretation of findings.

Dog-strangling vine would appear to be a research priority, as its observed invasion severity exceeds what would be predicted on the basis of its known characteristics.

It may also be worthwhile to survey a subset of the TVMP sites for the larger list of priority exotic plants considered invasive in the region, in order to determine whether the presence of one or more of the current indicators, or the site severity of invasion score has predictive value with respect to the presence or severity of invasion by other invasive plants.

The results of the initial phase of invasive plant species monitoring under the TVMP once again demonstrate the value of engaging citizen scientists in the collection of biological data. Critical aspects for success include a study design that maximizes the accuracy of species identification through careful selection of the species to be monitored, training of volunteers and the provision of appropriate field aids. Field protocols and instructions that are easy to follow, combined with repeated survey visits, and long-term volunteer participation help to enhance data quality.

The TRCA TVMP will continue to monitor both invasive plant and native species indicators over the long-term and will report on trends if and as they are recorded.

1.0 Introduction

Alien invasive plant species are an identified threat to the biodiversity and ecological integrity of terrestrial ecosystems in the Toronto region. While exotic species are of concern generally due to their potential to negatively impact native plant and animal communities, they differ considerably in the degree to which they invade and expand through natural areas to become what is considered invasive. Some become naturalized over time. In this situation, they are established and reproduce naturally in the wild, but do not have observable negative impacts on the native communities of which they have become a part, nor do they impact the abundance or continued existence of one or more native species. An invasive species, on the other hand, is an alien that has been observed to have these negative impacts, either within the region of interest or at other locales where it has been introduced. Conservation authorities and other agencies have developed lists of invasive species (both flora and fauna) of concern in their regions, and are working on strategies to prioritize activities and methods for reducing their impact. Local sharing of information on invasive plants occurs through various agency communication methods, including the Ontario Invasive Plant Council, in which the Toronto and Region Conservation Authority (TRCA) participates.

Since 2002, the TRCA Terrestrial Volunteer Monitoring Program (TVMP) has collected presence data for a set of 50 native indicator species at 56 fixed ten-hectare sample sites in natural areas throughout the Toronto region. Earlier reporting (TRCA 2006), described the program rationale, study design, monitoring protocols, the native indicator species monitored, volunteer management, and data quality assurance. The five-year report of monitoring results (TRCA 2008a) evaluated the condition of the Toronto region's terrestrial ecosystem on the basis of native indicator species richness score, documented the differences found between the urban and rural zones within the region, and compared results to predictions of the TRCA Terrestrial Natural Heritage System Strategy (TNHSS) model (TRCA 2007a).

The five-year review indicated that, while native indicator species richness provided a very good index for ecosystem condition, there was also a need for better information on the presence and degree of invasion by priority alien invasive plant species across the region, and recommended that an invasive plant monitoring component be incorporated into the TVM program (TRCA 2008a). Eight invasive plant indicator species were subsequently selected for monitoring from a list of priority species identified by TRCA botanists on the basis of their potential for impact on biodiversity in the region. Additional criteria for selection were: that volunteers could be reliably trained to identify the species, and that it be feasible for them to effectively survey their existing ten hectare sites for the full suite of invasive indicators.

A monitoring protocol was designed both to answer the questions below and to fit within the established program and its schedule of survey visits. The objective was to collect sufficient information on the abundance and distribution of each invader found at a site to arrive at an objective index of site invasion that could be used to evaluate severity of invasion for the region and its urbanization zones.

Monitoring questions:

1. What is the distribution of each of the invasive indicator species within the Toronto regional jurisdiction?
2. To what degree are natural areas in the jurisdiction invaded by each of the invasive indicators and the suite of indicators?
3. Are there differences among urbanization zones or among watersheds with respect to invasion by individual indicators or by the overall suite?
4. Are there other characteristics of monitored sites that have predictive value with respect to the presence of invaders or extent of invasion? In particular do the TRCA TNHSS landscape patch scores (TRCA 2007c) predict invasion severity?
5. Is there a relationship between the severity of invasion by the total set of indicators on a site and native indicator species richness? If so, does this differ between urbanization zones, or watersheds?
6. Do invasiveness characteristics of the selected invasive indicator species predict the observed severity of invasion in the jurisdiction?
7. Are there identifiable temporal trends in either severity of invasion and/or native indicator species richness and, if so, are they related?

Training sessions and support materials were developed and provided to volunteers in 2008/2009, and the protocol was launched during the summer of 2009 (TRCA 2008b).

This document reports on the severity of invasion found on TVMP sites during the 2009 - 2011 period, and the extent to which site severity of invasion varied between urbanization zones in the region. It investigates the potential relationship between severity of invasion and native species richness, and discusses the monitoring results for individual species in relation to their potential for invasive impact as predicted by their invasiveness scores and estimated time since arrival. It further reports on validation of the TRCA TNHSS natural cover patch scoring method, on the basis of monitoring data. As the baseline period for the invasive monitoring component, it does not address the question of trends over time. The first temporal analysis will require between six and eight years of data.

2.0 Methods

2.1 Study Area and Fixed Monitoring Sites

The area monitored encompasses the existing terrestrial ecosystem throughout the nine watersheds of the TRCA jurisdiction. These include Etobicoke Creek, Mimico Creek, Humber River, Don River, Highland Creek, Rouge River, Petticoat Creek, Duffin's Creek and Carruther's Creek, along with Frenchman's Bay, the Toronto Islands and the Lake Ontario waterfront within the jurisdictional boundaries. The total area is approximately 250,000 hectares in size and includes the entire city of Toronto, significant portions of the regional municipalities of York, Durham, and Peel as well as a small area of Mono-Adjala township.

Physiographic features within the region include part of the Oak Ridges Moraine, the morainal south slope, Peel plain, and old Lake Iroquois shoreline.

The Toronto region lies in an ecological transition zone between the Great Lakes-St. Lawrence forest to the north and the Carolinian forest to the south. Terrestrial natural cover is primarily deciduous and mixed forest, interspersed with smaller tracts of wetland, native meadow and Great Lakes coastal habitats (TRCA, 2007). Approximately 61,900 hectares (25%) of the Toronto regional landscape was under natural cover in 2008, as determined by landscape level analysis of aerial photography.

The region is highly urbanized but does have a large zone of rural/agricultural land use, primarily in the north, and a zone in transition from rural to urban land use. Areas not urban as of 2008, but identified in regional official plans as committed for future urban use are referred to as the urbanizing zone in this report. The urbanizing zone occupies 10% of regional area. The rural zone includes lands under rural/agricultural use, whether designated to remain so (i.e. greenbelt), or with undetermined planning status, and makes up 30% of regional area. The urban zone refers to all areas urbanized by 2008, and covers 60% of the total area.

Invasive indicator species monitoring was conducted at the same fixed sites where native indicator species are monitored under the ongoing TVMP (TRCA 2008a) (Figure 1).

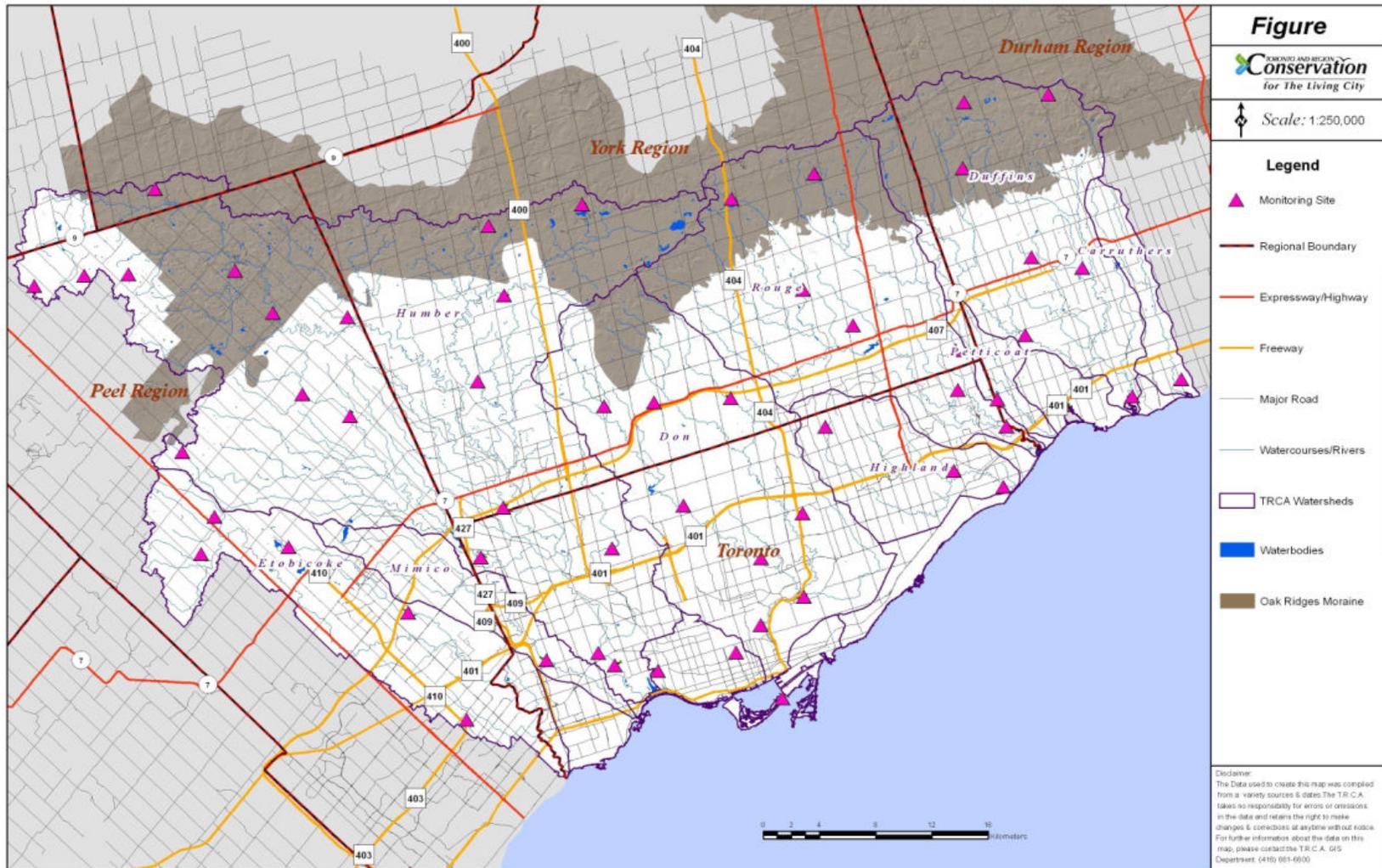


Figure 1: Map of the Toronto region showing the TRCA jurisdiction and the locations of TVMP monitoring sites

2.2 Invasive Indicator Species

The species chosen for monitoring under the TVMP are among the more serious alien plant invaders previously observed within the region, and believed to be spreading, or are species known to be at issue in localities adjacent to the region. In the latter case, an early warning system for arrival of the species is desired.

The eight indicators are:

- garlic mustard (*Alliaria petiolata*)
- dog-strangling vine, also known as swallowwort (*Cynanchum rossicum* & *C. nigrum*)
- common buckthorn (*Rhamnus cathartica*)
- glossy buckthorn (*Rhamnus frangula*)
- Himalayan balsam (*Impatiens glandulifera*)
- common reed (*Phragmites australis australis*)
- periwinkle (*Vinca minor*)
- European frog-bit (*Hydrocharis morsus-ranae*)

In the case of dog-strangling vine, occurrences within the TRCA jurisdiction are overwhelmingly of *Cynanchum rossicum*, although at least one occurrence of *C. nigrum* has been found in the past (TRCA, 2008b). Because these two species are very difficult to distinguish from each other when not in bloom, they are monitored as a single indicator and the species identification noted where possible.

Recognizing that alien plant species exist along a continuum of invasiveness (Farnsworth and Meyerson 2003, Ortega and Pearson 2005, and others), a method by which the invasiveness of the indicators selected could be objectively scored was desired. A literature search revealed an "Index of Alien Impact" method applicable to our needs that had been developed and applied by Magee *et al.* (2010). With one modification, the "Ecological traits used in assigning the Invasiveness Score (I)" presented by Magee *et al.* (2010) (Table 1), were used to calculate an invasiveness score for each of the indicator species selected. Information on the traits used to score individual species was obtained from NatureServe (NatureServe.org, 2009), combined with local expert knowledge. The resulting scores (Table 2) are in general agreement with the subjective ratings applied by NatureServe, while being more "transparent/reproducible, and easily revised should new information become available for a species", as Magee *et al.* (2010) point out.

Table 1: Ecological traits used in assigning the Invasiveness Score (I), (adapted from Magee *et al.* 2010)

Life history (n = 9)	Ecological amplitude (n = 8)	Ecosystem alteration (n = 6)
Strongly clonal —perennials able to spread aggressively via features such as rhizomes, tillers, or stolons	Drought tolerant —described as drought or xeric adapted, growing in dry soil or in rangeland habitat, or where annual precipitation < 50cm	Alters hydrology —changes flooding patterns; raises or lowers water table or surface water levels; changes seasonal availability of water in rooting zone
Large propagule crop —1,000 seeds/plant or 1,000 seeds/m ² , classified as prolific or high seed producers	Wide moisture regime —described as growing in conditions that range from xeric to saturated, xeric to mesic, or mesic to saturated	Alters nutrient cycling —depletes or adds nutrients, alters nutrient cycling patterns
Small seeds/fruits —<5 mm in longest dimension	Flooding/saturation tolerant —described as growing in wet conditions, or adapted to intermittent flooding	Alters soil stability —either facilitates erosion or enhances stability
Wind dispersal —presence of specialized structures or traits that facilitate movement in wind, and observation of movement in wind	Wide nutrient or soil texture ranges —described as growing on a wide range of soil types, or across low to high nutrient ranges	Excretes salts or toxins —produces salts or toxins that are known or suspected to alter soil chemistry or act as allelopathic compounds
Animal dispersal —presence of specialized structures or traits that facilitate attachment, survives consumption and excretion by animals	Wide light regime —described as shade tolerant or able to grow under multiple light conditions, e.g., from bright sun to partial or deep shade	Forms monocultures or near-monocultures —forms dense patches, excludes other species
Water dispersal —observation of floating or long distance water dispersal or seed or plant fragments	Alkaline or saline tolerant —documented as salt tolerant, or growing in alkaline soils, saline soils, or coastal habitats	Invades in absence of human disturbance - able to establish and spread into relatively intact natural vegetation
Specialized dispersal —unique dispersal traits such as explosive dehiscence, tumbling of seed laden dead plants	Grazing tolerant or increaser —documented as resilient to direct grazing impacts; increases with grazing due to low palatability, to toxicity, or release from competition	
Dispersal over time —Persistent seed bank, long seed life, staggered germination, staggered dispersal from inflorescence	Increases post-fire or other vegetation-clearing disturbance —able to expand aerial coverage and biomass following disturbance	
Plasticity —high morphological, phenological, or genetic variability		

As Magee *et al.* (2010) suggest, the scoring of ecosystem alteration traits was modified to better fit the local region. Natural fire regimes have been virtually eliminated by the human population in the region so that fire is no longer a primary driver of ecosystem alteration in our, already highly altered, system. Fire was therefore not included as a scoring criterion. The formula below was adapted from Magee *et al.* (2010) and applied to calculate the Invasiveness score (I):

$$\text{Invasiveness score} = \frac{\sum \text{life history} + \sum \text{eco amplitude} + (\sum \text{eco alteration})^2}{\text{trait maximum}} \times 100$$

The invasive plant indicators had resulting invasive impact scores from 15 to 89 on a 0 to 100 scale (Table 2), representing levels from weak or poorly understood, through extremely aggressive.

The invasive indicators were selected subjectively for monitoring based on expert opinion of priority, and project feasibility, prior to application of the Magee *et al.* (2010) method. The fact that they were subsequently found to encompass a wide range of the Magee *et al.* invasiveness scale, supports the utility of their application as a set of invasive indicators under the monitoring program.

Table 2: Invasiveness scores for TVMP invasive indicators (method adapted from Magee *et al.* 2010)

Invasive Indicator Species	Invasiveness Impact score (0 – 100)	Corresponding Level of invasiveness
common buckthorn, <i>Rhamnus cathartica</i>	89	extreme
common reed, <i>Phragmites australis australis</i>	72	extreme
European frog-bit, <i>Hydrocharis morsus-ranae</i>	43	aggressive
dog-strangling vine, <i>Cynanchum rossicum</i> / <i>C. nigrum</i>	38	aggressive
garlic mustard, <i>Alliaria petiolata</i>	36	strong
glossy buckthorn, <i>Rhamnus frangula</i>	21	moderate
Himalayan balsam, <i>Impatiens glandulifera</i>	19	moderate
periwinkle, <i>Vinca minor</i>	15	weak/poorly understood

2.3 Survey method

The invasive monitoring protocol includes two annual site surveys, each two hours in duration, the first completed during the month of July and the second during August. The trained volunteer searches the entire site for each of the eight invasive indicator species. For each species found, the number of occurrences (patches) on the site are recorded in one of four categories: few or scattered individual plants, fewer than 5 patches (i.e. areas of dominance), 5 to 10 patches, or greater than 10 patches. In addition, the estimated size of the largest patch found is recorded in one of three categories: less than 100 square metres, greater than 100 square metres, but less than 1 hectare, or greater than 1 hectare. Finally, if the volunteer conducting the survey is the same volunteer who conducted the previous year's invasive species survey, they are asked to record a subjective observation as to whether the species has increased, decreased or remained the same with respect to its cover on the site.

2.4 Data management and analysis

Invasive indicator data have been maintained in an Excel spreadsheet (currently migrating to an MS Access database), while the native indicator species data is held in an MS Access database. Statistical analyses were carried out using JMP 7.02, SAS Institute Inc. software (SAS 2007), with alpha of 0.05 as the threshold for significance.

Species and Site Severity of Invasion Scoring

The categories for # occurrences and size of largest patch recorded during the surveys were converted to ordinal scores as shown in table 3. The scores were further combined to calculate a severity of invasion score for each species found on a site, and an overall site severity of invasion score by using the following formulas:

Species severity of invasion = # occurrences score X largest patch size score

Site severity of invasion = $\frac{\sum \text{species severity of invasion scores}}{\text{maximum } \sum \text{species severity of invasion}} \times 100$

The resulting site severity of invasion scores are listed in Appendix A.

For the current analysis, the annual site severity of invasion scores were averaged and the resulting 3 year mean was used.

Table 3: Ordinal scoring of abundance, and size of largest occurrence, for invasive indicator species surveyed during a monitoring visit

Number of occurrences		Size of largest occurrence (patch)	
Score	# occurrences observed	Score	Patch size estimate
0	Species not found	0	Species not found
1	Few or scattered individuals	1	< 100 m ²
2	< 5 patches	2	> 100 m ² < 1 ha.
3	5 - 10 patches	3	> 1 ha.
4	> 10 patches		

Native Indicator Species Richness Scoring

All vascular plants and vertebrate animals native to the Toronto region are scored on a set of ecological sensitivity, habitat requirement and abundance criteria by TRCA biologists in order to assign local ranks of conservation concern. The method is designed to enhance the ability to recognize species of regional concern before they have become rare, such that conservation action has better prospects for success over efforts directed at rare species alone.

Flora are scored using four criteria: local occurrence, population trend, habitat dependence, and sensitivity to impacts associated with development. Fauna are scored on seven criteria: local occurrence, local population trend, continent-wide population trend, habitat dependence, sensitivity to development, area-sensitivity, and patch isolation sensitivity.

The total scores are grouped by range into a set of five local ranks, referred to as L ranks. The highest level of conservation concern is represented as L1, with L1 through L3 ranked species designated as Species of Conservation Concern for the Toronto region. Species ranked L4 are considered of concern in the urban and urbanizing zones, and those ranked L5 are considered to be secure regionally. Additional information on the scoring and ranking rationale and methodology can be found in the document entitled *Vegetation community and species ranking and scoring method* (TRCA 2010).

The TVMP native indicator set includes 44 flora and fauna species encompassing a wide range of total scores, corresponding to ranks of L2 through L5, in addition to six lichen species. While lichens are known to vary in their sensitivity to various urban-related impacts, they have not as yet been scored for the Toronto region. Appendix B lists the native indicator species monitored under the TVMP along with their total scores and L ranks.

Previous reporting (TRCA 2008a) discussed the differences found between native indicator flora and native indicator fauna with respect to their likelihood of presence on sites in the urban versus the rural zones in the region. Because fauna species more quickly disappear from sites impacted by disturbance than do flora of a similar rank, they can be considered more sensitive indicators from a monitoring perspective. For this reason, the native indicator species richness calculation used herein assigns a doubled weighting for fauna indicators found as compared to flora indicators. Native indicator species richness for each of the TVM sites is calculated as the sum of the weighted total scores for native indicator species present on the site for the period under analysis, divided by the maximum score possible (i.e. were all the native indicators to be present on a site), resulting in a possible range of scores from 0 – 100.

Appendix B displays the weighted score used in the species richness calculation for each of the native indicator species. The method provides differentiation between sites with equal numbers of native indicator species, but differing proportions of flora/fauna and levels of conservation concern. By doing so, it enhances the utility of the score for evaluating ecosystem condition across the region and for comparison of land-use zones.

3.0 Results

3.1 Invasive indicator severity of invasion

Fifty-three of the 56 TVMP sites were surveyed for the invasive indicators during the 2009 – 2011 period. One site had none of the invasive plant indicators found, and one had 6 of the 8. The majority of sites (68%) had 3 or 4 species represented (Figure 2), with common buckthorn, garlic mustard and dog-strangling vine the most commonly encountered. European frog-bit, while not found within any TVMP sites during this period, was observed just outside a site boundary in 2009, representing the first observation record in the TRCA jurisdiction. It was reported at the same location in both 2010 and 2011.

The species severity of invasion scores encompassed the full range possible, from 0 to 12 (Table 4). Appendix C contains a set of maps displaying the regional distribution and severity score range for each of the invasive species found.

Common buckthorn was present on the highest proportion of sites at 92%. It also displayed the highest mean and maximum severity of invasion score and was distributed throughout the jurisdiction. Garlic mustard and dog-strangling vine were

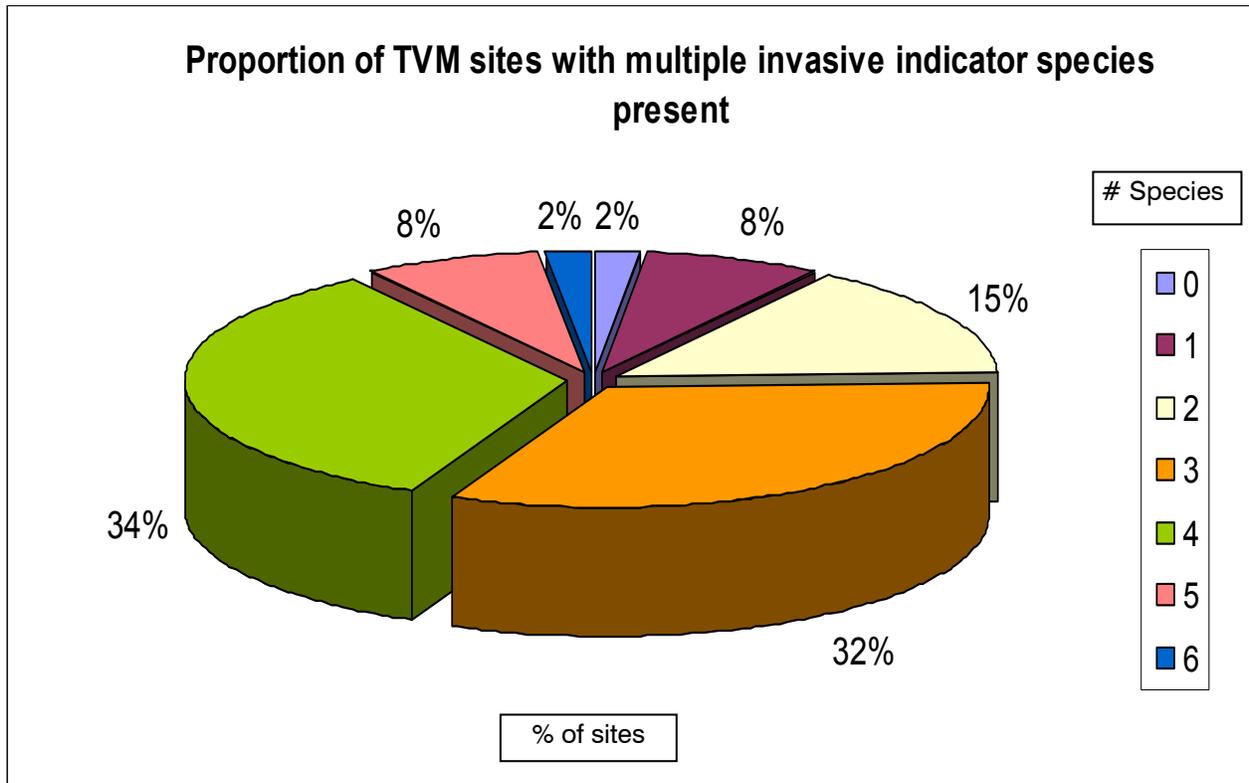


Figure 2: Proportion of TVMP sites with multiple invasive indicator species

found at well over half of the sites, at a similar level of invasion. The distribution of dog-strangling vine was higher in the eastern half of the region. Common reed was found at one-third of sites, again having a distribution weighted towards the east. Glossy buckthorn and Himalayan balsam were found at a smaller proportion of sites, and in all cases at lower invasion levels. Periwinkle, while found at just seven sites, was a serious invader at one. It had been recorded at this location prior to the beginning of the systematic invasive species monitoring and has been expanding in extent since that time. During the 2009 – 2011 period, its severity of invasion score increased from 6 to the maximum score of 12.

Four watersheds had sufficient data for analysis: the Humber, Don and Rouge Rivers, and Duffin's Creek.

No significant differences were evident by land-use zone for severity of invasion by individual species. By watershed, one difference was evident. Dog-strangling vine scores were lower in the Humber than in the Don watershed, while not significantly different between other pairings (ANOVA, Tukey-Kramer test). Neither common buckthorn, nor garlic mustard showed differences between watersheds.

Table 4: Invasive indicator species found on TVMP sites 2009 – 2011, with proportion of sites invaded (n=53), mean and maximum severity of invasion scores.

Common name	Scientific name	% of Sites invaded	Severity scores (scale 0 – 12)	
			Mean	Maximum
common buckthorn	<i>Rhamnus cathartica</i>	92%	5.6	12
garlic mustard	<i>Alliaria petiolata</i>	83%	4.8	12
dog-strangling vine	<i>Cynanchum rossicum/ C. nigrum</i>	64%	5.7	12
common reed	<i>Phragmites australis australis</i>	32%	3.6	8
glossy buckthorn	<i>Rhamnus frangula</i>	21%	3.6	8
Himalayan balsam	<i>Impatiens glandulifera</i>	15%	2.6	8
periwinkle	<i>Vinca minor</i>	13%	5.1	12

Regionally, the site invasion severity scores for the period ranged from 0 to 31, with a regional mean of 13.5. When summarized by land-use zone, urban sites were significantly more highly invaded than rural, while the urbanizing zone scores were similar to urban zone scores (Table 5). When sites were divided into east and west groups, sites in the eastern half of the region (n=27) showed significantly higher invasion (p=0.05) than those in the western half (n=26). There was no significant difference between watersheds with respect to site severity of invasion.

Table 5: Summary of site severity of invasion mean scores for TVMP sites 2009 – 2011 for the Toronto region and 3 land-use zones

Zone	N	Score Range	Score Mean	Significant Difference	
Region	53	0 - 31	13.5		
Rural (R)	24	0 - 24	10.4	R from U, yes, p=0.01	R from Uz, yes, p=0.04
Urban (U)	21	4 - 31	15.8	U from Uz, no, p=0.82	
Urbanizing (Uz)	8	6 - 26	16.5		

3.2 Site severity of invasion score in relation to site characteristics

Site characteristics, including the size of the natural cover patch on which the site is located, distance to the nearest road, road density (km of road within 2 km radius of site centroid), total patch score and matrix influence score were documented in the previous program monitoring report (TRCA 2008a). Relevant site characteristics are reproduced in Appendix A herein.

Characteristics which might be expected to have predictive value with respect to site scores were investigated for correlation with them. Several characteristics that were earlier reported to increase with site condition (ecological integrity) (TRCA 2008a), showed a negative correlation with the site severity of invasion results. Total patch score ($p=0.01$, Figure 3), matrix influence score ($p=0.02$), and road density ($p=0.02$) were all significantly correlated at the 95% confidence level. Size of natural cover patch ($p=0.07$) and distance to nearest road ($p=0.09$) were not significant at that threshold, but were at a 90% confidence level.

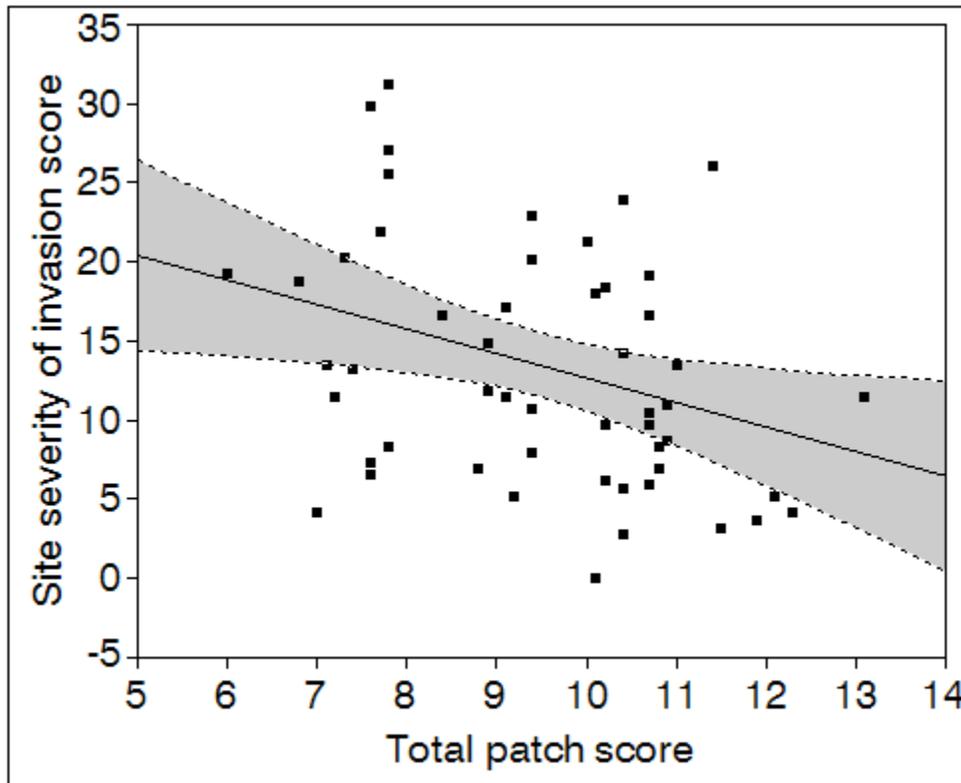


Figure 3: Total patch score versus site severity of invasion ($p=0.01$). Shaded area reflects 95% confidence interval.

An additional characteristic considered was whether the monitored site had open public access (n=34) or did not (n=19). Sites with access to the general public had a higher site invasion score (mean=14.9) versus those without (mean=10.9). The difference was not significant at a 95% confidence level, but was at 90% (p=0.07).

3.3 Native indicator species richness in relation to severity of invasion

Native indicator species data collection was completed on 52 of the 53 TVMP sites that had invasive species data for the 2009 – 2011 period. Species richness scores ranged from 7.0 to 65.3 regionally, with a mean of 29.6. There was a significant difference between the urban zone mean of 22.8, and the rural mean at 34.8. The urbanizing zone was intermediate between the two at 32.4 and not significantly different from either. The rural zone had an outlier value of 65.3, with the next highest value being 48.6. When the outlier was excluded, the resulting rural zone mean was 33.4. The difference between the rural and urban zones remained significant while the difference between the urbanizing zone and urban zone reached the significance threshold. The outlier was not an error, but rather a site that is unique with respect to the high quality of its habitat relative to the balance of the rural zone and the region as a whole.

When grouped by watershed, analysis of variance showed a significant difference in species richness score between the Humber and Don at a 95% confidence level. However, exclusion of the rural zone outlier, which is located in the Humber watershed, resulted in no significant differences among watersheds. Appendix D illustrates the geographical distribution of native species richness scores.

There was no statistical support for a correlation between native species richness and site severity of invasion at the regional level, nor within the urban or rural zones. In the urbanizing zone however, a negative correlation was significant (Figure 4).

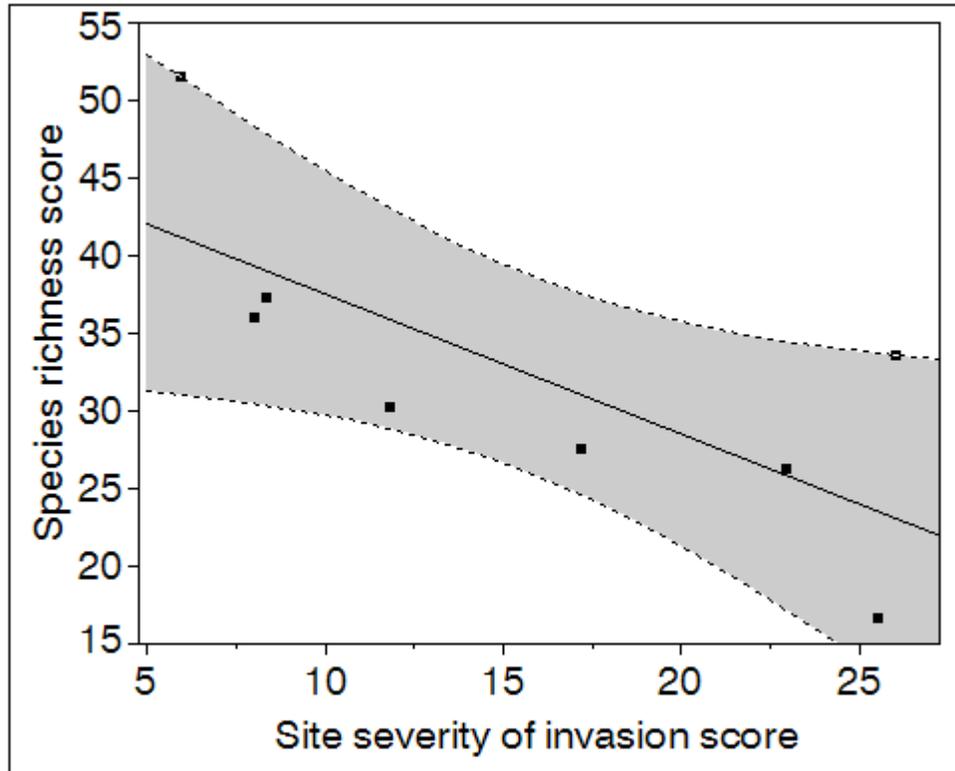


Figure 4: Native species richness versus site severity of invasion at TVM sites in the urbanizing zone ($R=-0.56$, $p=0.034$).

The linear regression of species richness score on site severity of invasion score in the urban zone was interesting in that it suggested a weak positive relationship, although it was not significant ($R^2=0.11$, $p=0.15$).

In the Don watershed, all TVMP sites are located in land-use areas designated urban. Here, native species richness scores were from 7.0 to 43.3 with a mean of 21.3, and native species richness significantly increased with increasing site severity of invasion score (figure 5). Correlation and linear regression analysis for the urban zone in the Humber watershed, with just 4 sites, was inconclusive ($p=0.57$).

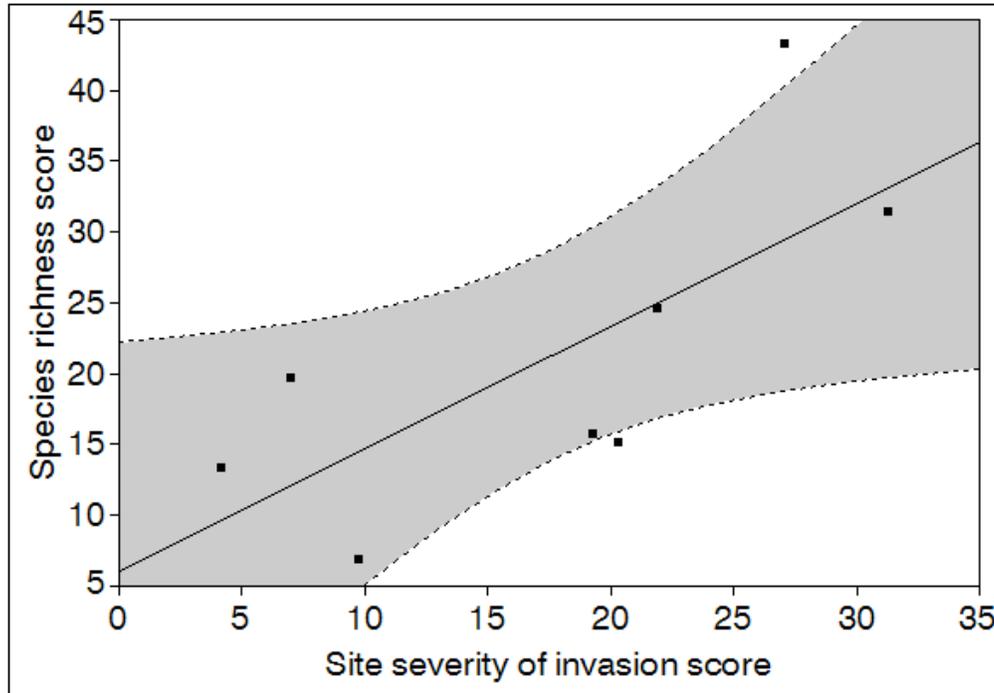


Figure 5: Native species richness versus site severity of invasion in the Don watershed, Urban zone (n=8, $R^2 = 0.53$, $p=0.047$)

The Humber watershed was analyzed both including and excluding the aforementioned outlier. A significant negative correlation of native species richness with site invasion severity score resulted in both cases for the watershed as a whole (Figure 6), while a similar trend in its rural zone was not significant ($p=0.15$, Figure 7).

The Duffin's and Rouge watersheds showed no evidence of a relationship between native species richness score and site severity of invasion score. Both had small data sets (n=6, n=7 respectively). Etobicoke, Mimico, Petticoat, Carruther's and Highland Creek watersheds had insufficient data for analysis by watershed.

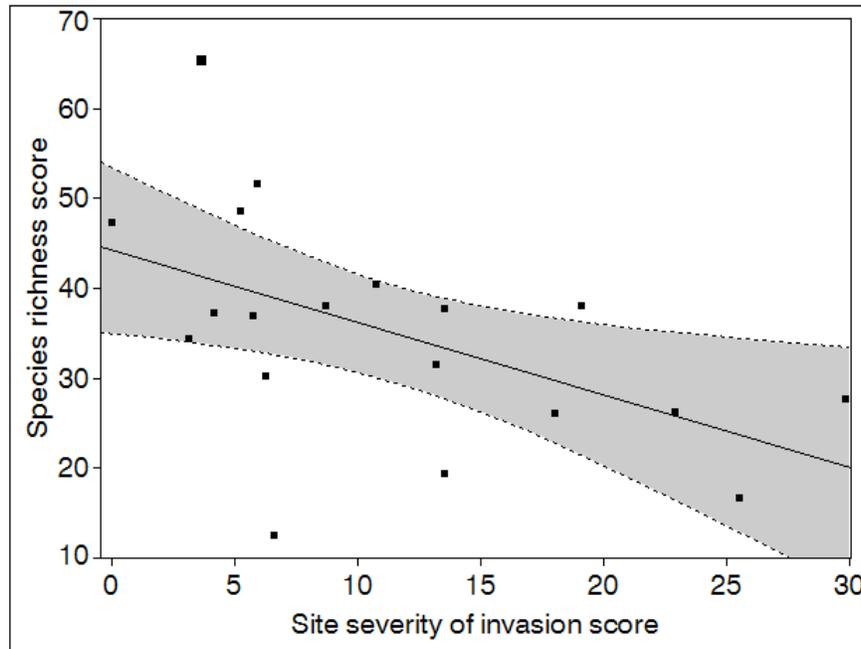


Figure 6: Native species richness versus site severity of invasion in the Humber watershed, (n=19, $R^2=0.29$, $p=0.02$)

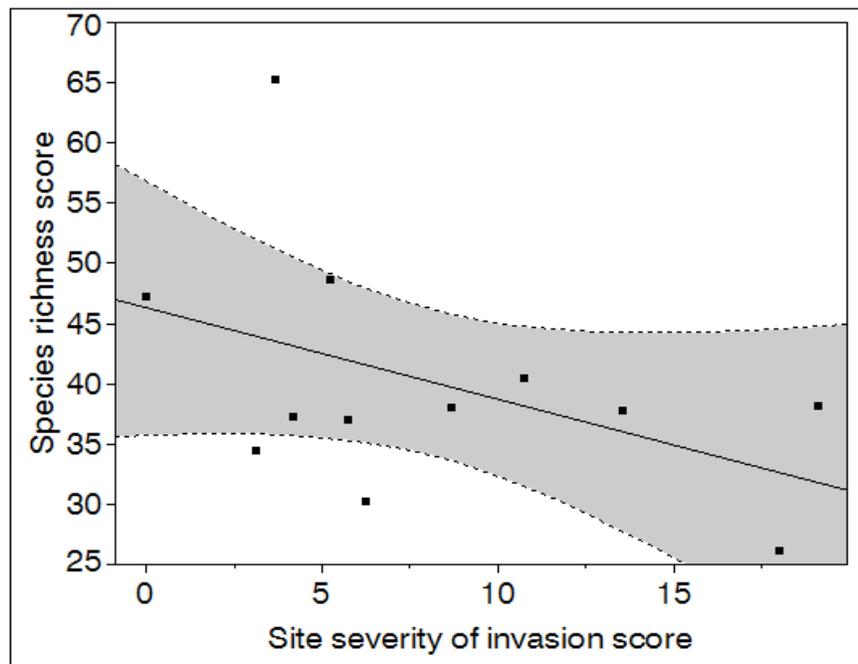


Figure 7: Native species richness versus site severity of invasion in the Humber watershed, rural zone (n=12, $p=0.15$)

3.4 Regional invasion by individual species in relation to invasiveness

Regional invasion for each invasive indicator was calculated as the product of the proportion of sites invaded and the mean severity of invasion score. Predicted relative regional invasion was estimated as the product of the invasiveness score and the estimated time since arrival in centuries (Table 6). The prediction was then tested for correlation with actual results to determine if the latter measure might provide predictive value for other alien plant species for which the biology and time since arrival are known. A literature search provided sufficient information to roughly estimate time since arrival in North America, but not necessarily arrival in the Toronto region. For consistency, the North American arrival year was used in the calculation, even in the case of European frog-bit, where just one population has so far been identified locally, near the eastern extremity of the region. Estimates for some species are undoubtedly better than for others. Nevertheless, and in spite of the fact that there were differences in species ranks between observed and predicted, this coarse relative prediction did correlate with the observed results for our indicators. A linear regression was significant ($R^2=0.58$, $p=0.03$) (Figure 8).

Table 6: Regional invasion and predicted relative invasion for invasive species monitored 2009 – 2011

Common name	% of Sites invaded (n=53) (a)	Mean severity score (b)	Regional Invasion score (a x b)	Rank	Invasiveness Score (c)	Time since arrival (centuries) (d)	Predicted Relative Invasion (c x d)	Rank
common buckthorn	92%	5.6	5.2	1	89	1.61	143.3	1
garlic mustard	83%	4.8	4.0	2	36	1.32	47.5	3
dog-strangling vine	64%	5.7	3.6	3	38	1.09	41.4	4
common reed	32%	3.6	1.2	4	72	0.71	51.1	2
glossy buckthorn	21%	3.6	0.8	5	21	0.91	19.1	7
periwinkle	13%	5.1	0.7	6	15	2.11	31.7	5
Himalayan balsam	15%	2.6	0.4	7	19	0.61	11.6	8
European frog-bit	0%	0	0.0	8	43	0.72	31.0	6

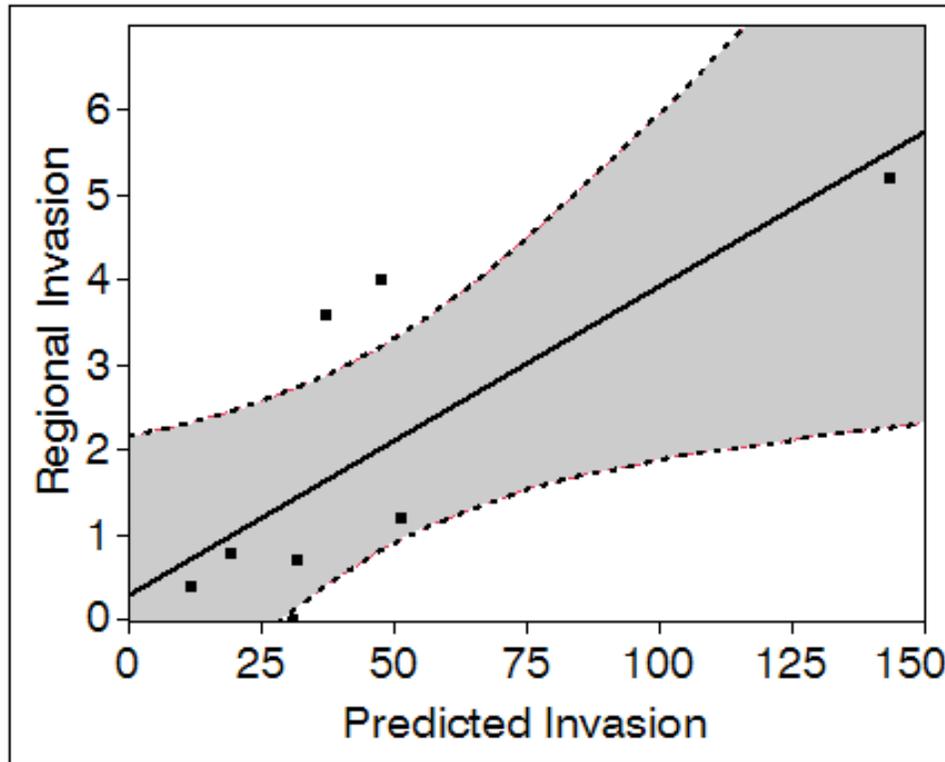


Figure 8: Relative regional invasion versus predicted relative invasion for monitored indicators in the Toronto region

4.0 Discussion

Clearly, several of the invasive indicator plants are already well established throughout the Toronto region. This result was expected and is in agreement with observations made by TRCA botanists and others during biological inventory work. However, the extent of the invasion on some sites was higher than anticipated, particularly when considered as a proportion of the total site area. The number of sites on which one or more invasive species were estimated to have dominance occurrences at a cover exceeding 1 hectare, or 10% of the site, is a cause for concern. The top three ranking species for number of sites invaded, i.e. common buckthorn, garlic mustard and dog-strangling vine, also reached this maximum category for extent, while periwinkle, less frequently encountered, was able to expand to this level at one site, invading an L2 swamp vegetation community of concern (TRCA 2009a).

The TRCA Terrestrial Natural Heritage System Strategy aims to increase natural cover to 30% of land area in the region over an extended timeframe (TRCA 2007a).

Quantification of the existing natural system has not previously adjusted for invasive cover due to a lack of data on which to base estimates. The results presented herein provide a basis for a conservative estimate of minimum system invasion to be derived, and taken in to account when re-quantifying the total area considered to be natural cover (TRCA 2007c).

The site severity of invasion scores are most useful in a relative sense, since they account only for the invaders selected as indicators, providing no information on other invasive species that may be present on sites. The difference shown in these scores between urbanization zones was as expected, with the presence and extent of invasion by alien species being directly related to human presence and activity.

An expectation that site severity of invasion scores would be inversely related to native indicator species richness was not supported by the analysis for the overall region, nor for its urban or rural zones, although it was in the urbanizing zone. There are likely multiple factors affecting this result. A review of the regional distribution of site invasion severity (Appendix D) shows a weighting towards the eastern half of the jurisdiction, which may reflect the path of invasion, at least for some of the species. Species richness scores showed no difference when similarly grouped, while they did exhibit significant differences by urbanization zone. An east-west pattern for invasion would tend to obscure an urbanization effect, if present, since the urbanization zones are oriented primarily along a north-south gradient.

The urbanizing zone was the only one where native species richness score decreased with increasing site invasion score. Perhaps here, invaders are able to capitalize on niche gaps as sensitive native species decline in response to a combination of urbanization impacts, and we are seeing this as it occurs. Rapid expansion of invasive species in this case would then be expected to exert a further impact on native species. Much of the urbanizing zone's natural cover is currently in the form of meadows, so it may also be the case that the impact of invaders on native species is simply greater or more apparent in communities at this earlier stage of succession.

The analysis by watershed was conducted in an effort to control for the east-west effect by providing a series of functional north-south subsets across the east-west axis. Insufficient data hampered the investigation for smaller watersheds, but the results for the Don and Humber watersheds are interesting. The increase in native species richness with increasing site severity of invasion in the Don watershed's urban zone is counterintuitive. The time since human settlement is longest here, suggesting that time since invasion may be similarly longer for at least some of the invaders. Further, the native species richness scores are at the low end of the range here. Perhaps the native indicators that remain are those able to co-exist with the invasive indicators monitored, (possibly species which have adapted to co-exist with them over the longer timeframe of invasion here), while species more sensitive to them have already been lost from the

habitat in this zone. It could be argued that invasive plant species may provide some level of habitat for native species on sites where more sensitive flora have already been lost, although it is difficult to suggest examples from the invasive plant and native indicator species monitored where this would appear likely. Rather, other studies and TRCA biologists' experience suggests that we are unlikely to find scarlet tanagers or ovenbirds nesting in common buckthorn forest for example, or Virginia rails in common reed dominated marshes, although swamp sparrows may be found there (Conover 2011, Meyer 2003, TRCA unpublished data). Perhaps it is simply a matter of the overall availability of habitat in the local landscape. Marginal habitat in a landscape that is not habitat-limited is likely to remain unoccupied, while native species preferentially occupy the higher quality habitat. However, in a habitat-limited landscape, marginal habitat containing invasives may be used by those native species that can do so. The Don watershed, having just 9% natural cover, is more likely to be habitat-limited from the perspective of the native indicators than the Humber at 22% or Duffin's at 29%. Further, the TVMP data establishes the presence of the native indicators, but not the degree of breeding success they experience. Longer term data collection and analysis will provide the opportunity to investigate the degree to which the native indicators found are able to persist in coincidence with large populations of invasive species.

If invasive plant severity of invasion increases with regular human activity, as suggested by the higher severity on sites with public access, then we should also consider whether there is human activity occurring on these Don watershed urban sites which might result in both an increase in native indicator species richness, and severity of invasion. A variety of restoration activities such as tree-planting, habitat creation and the like come to mind. It is possible that these activities, while planned and executed to directly enhance native biodiversity, may indirectly also import invasive plants to the site. One activity of concern is the use of members of the public in invasive plant control activities. An event operated to pull garlic mustard, for example, may simply provide disturbed space ideal for germination of the garlic mustard seeds already present in the seed bank, while also causing the spread of seeds as volunteers access, move through and exit the site. Participants are likely to further spread seeds carried on footwear and clothing to any additional natural areas they subsequently visit. Improper transport and disposal of the removed plants can further defeat the objective of the exercise.

It is also possible that other biotic and abiotic factors in these urban locations having a history of various types of disturbance, are acting separately on native and non-native species. Matthews *et al.* (2009) investigated relationships between native and non-native species richness as well as the dominance of non-natives in restored wetlands in Illinois. They found that large restoration sites located closer to the city of Chicago had both higher native and non-native species richness, and presumed that this was related to a high degree of propagule-pressure (input of seeds of a variety of plants) combined with a disturbed site on which these plants could establish. Total cover by non-natives,

however, increased with nitrogen availability, whereas native species richness decreased with increasing soil nitrogen and urbanization in the surrounding landscape.

Whether the ability of specific native indicators to persist on urban-influenced TVMP sites is related to pre-existing characteristics of the species, to long association with invaders driving adaptation, or to some combination of the two, is an interesting question that deserves further study, especially in view of the fact that previous work investigating the relationship between alien plant invasion and plant community species richness has delivered mixed results (Rooney *et al.* 2004, Hejda *et al.* 2009, and others). Most of the published work considers the response of the native plant community to alien plant invaders, although there are a few that investigate the use of alien plants by fauna species (Maerz *et al.* 2005, Conover 2011). Some authors have concluded that the relationship between non-native flora presence and site flora species richness is scale-dependent (Powell *et al.* 2011, Hejda *et al.* 2009, Chen *et al.* 2010). The TRCA monitoring results are unusual in that they report on invasion at a regional scale, and consider the response of both flora and fauna indicators, providing a valuable data set that could perhaps be used in considering this question further. The TRCA data have the additional value of incorporating pre-determined scores and L ranks for native indicators that summarize their observed sensitivity to urbanization-related disturbance over time, along with objectively determined invasiveness scores for the invasive indicators. Both enhance the analysis and ability to interpret results.

The Terrestrial Volunteer Monitoring Program was implemented in part to provide the ability to test Terrestrial Natural Heritage System Strategy (TNHSS) model validity using regional biodiversity data. Previous reporting (TRCA 2008a) found good agreement with model predictions, indicating that the landscape analysis' patch total score was a good index for ecological integrity, since it demonstrated a strong and significant correlation with native indicator species richness, fauna species of conservation concern richness and forest/wetland habitat guild richness. The total patch score incorporates "matrix influence", an index designed to encompass all of the positive and negative effects exerted on the natural cover patch by land-use in the surrounding area. The inverse correlation of site severity of invasion score with both patch total score, and matrix influence score found herein once again supports the validity of the quality of cover scores used in the TNHSS modelling work (TRCA 2007a, 2007b).

The comparison of the relative regional invasion scores observed for the invasive indicators to a relative invasion predicted on the basis of each species invasiveness score and estimated time since arrival is encouraging. More accurate time since arrival data is clearly desirable for the prediction estimate, and certainly better accuracy is likely available in the case of exotic species discovered more recently. Application of the Magee. *et al.* (2010) method to score new exotic species of concern would allow comparisons to be made and rankings to be arrived at in order to inform management prioritization. Where the scoring does not appear to match the observed invasion

progress, i.e. a species is clearly invading much more quickly than its invasiveness score would suggest, the resulting "red flag" would indicate a research priority. Such may be the case with dog-strangling vine. Its invasiveness score of 38 belies the speed with which it is invading the Toronto region, and the degree to which it is able to dominate in quite large patches. Kricsfalussy & Miller (2010) suggest that this species may have as yet undetermined characteristics, such as the production of allelopathic compounds, that might explain the observed aggressive invasiveness. The monitoring data presented herein show it ranked number 3 in observed regional invasion versus a prediction of a rank of 4. Referring to the map of its distribution in the region (Appendix C), the concern is increased since its level of invasion in the eastern half of the jurisdiction is clearly higher than the regional invasion number would suggest. If this distribution simply reflects the path of invasion, rather than differences in physiographic or climatic conditions east to west, then future prospects for invasion across the region by this species would appear dire. The Kricsfalussy & Miller (2010) paper reviews physiographic and climate variables in the species' home range (Ukraine and eastern Russia) as well as its new North American range. They find the species to exhibit a high degree of plasticity, with the ability to colonize a much wider range of conditions in the new range over the native one.

Common reed was observed at a lower level of invasion rank than the prediction. This result may be partly an artifact of its being a wetland species while some of the TVMP sites monitored do not have a significant area of wetland. However, qualitative observations also indicate that where it is observed to be very abundant in wet roadside ditches in the vicinity of volunteer sites, it is often not observed in wetland within the site that is not adjacent to a road. This may reflect a path of invasion along roadsides. However it may also reflect differences in conditions between roadside ditches and natural wetlands in our region. Clearly there are many aspects which will differ. One that should be investigated further is the level of salt contamination in the wet areas. Common reed is a salt tolerant species (Jodoin *et al.* 2008) and this tolerance may provide it an advantage over native wetland plants in areas close to roads that are regularly salted in winter. Stream water quality monitoring in the Toronto region has documented high chloride (salt) concentrations, well above the natural background level expected (TRCA 2009b), indicating that road salt is being transported in surface waters to natural areas. If this contamination extends into wetlands, common reed may gain a further advantage over native wetland species not adapted to saline conditions.

European frog-bit was observed at a lower rank than the prediction. However in this case, the time since arrival used for consistency is indeed inaccurate with respect to time of arrival in the Toronto region. It is a quite recent arrival and remains a high priority concern for the region.

5.0 Conclusion & Recommendations

The results of the initial phase of invasive plant species monitoring under the TVMP once again demonstrate the value of engaging citizen scientists in the collection of biological data. Critical aspects for success include a study design that maximizes the accuracy of species identification through careful selection of the species to be monitored, training of volunteers and the provision of appropriate field aids. Field protocols and instructions that are easy to follow, combined with repeated survey visits, and long-term volunteer participation help to enhance data quality.

In view of the lack of invasive species monitoring in Southern Ontario, it is recommended that other organizations with a need to inform invasive species management consider a similar approach. The protocols followed under the current program may well be applicable, whether applied to the same invasive indicators or species of higher priority in the region of interest. If similar protocols were followed it would provide an opportunity for comparison between jurisdictions, enhancing the interpretation of findings.

The Magee *et al.* (2010) method is recommended as a tool for ranking alien plants with respect to their invasiveness potential. It may provide value to others working to prioritize invasive species for management planning, and will have additional benefit if widely adopted.

Best management practices designed to preclude the introduction of invasives during monitoring and restoration activities should be developed and followed by those working in natural areas. Public education directed towards groups that visit multiple natural areas during the course of recreational activities, may be helpful in reducing the rate at which some of these invaders are spreading, particularly in the interim until effective control methods such as biological agents are in place. Groups such as birders, naturalist clubs, and hiking clubs are generally unaware of individual actions they can and should take to avoid spreading seeds from one natural areas to another.

Dog-strangling vine would appear to be a research priority, as its observed invasion severity exceeds what would be predicted on the basis of its known characteristics.

This observational study does not provide data to inform specific recommendations with respect to individual species control. However, the extent of invasion by several of the species studied indicates that they are established beyond the feasibility of any control method other than a biological control. Manual and chemical methods are more likely to have negative effects without any appreciable long term impact on the invader. Application of a biological control also has the potential for unintended negative results. Subject to rigorous testing of its specificity to the target invader prior

to release, it does have the potential to control populations of the invasive species to a level where the impact on native species is less dire. Recommended focal areas for management action are: preventing the introduction of new exotic species, monitoring for the appearance of new populations of exotic invaders in managed conservation lands, and acting quickly to eradicate them before they can become established. Whatever control method is selected, it should be followed up by planting of appropriate hardy native species for the best opportunity of long term success.

It may be worthwhile to survey a subset of the TVMP sites for the larger list of priority exotic plants considered invasive in the region, in order to determine whether the presence of one or more of the current indicators, or the site severity of invasion score has predictive value with respect to the presence or severity of invasion by other invasive plants.

The TRCA TVMP will continue to monitor both invasive plant and native species indicators over the long-term and will report on trends if and as they are recorded.

6.0 References

- Averill, K. M., A. DiTommaso, C. L. Mohler, and L. R. Milbrath. 2011. *Survival, growth and fecundity of the invasive swallowworts (*Vincetoxicum rossicum* and *V. nigrum*) in New York State*. *Invasive Plant Science and Management*. 4(2):198-206
- Chen, H., H. Qian, G. Spyreas and M. Crossland. 2010. *Native-exotic species richness relationships across spatial scales and biotic homogenization in wetland plant communities of Illinois, USA*. *Diversity and Distributions* 16: 737–743
- Conover, A. M. 2011. *The impact of non-native plants on bird communities in suburban forest fragments*. M.Sc. Thesis, University of Delaware
<http://ag.udel.edu/enwc/faculty/Williams/Amanda%20Conover%20MS%20Thesis.pdf>
- Denis, J. 2011. *Invasion dynamics of exotic and native common reed in freshwater wetlands*. M.Sc. thesis. McGill University
- Devine, Kevin and Songlin Fei 2011. *A Review of impacts by Invasive exotic plants on forest ecosystem services*. Proceedings of the 17th Central Hardwood Forest Conference <http://www.nrs.fs.fed.us/pubs/gtr/gtr-p-78papers/45devinep78.pdf> accessed Nov. 15, 2011
- DiTommaso, A., F. M. Lawlor, S. J. Darbyshire. 2005. *The biology of invasive alien plants in Canada. 2. *Cynanchum rossicum* (Kleopow) Borhidi [= *Vincetoxicum rossicum* (Kleopow) Barbar.] and *Cynanchum louiseae* (L.) Kartesz & Gandhi [= *Vincetoxicum nigrum* (L.) Moench]*. *Canadian Journal of Plant Science* 85(1):243-263
- Environment Canada. 1999. *Invasive Plants of Natural Habitats in Canada*. Canadian Wildlife Service <http://www.ec.gc.ca/eee-ias/78D62AA2-55A4-4E2F-AA08-538E1051A893/invasives.pdf> accessed Feb. 24, 2012
- Farnsworth, E.J. and Meyerson, L.A. 2003. *Comparative ecophysiology of four wetland plant species along a continuum of invasiveness*. *Wetlands* 23:750–762
- Frappier, B. Lee, T., Olson, K., Eckert, R. 2003. *Small-scale invasion pattern, spread rate, and lag-phase behavior of *Rhamnus frangula* L.* *Forest Ecology and Management*. 186(1-3): 1-6.

- Gray, A. 1868. *Manual of Botany of the Northern United States*, 5th ed. Ivison, Blakeman, Taylor and Company, New York. as cited in Denis, J. 2011. *Invasion dynamics of exotic and native common reed in freshwater wetlands*. M.Sc. thesis. McGill University
- Hartmana, Kurt M. and Brian C. McCarthy. 2008. *Changes in forest structure and species composition following invasion by a non-indigenous shrub, Amur honeysuckle (Lonicera maackii)*. The Journal of the Torrey Botanical Society 135(2):245-259.
- Havinga, D. and the Ontario Invasive Plants Working Group. 2000. *Sustaining biodiversity: A strategic plan for managing invasive plants in Southern Ontario*. Ontario Invasive Plants Working Group. www.toronto.ca/trees/pdfs/sustain.pdf
- Hejda, M., P. PyÅiek, V JaroÅiÅ-k. 2009. *Impact of invasive plants on the species richness, diversity and composition of invaded communities*. Journal of Ecology 97(3): 393-403
- Heneghan, Liam, Farrah Fatemi, Lauren Umek, Kevin Grady, Kristen Fagen, Margaret Workman. 2006. *The invasive shrub European buckthorn (Rhamnus cathartica, L.) alters soil properties in Midwestern U.S. woodlands*. Applied Soil Ecology 32
- Hui, Cang, L. C., Foxcroft, D. M. Richardson and S. MacFadyen. 2011. *Defining optimal sampling effort for large-scale monitoring of invasive alien plants: a Bayesian method for estimating abundance and distribution*. Journal of Applied Ecology 48(3):768-776
- Jodoin, Y., C. Lavoie, P. Villeneuve, M. Theriault, J. Beaulieu & F. Belzile. 2008. *Highways as corridors and habitats for the invasive common reed Phragmites australis in Quebec, Canada*. Journal of Applied Ecology 2008, 45 , 459-466
- Kricsfalusy V. V. & Miller G. C. 2010. *Community ecology and invasion of natural vegetation by Cynanchum rossicum (Asclepiadaceae) in the Toronto region, Canada*. – Thaiszia – J. Bot. 20: 53-70
- Levine, J. M., M. Vila, C. M. D'Antonio, J. S. Dukes, K. Grigulis and S. Lavorel. 2003. *Mechanisms underlying the impacts of exotic plant invasions*. Proc. R. Soc. Lond. B 270: 775-781 rspb.royalsocietypublishing.org accessed October 19, 2011
- Maerz, J. C., B. Blossey, and V. Nuzzo. 2005. *Green frogs show reduced foraging success in habitats invaded by Japanese knotweed*. Biodiversity and Conservation 14(12): 2901-2911

- Magee, Teresa K., Paul L. Ringold, Michael A. Bollman, Ted L. Ernst. 2010. *Index of Alien Impact: A Method for Evaluating Potential Ecological Impact of Alien Plant Species*. Environmental Management 45:759–778
- Matthews, J. W., A. L. Peralta, A. Soni, P. Baldwin, S. D. Kent, S. G. Endress. 2009. *Local and landscape correlates of non-native species invasion in restored wetlands*. Ecography 32(6): 1031-1039
- Melles, S., S. Glenn, and K. Martin. 2003. *Urban bird diversity and landscape complexity: Species–environment associations along a multiscale habitat gradient*. Conservation Ecology 7(1): 5. www.consecol.org/vol7/iss1/art5
- Meyer, S. W. 2003. *Comparative use of Phragmites australis and other habitats by birds, amphibians and small mammals at Long Point, Ontario*. M.Sc. thesis. University of Western Ontario www.deltawaterfowl.org/research/results/Meyer_Shawn.pdf
- Moore, R.J. 1959. *The dog-strangling vine, Cynanchum medium, its chromosome number and its occurrence in Canada*. The Canadian Field-Naturalist 73: 144-147.
- Moravcov, L., P. Pyšek, V. Jarošík, V. Havlíčková and P. Zákavský. 2010. *Reproductive characteristics of neophytes in the Czech Republic: traits of invasive and non-invasive species*. Preslia 82: 365–390
- NatureServe.org. 2009. www.natureserve.org accessed Nov. 10, 2011.
- Ortega, Y. K., and D. E. Pearson. 2005. *Weak vs. strong invaders of natural plant communities: assessing invasibility and impact*. Ecological Applications 15:651–661
- Powell, K., J. Chase and T. Knight. 2011. *A synthesis of plant invasion effects on biodiversity across spatial scales*. American Journal of Botany 98(3): 539-548
- Rooney, T. P., D. A. Rogers, S. M. Wiegmann, D. M. Waller. 2004. *Monitoring nonnative plant invasions over fifty years in Wisconsin forests*. Weed Technology 18: 1266-1268
- Rooney, T. P., D. A. Rogers. 2011. *Colonization of garlic mustard (Alliaria petiolata), European buckthorn (Rhamnus cathartica), and Bell's honeysuckle (Lonicera X bella) on understory plants after five decades in Southern Wisconsin forests*. Invasive Plant Science and Management 4(3): 317-325

- Sakai, A., F. Allendorf, J. Holt, D. Lodge, J. Molofsky, K. With, S. Baughman, R. Cabin, J. Cohen, N. Ellstrand, D. McCauley, P. O'Neil, I. Parker, J. Thompson, S. Weller. 2001. *The population biology of invasive species*. *Annu. Rev. Ecol. Syst.* 32:305–32
- SAS Institute. 2007. *JMP Statistics and Graphics Guide, Release 7*. SAS Institute Inc., Cary, NC, USA
- TRCA 2007a. *The Terrestrial Natural Heritage System Strategy*. Toronto and Region Conservation Authority <http://www.trca.on.ca/dotAsset/26746.pdf>
- TRCA 2007b. *Setting Terrestrial Natural Heritage System Targets*. Toronto and Region Conservation Authority <http://www.trca.on.ca/dotAsset/26732.pdf>
- TRCA 2007c. *Evaluating and Designing Terrestrial Natural Heritage Systems*. Toronto and Region Conservation Authority <http://www.trca.on.ca/dotAsset/26734.pdf>
- TRCA 2008a. *Terrestrial Volunteer Monitoring Program Results 2002-2007*. Toronto and Region Conservation Authority <http://www.trca.on.ca/dotAsset/17217.pdf>
- TRCA 2008b. *Terrestrial Volunteer Monitoring Program Volunteer Manual*. Toronto and Region Conservation Authority
- TRCA 2008c. *Dog-strangling vine – Cynanchum rossicum (Kleopow) Borhidi: a review of distribution, ecology and control of this invasive plant*. Toronto and Region Conservation Authority www.trca.on.ca/dotAsset/94451.pdf
- TRCA 2009a. *Biological Survey 2008, Study Area TNHVM 10*. Toronto and Region Conservation Authority
- TRCA 2009b. *Source Water Protection: Surface Water Quality Update*. Toronto and Region Conservation Authority
- TRCA 2010. *Vegetation Community and Species Ranking and Scoring method*. Toronto and Region Conservation Authority www.trca.on.ca/dotAsset/26728.pdf

Appendix A: Site severity of invasion scores, native species richness (SR) scores and site characteristics for TVMP sites, 2009 – 2011 period

Site #	Native SR Score	Site Severity of Inv.	Public Access	Total Patch Size (ha)	Total Patch Score	Matrix Infl. Score	Dist. to Road (m)	Road Dens.(km within 2 km)	Urb. Zone	Watershed	E-W
1	47.3	0	N	124	10.1	4.4	285	18.4	R	Humber	W
2	65.3	4	N	268	11.9	4.4	2	14	R	Humber	W
3	34.4	3	Y	194.4	11.5	4.6	1517	13.5	R	Humber	W
4	37.3	4	N	564	12.3	4.8	579	11.6	R	Humber	W
5	38.1	9	Y	231	10.9	4.4	791	21.1	R	Humber	W
7	37.0	6	Y	142.8	10.4	4.4	24	12.5	R	Humber	W
8	26.1	18	Y	157	10.1	3.8	299	40.7	R	Humber	W
9	48.6	5	N	1057.9	12.1	4.4	1914	9.4	R	Humber	W
10	38.2	18	Y	163.7	10.7	4.4	444	17.7	R	Humber	W
11	37.8	14	N	163	11	4.4	765	16.3	R	Humber	W
13	40.5	11	N	87.5	9.4	3.6	170	13.7	R	Humber	W
14	30.3	6	N	119	10.2	3.8	171	12.5	R	Humber	W
15	26.3	23	N	44.5	9.4	3.6	2	18.1	Uz	Humber	W
16	51.6	6	Y	312	10.7	4.4	25	24.8	Uz	Humber	W
17	12.6	11	N	50	9.1	3.6	403	11.6	R	Etobicoke	W
18	22.9	5	N	23	9.2	3.6	2	12.7	R	Etobicoke	W
19	36.0	8	Y	135.3	9.4	3	2	66.2	Uz	Etobicoke	W
20	38.3	11	Y	25.4	7.2	1.8	5	32	U	Etobicoke	W
22	16.7	26	N	38.4	7.8	2.5	40	59.3	Uz	Humber	W
24	27.7	30	Y	94.4	7.6	2	31	65.5	U	Humber	W
25	12.6	7	Y	41	7.6	1.6	70	92.6	U	Humber	W
26	10.5	7	Y	50.5	7.6	1.8	29	83.1	U	Etobicoke	W
27	11.0	19	Y	34	6.8	1.5	38	95.8	U	Mimico	W
28	31.5	13	Y	24.5	7.4	1.6	82	102	U	Humber	W
29	19.4	14	Y	22	7.1	1.6	34	109	U	Humber	W
30	23.7	15	Y	47.5	8.9	2	2	109	U	NA	W
31	5.1	17	Y	11	10.7	4.8	775	5	U	NA	E
32	15.2	20	Y	44.4	7.3	1.7	25	121	U	Don	E
33	24.6	22	Y	27.6	7.7	1.9	2	86	U	Don	E
34	15.8	19	Y	12.5	6	1.4	2	78.5	U	Don	E
35	43.3	27	Y	96.5	7.8	1.8	127	73.2	U	Don	E
36	31.5	31	Y	44.6	7.8	1.6	35	90.3	U	Don	E
37	19.7	7	Y	82.8	8.8	2.1	111	79.8	U	Don	E
38	7.0	10	Y	31.4	10.7	2.4	51	64.9	U	Don	E
39	13.4	4	N	26.8	7	1.9	15	47.8	U	Don	E
43	37.5	10	N	97.6	10.2	4.4	20	17.5	R	Rouge	E
44	24.3	3	N	31.5	10.4	4.4	149	12.8	R	Rouge	E
45	30.2	12	Y	47.4	8.9	3.6	261	31.4	Uz	Rouge	E

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46	16.0	20	Y	16.8	9.4	1.8	28	88.8	U	Rouge	E
47	22.4	17	Y	10	8.4	1.2	2	115	U	Highland	E
48	16.1	18	N	45.4	10.2	4.4	526	18.8	R	Rouge	E
49	45.4	24	N	32.1	10.4	4.4	2	31.9	R	Rouge	E
50	20.8	14	Y	97	10.4	3.2	333	67.8	U	Rouge	E
53	33.6	26	Y	131.5	11.4	4.4	279	39	Uz	Petticoat	E
54	41.4	8	Y	14.8	7.8	2.3	16	85.5	U	NA	E
55	27.5	17	Y	54.1	9.1	3.2	51	49	Uz	Duffin's	E
56	27.5	24	Y	165.8	10.4	4.5	28	17.1	R	Duffin's	E
58	41.6	11	Y	268.7	10.9	4.7	627	20.7	R	Duffin's	E
59	39.1	19	N	92.9	10	3.8	458	19.2	R	Duffin's	E
60	29.0	7	N	68.5	10.8	4.4	191	15.7	R	Duffin's	E
61	22.9	10	N	51.9	10.7	4.5	705	15.3	R	Duffin's	E
62	34.3	11	Y	1142.3	13.1	5	2337	8	R	Duffin's	E
63	37.3	8	Y	58.4	10.8	3.6	2	54.2	Uz	Carruther's	E

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Appendix B: TVMP Native indicator species, their L ranks, total scores and native indicator species richness contribution scores (see methods, section 2.4)

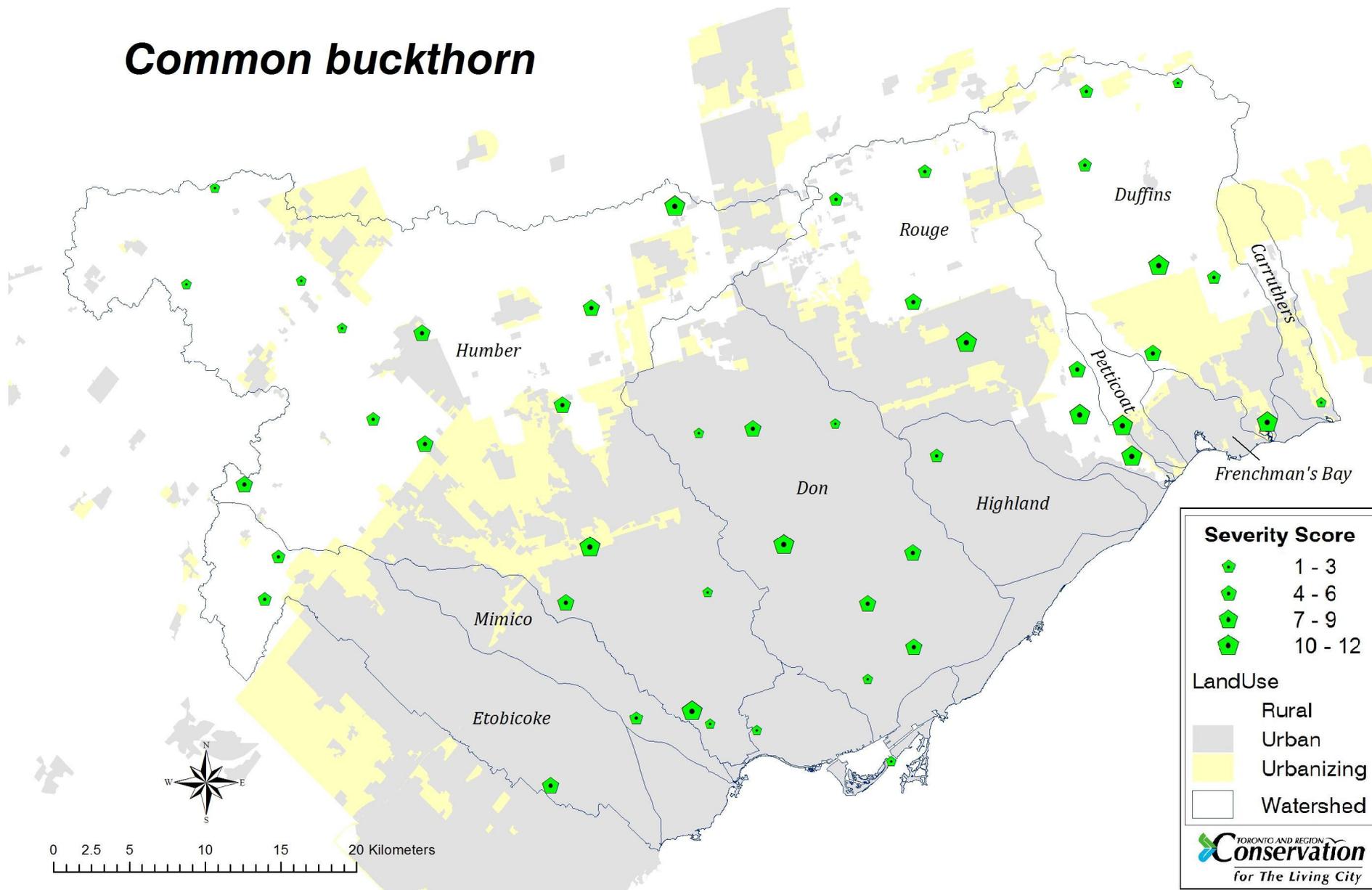
Species Common Name	Species Scientific Name	Group	L Rank	Total Score	Weight	SR Score Contribution	SR Score Contribution (scaled to 100)
striped chorus frog	<i>Pseudacris triseriata</i>	Fauna	L2	24	2	48	4.51
bullfrog	<i>Lithobates catesbeiana</i>	Fauna	L2	22	2	44	4.14
grey treefrog	<i>Hyla versicolor</i>	Fauna	L2	21	2	42	3.95
northern spring peeper	<i>Pseudacris c. crucifer</i>	Fauna	L2	21	2	42	3.95
wood frog	<i>Lithobates sylvatica</i>	Fauna	L2	21	2	42	3.95
porcupine	<i>Erethizon dorsatum</i>	Fauna	L2	20	2	40	3.76
ruffed grouse	<i>Bonasa umbellus</i>	Fauna	L2	20	2	40	3.76
ovenbird	<i>Seiurus aurocapilla</i>	Fauna	L3	19	2	38	3.57
northern leopard frog	<i>Lithobates pipiens</i>	Fauna	L3	18	2	36	3.38
bobolink	<i>Dolichonyx oryzivorus</i>	Fauna	L3	17	2	34	3.20
American woodcock	<i>Scolopax minor</i>	Fauna	L3	16	2	32	3.01
scarlet tanager	<i>Piranga olivacea</i>	Fauna	L3	16	2	32	3.01
Virginia rail	<i>Rallus limicola</i>	Fauna	L3	16	2	32	3.01
pileated woodpecker	<i>Dryocopus pileatus</i>	Fauna	L3	15	2	30	2.82
American toad	<i>Anaxyrus americanus</i>	Fauna	L4	14	2	28	2.63
green heron	<i>Butorides virescens</i>	Fauna	L4	14	2	28	2.63
mink	<i>Mustela vison</i>	Fauna	L4	14	2	28	2.63
wood duck	<i>Aix sponsa</i>	Fauna	L4	14	2	28	2.63
eastern chipmunk	<i>Tamias striatus</i>	Fauna	L4	13	2	26	2.44
eastern meadowlark	<i>Sturnella magna</i>	Fauna	L4	13	2	26	2.44
eastern screech-owl	<i>Megascops asio</i>	Fauna	L4	13	2	26	2.44
eastern wood-pewee	<i>Contopus virens</i>	Fauna	L4	13	2	26	2.44
green frog	<i>Lithobates clamitans</i>	Fauna	L4	13	2	26	2.44
swamp sparrow	<i>Melospiza georgiana</i>	Fauna	L4	13	2	26	2.44
savannah sparrow	<i>Passerculus sandwichensis</i>	Fauna	L4	12	2	24	2.26
white oak	<i>Quercus alba</i>	Flora	L2	16	1	16	1.50

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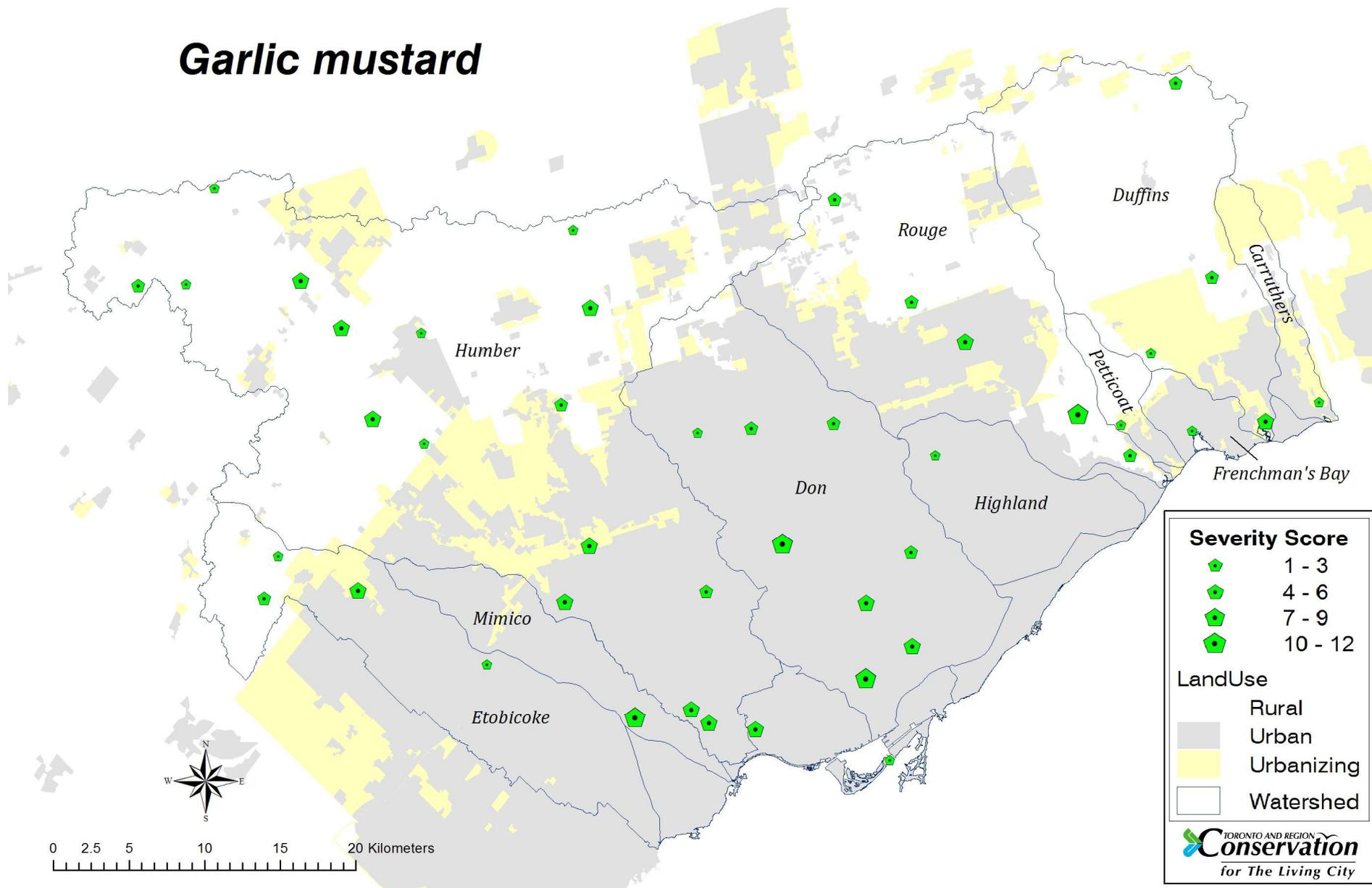
narrow-leaved spring beauty	<i>Claytonia virginica</i>	Flora	L3	15	1	15	1.41
star-flower	<i>Trientalis b. borealis</i>	Flora	L3	15	1	15	1.41
winterberry	<i>Ilex verticillata</i>	Flora	L3	15	1	15	1.41
Christmas fern	<i>Polystichum acrostichoides</i>	Flora	L3	14	1	14	1.32
turtlehead	<i>Chelone glabra</i>	Flora	L3	14	1	14	1.32
eastern hemlock	<i>Tsuga canadensis</i>	Flora	L4	13	1	13	1.22
marsh marigold	<i>Caltha palustris</i>	Flora	L4	13	1	13	1.22
Michigan lily	<i>Lilium michiganense</i>	Flora	L4	13	1	13	1.22
swamp milkweed	<i>Asclepias i. incarnata</i>	Flora	L4	13	1	13	1.22
white pine	<i>Pinus strobus</i>	Flora	L4	13	1	13	1.22
white Trillium	<i>Trillium grandiflorum</i>	Flora	L4	13	1	13	1.22
foam-flower	<i>Tiarella cordifolia</i>	Flora	L4	12	1	12	1.13
riverbank wild rye	<i>Elymus riparius</i>	Flora	L4	12	1	12	1.13
barber-pole bulrush	<i>Scirpus microcarpus</i>	Flora	L4	11	1	11	1.03
white cedar	<i>Thuja occidentalis</i>	Flora	L4	11	1	11	1.03
spotted joe-pye weed	<i>Eutrochium maculatum</i>	Flora	L5	10	1	10	0.94
Jack-in-the-pulpit	<i>Arisaema triphyllum</i>	Flora	L5	9	1	9	0.85
zig-zag goldenrod	<i>Solidago flexicaulis</i>	Flora	L5	8	1	8	0.75
candleflame	<i>Candelaria concolor</i>	Lichen	NA	NA	NA	NA	NA
common greenshield	<i>Flavoparmelia caperata</i>	Lichen	NA	NA	NA	NA	NA
hammered shield	<i>Parmelia sulcata</i>	Lichen	NA	NA	NA	NA	NA
hooded sunburst	<i>Xanthoria fallax</i>	Lichen	NA	NA	NA	NA	NA
mealy rosette	<i>Physcia millegrana</i>	Lichen	NA	NA	NA	NA	NA
rough speckled shield	<i>Punctelia rudecta</i>	Lichen	NA	NA	NA	NA	NA

Appendix C: Individual species and site severity of invasion scores for invasive indicators on TVMP sites 2009 - 2011

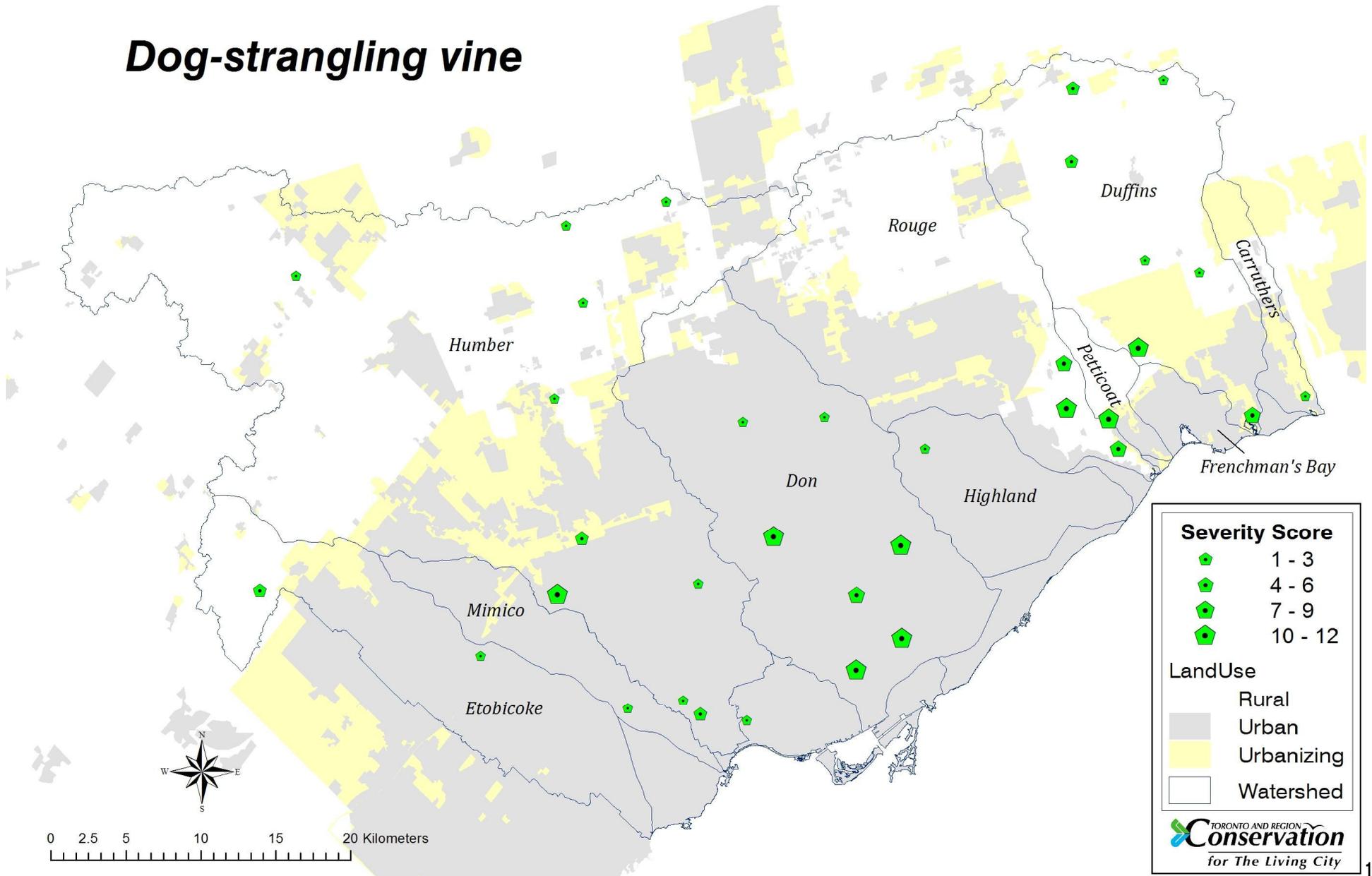
Common buckthorn



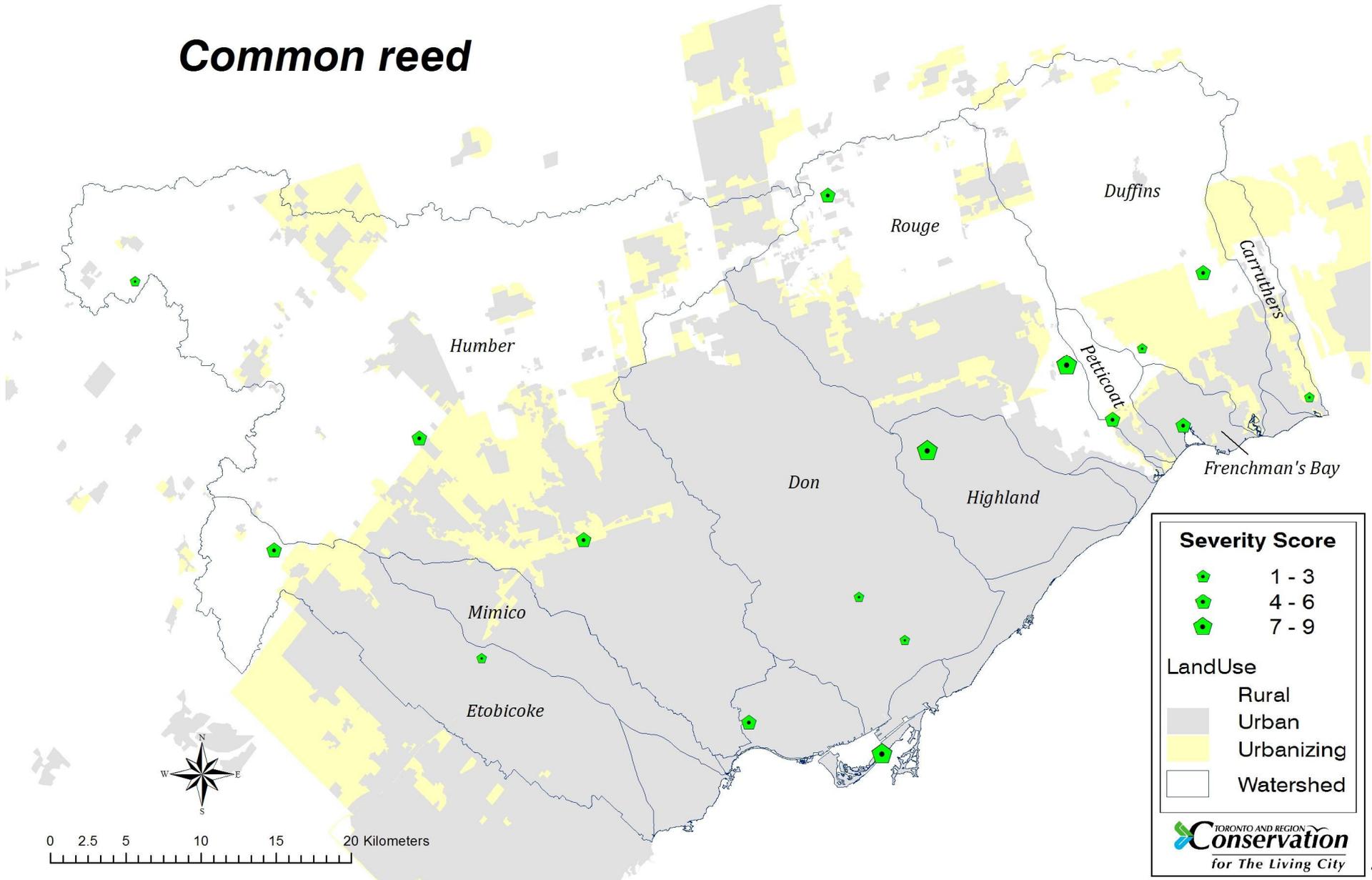
Garlic mustard



Dog-strangling vine



Common reed



Severity Score

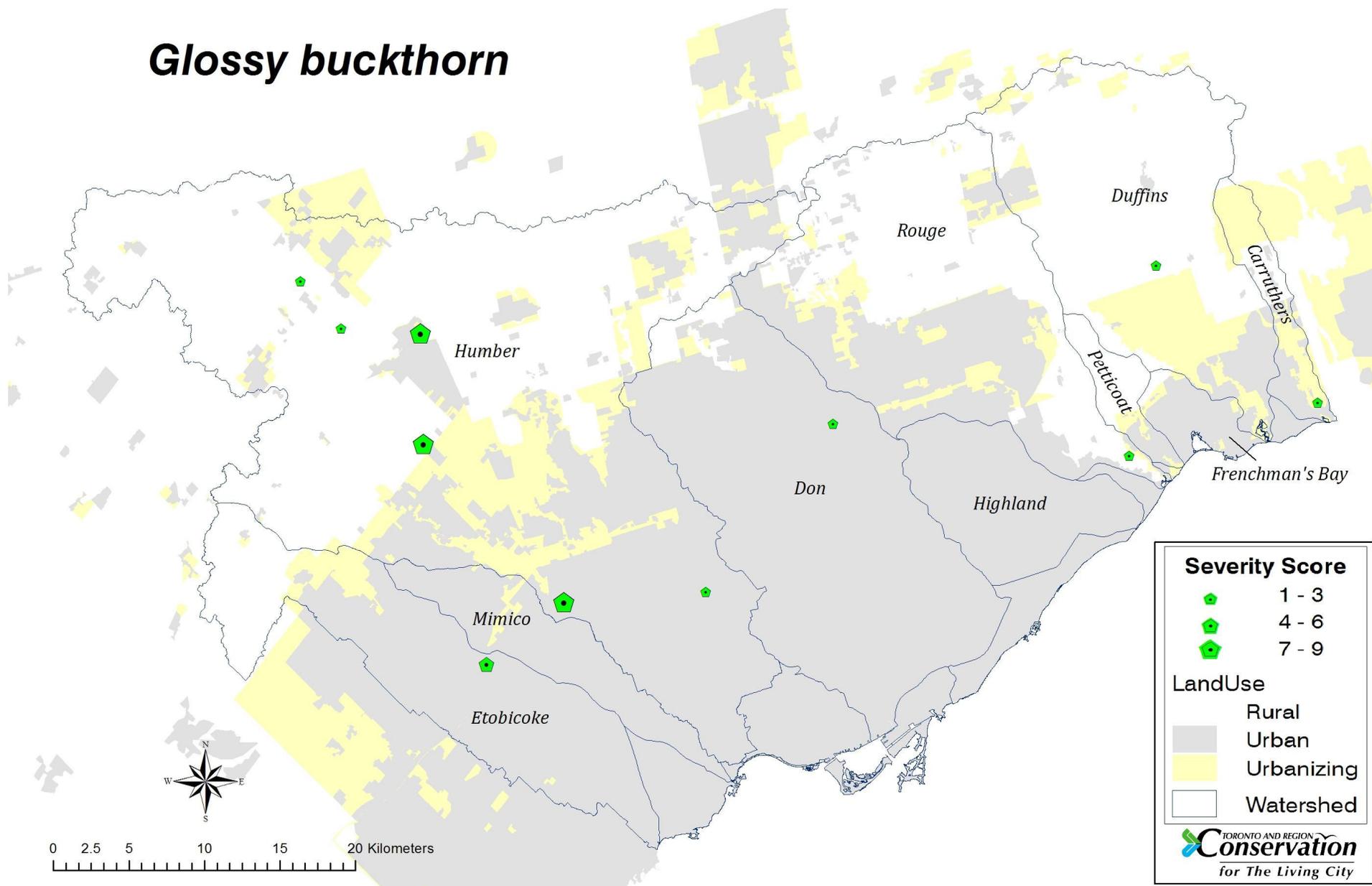
- 1 - 3
- 4 - 6
- 7 - 9

LandUse

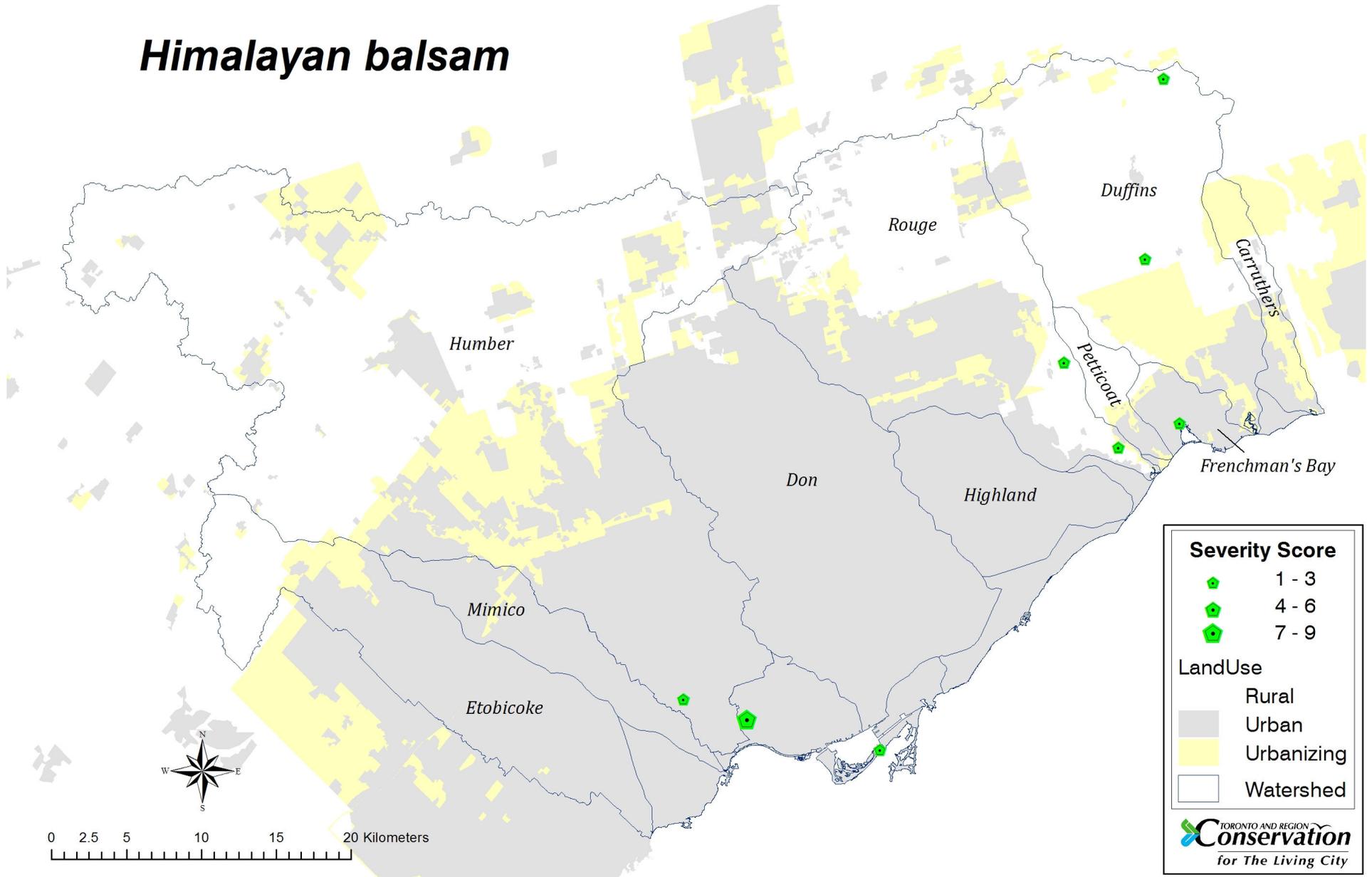
- Rural
- Urban
- Urbanizing
- Watershed

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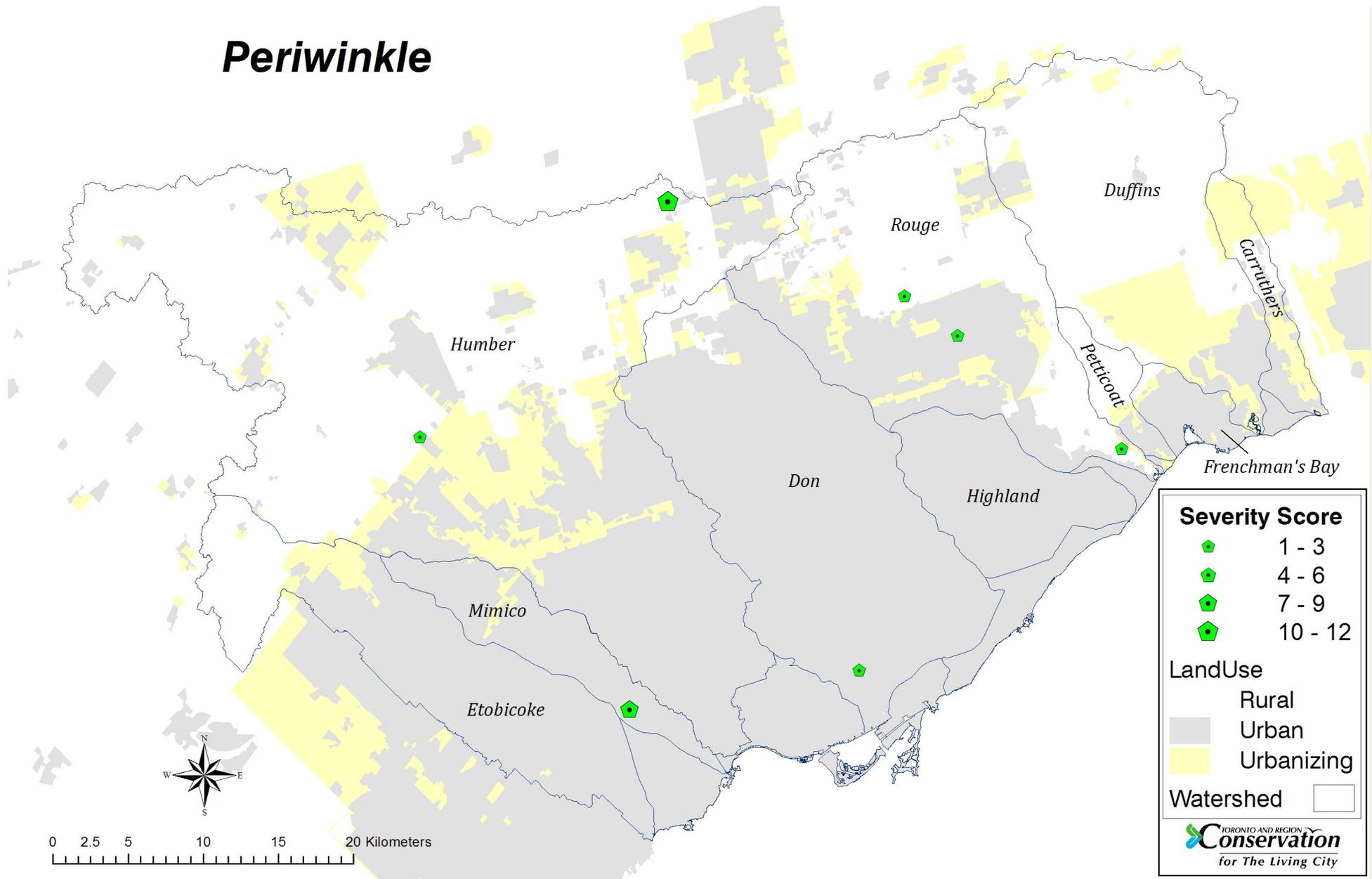
Glossy buckthorn



Himalayan balsam



Periwinkle



Severity Score

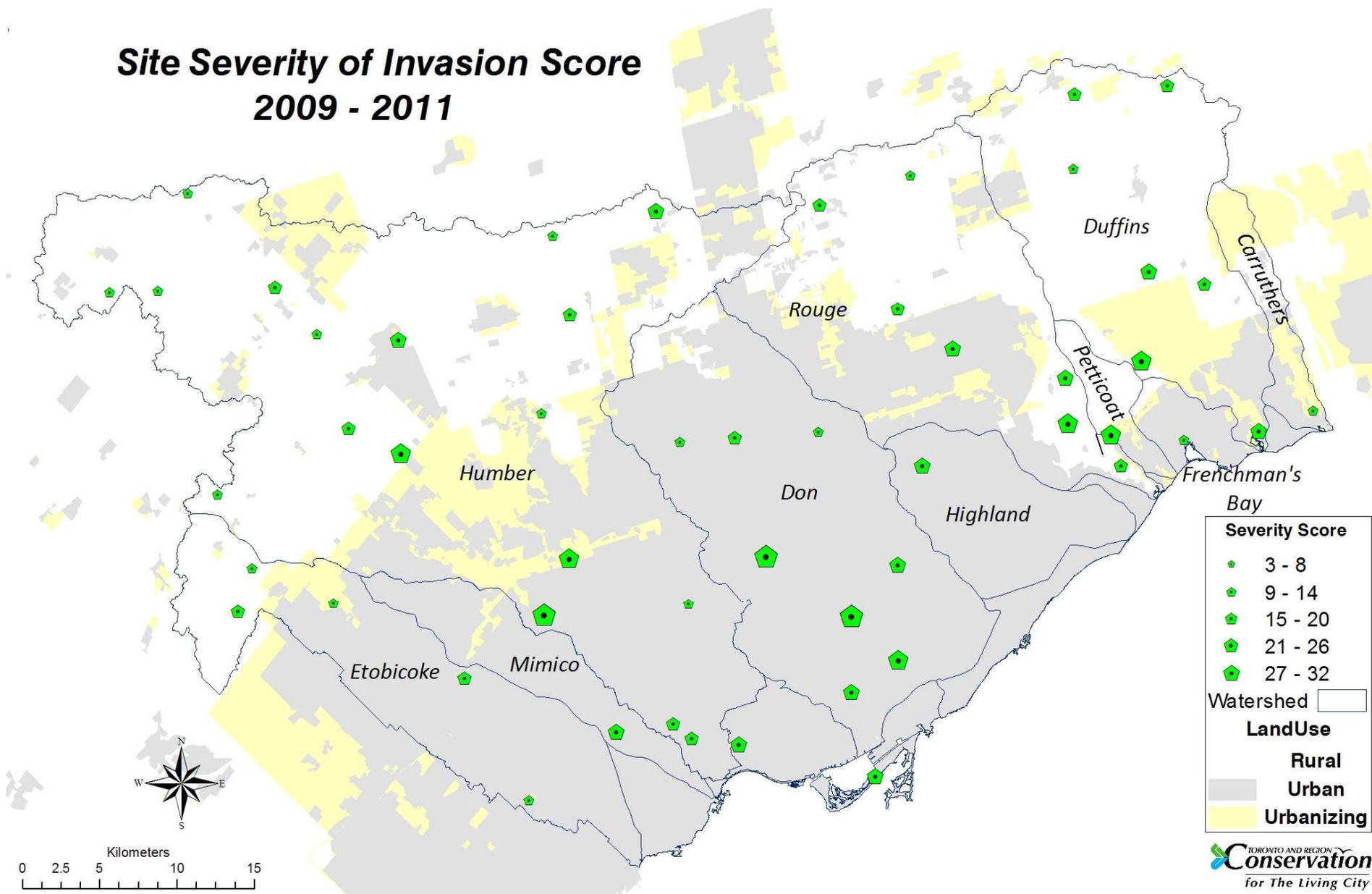
- 1 - 3
- 4 - 6
- 7 - 9
- 10 - 12

LandUse

- Rural
- Urban
- Urbanizing

Watershed

Site Severity of Invasion Score 2009 - 2011



Appendix D: Native species richness scores on Terrestrial Volunteer Monitoring Program (TVMP) sites 2009 – 2011

**Native Species Richness Score
 2009 - 2011**

