   

Biodiversity quality in the Toronto region
2003 - 2016

Environmental Monitoring and Data Management
Toronto and Region Conservation Authority

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ACKNOWLEDGEMENTS

We offer our sincere thanks to the many volunteers who have contributed to the collection of data under the Terrestrial Volunteer Monitoring Program. Their efforts are sincerely appreciated.

We also thank the landowners who have generously permitted our monitoring to take place on their properties. Their hospitality is likewise appreciated.

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CONTENTS

List of Tables:

List of Figures:

1.0 Executive Summary

This is the fourth in a series of reports that summarize and discuss the results of the indicator species monitoring conducted since 2002, under the Terrestrial Volunteer Monitoring Program (TVMP) of the Toronto and Region Conservation Authority (TRCA). Earlier reports may be accessed at:
https://trca.ca/conservation/environmental-monitoring/environmental-monitoring-resource-library/.

The current report updates information on the condition (ecological integrity) of the terrestrial ecosystem within the Toronto regional jurisdiction, as viewed through the lens of biodiversity quality. It builds upon the themes and information provided in the 10-year report (TRCA 2013), but does not reiterate all of the key findings of that document. The two reports should be viewed as companion documents.

The introduction (Section 2.0) summarizes the global biodiversity issue; although global agreements to address the issue have been signed by many countries including Canada, action can realistically be effected only at a local/regional scale. In practical terms it is only at this scale that knowledge of the historical components of biodiversity, combined with the organizational capacity to conduct monitoring and assessments at the species level, make species conservation work feasible. Further, when individual species are considered, each species' native geographical range is much smaller than total planetary area; jurisdictions that host species' native ranges thus must accept the responsibility to ensure their continued existence. Conservation organizations, including TRCA, have done so. In the case of the TRCA, the protection and enhancement of regional biodiversity is a strategic goal, with biological monitoring and assessment a basic component of the effort.

Protection and enhancement of regional biodiversity at TRCA begins with a prioritization step under which the native species most sensitive to disturbance of their habitats and most at risk of decline/disappearance from the region are identified. In fact, all flora and fauna known to be native to the region are ranked through a scoring methodology and assigned L-ranks, or local ranks of conservation concern. L1 ranked species are of the highest concern, with ranks running through to L5, the latter designation applied to the species considered at lowest risk.

The TVMP monitoring program used the scoring and ranking detail for native species to inform selection of a set of 50 indicator species to monitor at sites throughout the region. Multiple taxonomic groups (plants, birds, amphibians, mammals and lichens) and species from across the range of concern (L2 - L5) were included. Presence/absence data for the selected species were collected annually by trained volunteers, and the data compiled into two-year periods for analysis. Indicator species scores (ISS) for sites and time periods were calculated. By taking the conservation concern score for each species into account in the calculation (i.e. the ISS is weighted by conservation concern score), the ISS provides information beyond simply how many of the indicator species were found. The ISS increases according to the level of concern of the species found, and thus the ISS is an indicator of biodiversity quality. Biodiversity quality is higher where a greater proportion of species of concern (priority species) persist than where this proportion is lower. The ISS is a metric for this, designed to inform decision making and target setting relative to the TRCA's *Terrestrial Natural Heritage System Strategy* (TRCA 2007) for the region.

The TVMP also monitored 8 high priority invasive plant species, beginning in 2009. The priority in this case relates to the risk these invaders pose to native species, especially sensitive species of concern. Scores for severity of invasion (SevInv) on TVMP sites increase with increased abundance and with increased area coverage by these invaders. A high SevInv score is a negative indicator of biodiversity quality.

ISS and SevInv scores were analyzed to assess relative differences among sites, between the urban and rural zones of the region (Map 1) and to investigate change in mean scores across the 7 two-year time periods, which encompass the years 2003 through 2016.

ISS were also investigated for associations with landscape characteristics of the monitoring sites, including the area of natural cover (NatCov), the area of wetland, and road density within 500 m, 1 km, and 2 km of the site. Relationships between the ISS and SevInv scores were also investigated.

Comparison of the ISS results for the urban and rural zones of the Toronto region (Fig. 3) showed large, significant differences for the Full ISS and all subgroups analyzed (Fauna, Avian, Amphibian and Species of Conservation Concern, or SOCC). The reduced biodiversity quality in the urban zone is a concern; although some conservation lands under natural cover have been preserved there, impacts from the surrounding urban land use reduce the quality of the habitat and the ability for it to support species of concern, and in fact most fauna species (Section 5.4; Appendix E). Key impacts that need mitigation include the high intensity of recreational use, disturbance by off-leash dogs and free-roaming cats, off-trail activity, encroachment, dumping, introduction and dispersal of invasive species, noise pollution and the barrier or hazard effect of roads to movement by fauna. Prohibition of damaging activities is often already in place via bylaws or rules of behaviour for individual properties. Enforcement and other creative methods to induce residents and visitors to abide by the rules are needed, as is the establishment of areas out-of-bounds for human use to provide usable habitat for sensitive species.

Of even greater concern is the fact that clear impacts on biodiversity quality were recorded in the rural zone, including a significant decline in ISS for the Full group and the SOCC regionally, as well as for the Avian group and SOCC in the rural zone across the 2003 - 2016 time frame (Table 4; section 5.1.1). Where conservation lands in the rural zone were at one time lightly used for recreation, their proximity to a growing human urban population has resulted in quickly growing intensity of use. This has been exacerbated by the relaxation of rules that previously prohibited other than passive recreation and by a declining understanding among the general public of the value of regulations where they do exist. Without a change in the regional management approach to, and effective public education of the value of conservation lands, biodiversity will continue to decline in the rural zone, and soon reach the minimal levels of the urban zone. Despite the strategic objective of protecting and enhancing regional biodiversity, it is declining.

The TVM program has been discontinued as a result of funding limitations, yet the long-term dataset remains of value, and its existence results from significant investment by the organization over the past two decades. It has been a key component of the Terrestrial Natural Heritage (TNH) Program that began in the late 1990's. Incorporating the development of the Terrestrial Natural Heritage System Strategy, the Conservation Concern scoring methodology for species, the regional scale landscape analysis methods, the region-wide application of field biological inventories, and the TVM monitoring, the TNH program has been leading edge with respect to biodiversity assessment and conservation planning practice. Its comprehensive approach, real-world practical methods, and design for application in an urbanizing regions are major strengths.

TRCA terrestrial monitoring has transitioned to a more detailed, plot-based program, in operation since 2008. The archival TVM dataset provides a less detailed high-level view of overall ecological condition, and biodiversity quality over the 2003 - 2017 period.

The overlapping timeframes of the two programs provide an opportunity, to conduct an integrated analysis of data from both programs for the overlapping timeframe. Such an analysis would provide valuable information:

- through a calibration exercise, high-level indicators of ecological condition and biodiversity quality could be identified; such indicators could be reported in a consistent way over a longer time-period, and continuing into the future (in effect extending the time series for the current monitoring program)
- the exercise would provide an opportunity to test and assess potential new methods to analyze and interpret the plot monitoring dataset, in order to maximize the ability for monitoring reports to inform the conservation management work of the authority

There is also value in reviewing the methods developed to monitor and score the severity of invasion for the high priority invasive plants monitored under the TVM program, as potentially informative for other future invasive monitoring or assessments.

2.0 Introduction

This is the fourth in a series of reports that summarize and discuss the results of the indicator species monitoring conducted by the Toronto and Region Conservation Authority (TRCA) since 2002, under the Terrestrial Volunteer Monitoring Program (TVMP). Earlier reports may be accessed at:
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The current report updates information on the condition (ecological integrity) of the terrestrial ecosystem within the Toronto regional jurisdiction, as viewed through the lens of biodiversity quality. It builds upon the themes and information provided in the 10-year report (TRCA 2013), but does not reiterate all of the key findings of that document. The two reports should be viewed as companion documents.

The state of global biodiversity is of critical concern as its decline threatens the long-term sustainability of human populations (Butchart *et al*. 2010). At the global scale, the simplest of the metrics used to measure biodiversity is species richness, i.e. a count of the species with living populations on the planet. Estimates are compiled from information collected at a range of scales from site-based surveys, through local and regional monitoring programs, and national state of the environment reporting. At the global scale, maximizing species richness is the goal (i.e. minimizing the loss of species as a result of human actions). The terms "species richness" and "biodiversity", while not synonymous, are often used interchangeably in this context.

Because each species occupies a geographic range that is much smaller and more localized than total global area, political jurisdictions that host individual species' ranges, or portions of them, have the responsibility to ensure that this local subset of global species richness persists. Conservation organizations, including Conservation Authorities, may further prioritize their regional biodiversity efforts in order to apply limited resources to the greatest effect. This may be accomplished by determining which species are in most need of protection, developing an understanding of the impacts and specific risks that affect such regional Species of Conservation Concern, and reducing or mitigating identified impacts and risks through conservation management. Invasive exotic species are well understood to be a risk factor for native species, and they represent an even higher risk to the more sensitive, and usually rarer, Species of Conservation Concern. In an ideal situation, efforts are made to prevent invasive species entry and establishment, and where possible, to control populations already established. With success, the biodiversity effect will be to reduce the species richness of invading species.

At a regional or local scale therefore, all species are not considered equal, and maximum total species richness is not the goal. Efforts are directed towards maximizing *biodiversity quality* (Feest *et al*. 2006), rather than biodiversity *per se*. Biodiversity quality is high if a large (or full) complement of the native species that were historically common and well-distributed in the region of interest remain so. If multiple, or many, previously common and previously well-distributed species are absent or reduced in distribution, biodiversity quality has declined. If this decline has disproportionately affected species already identified as conservation priorities, then biodiversity quality has declined more than if such is not the case (McKenzie *et al*. 2018).

2.1 The Indicator Species Score (ISS)

The Indicator Species Score (ISS) is a metric used to track biodiversity quality, to determine where in the Toronto region conservation effort is most needed, and to understand how biodiversity is changing over time. The ISS is compiled from observational data collected on a set of 50 indicator species by trained volunteers conducting surveys under a standardized protocol (TRCA 2014).

The ISS is designed to inform decision making and target setting relative to the TRCA's *Terrestrial Natural Heritage System Strategy* (TRCA 2007) for the region. Both the strategy and the monitoring program are built upon a foundation of earlier work that included the development of the regional Species of Conservation Concern scoring and ranking method. This method scores native vascular plant (flora) and vertebrate animal (fauna) species on a suite of generalized ecological requirement and sensitivity criteria, and uses the resulting sum of criteria scores, the Conservation Concern score (CC score) to assign a regional conservation concern rank (L rank). The ranks are from L1, assigned to species considered the highest level of concern, through L5, the designation used for species not considered of concern regionally.

Ongoing maintenance of the species scores and L ranks according to the protocol (TRCA 2017) is key to the analysis of terrestrial monitoring program ISS results. The ISS is a weighted score, with the Conservation Concern score for each species found on a site in a given time period contributing to the ISS for that site/time period.

The 10-year report of monitoring results (TRCA 2013) evaluated the condition of the Toronto region's terrestrial ecosystem, and documented large differences between the urban and rural land use zones of the region. It further investigated how the ISS responded to both habitat area and urban stressors. (That report referred to the ISS as the Native Indicator Species Richness Score, or SR score. The two terms are synonymous.)

3.0 Methods

3.1 Study Area

The area monitored encompasses the existing terrestrial and wetland natural cover in 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. Also included are the land areas of Frenchman's Bay, the Toronto Islands and the Lake Ontario waterfront within the jurisdictional boundaries. The total area is a little more than 2500 km^2 and includes the entire City of Toronto, significant portions of the regional municipalities of York, Durham, and Peel as well as a small area in Mono-Adjala township (Figure 1).

Physiographic features within the region include a portion of the Oak Ridges moraine, the morainal south slope, Peel plain, and the glacial Lake Iroquois shoreline. The Niagara escarpment passes through the northwestern corner of the jurisdiction where it meets the western boundary of the Oak Ridges moraine landform.

The Toronto region lies in an ecological transition zone between the Great Lakes-St. Lawrence forest in the north and the Carolinian forest to the south. Terrestrial natural cover is primarily deciduous and mixed forest, interspersed with smaller tracts of wetland, meadow and Great Lakes shoreline habitats (TRCA, 2007). Approximately 25% of the Toronto regional landscape was under natural cover in 2013.

The region is highly urbanized, but also has a large zone of rural/agricultural land use, primarily in the north, and areas in transition from rural to urban land use. Lands currently under development as well as those identified in regional official plans by 2008 as committed for future urban use are identified as the urbanizing zone. This zone occupies 10% of regional area. The rural zone includes lands under rural/agricultural use, whether designated to remain so or having undetermined planning status, and makes up 38% of regional area. The urban zone refers to all areas urbanized by 2008, and covers 52% of the total area (Figure 1). Natural cover exists within all three zones, although it is weighted towards the northern, more highly rural part of the jurisdiction (Figure 2). Landscape analysis is conducted periodically by TRCA and updated information is used for the monitoring program as it becomes available.

Urban development continues at a rapid pace in the region, while agricultural land use is declining (Cummings *et al.* 2010). In addition to authority conservation lands, provincial and federal protected lands relevant to the study area include those designated under the Oak Ridges Moraine and the Ontario Greenbelt provincial legislation (Province of Ontario 2017) as well as lands managed federally within the Rouge Urban National Park (Parks Canada 2018).

3.2 Native indicator species

The species monitored include 50 regionally native birds, frogs/ toad, mammals, vascular plants and lichens. The set includes representatives of the major terrestrial and wetland habitats in the region, and of a range of conservation concern ranks from L2 through L5 (TRCA 2017).

The presence of a given indicator species provides specific information about conditions on the site where it was found. If consistently absent from a site where the appropriate habitat type exists, knowledge of its requirements and sensitivities suggests factors to be considered when interpreting the absence result.

Selected subsets of the full group were also assessed for the finer level of detailed information they provide. The present document reports ISS results for the full set (Full ISS), the fauna (Fauna ISS), the birds (Avian ISS), the amphibians (Amphibian ISS) and the *Species of Conservation Concern* (SOCC ISS). During earlier analyses, these groups were identified as the most informative with respect to biodiversity quality differences and ecosystem condition for the region.

Scores for the native flora indicator group (Flora ISS) for time periods 4 through 7 are also reported to support assessment of relationships between native plant diversity and the invasion status of the sites.

Appendix A lists the native indicator species with common and scientific name, CC score, L rank and analysis subgroup(s).

3.3 Invasive plant indicator species

Beginning in 2009, monitoring was added for eight of the highest priority invasive plant species in the region (TRCA 2014). The invasive indicators are listed in Appendix B with common and scientific names.

3.4 Sample sites

The 54 sites monitored were 10 hectares in size, randomly located in natural cover on both public and private lands, and distributed throughout the 9 watersheds of the TRCA jurisdiction (Fig. 2).

While urbanization zone boundaries may change at some future point, during the affected period, 24 sites were in the rural zone, 22 in the urban zone, and 8 fell within the urbanizing zone (Fig. 1).

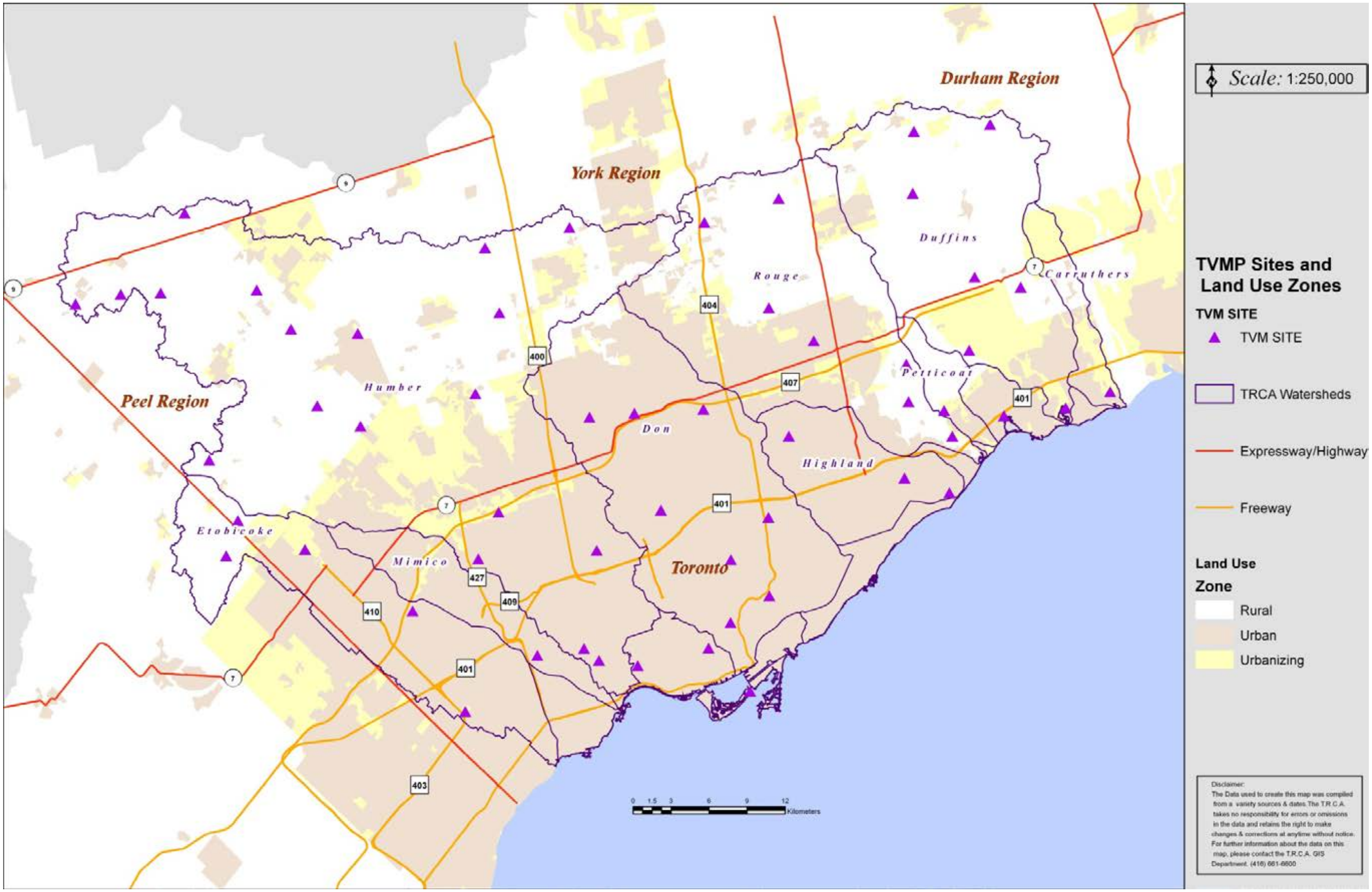

Figure 1: Map of the TRCA jurisdiction (Toronto region) showing the land use zones and locations of TVMP monitoring sites.

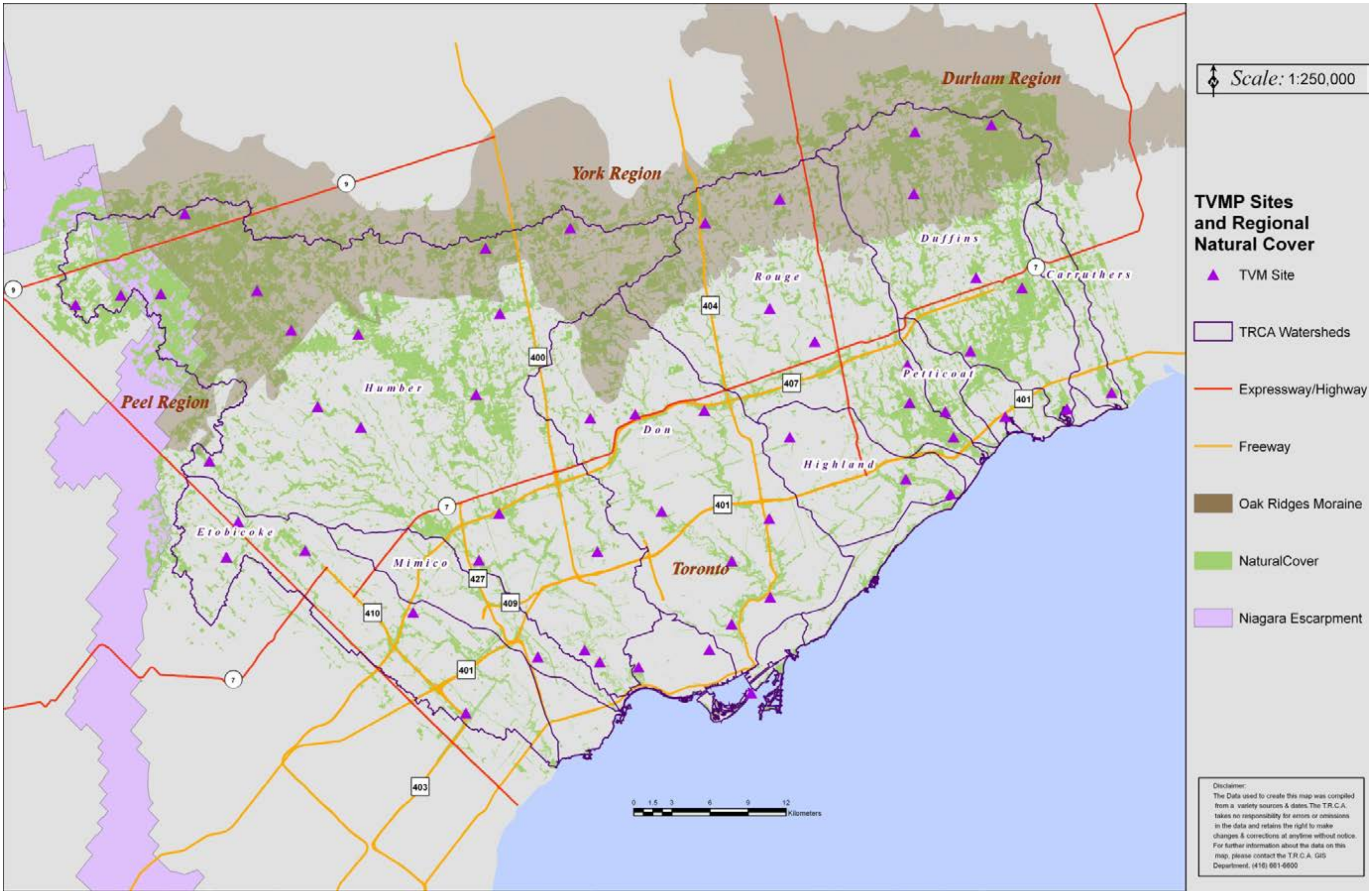

Figure 2: Map of the Toronto region showing natural cover, the locations of TVMP monitoring sites, the Oak Ridges moraine and the Niagara escarpment.

3.5 Survey method

Sites were surveyed 10 times annually. Each visit recorded presence observation data for a subset of the native indicator species list. Absences were inferred for species not found during any visit targeting that species within a time period. The survey timing, length of survey, search method and observation method varied by species (TRCA 2014). Methods were selected to maximize the likelihood of finding and correctly identifying individual species. For most of the fauna indicators surveys were conducted during the breeding season for the affected species, in order to obtain the best evidence available with respect to whether the site provided breeding habitat. Exceptions included ruffed grouse (*Bonasa umbellus*) and porcupine (*Erethizon dorsatum*). Both are year round resident species, and considered indicators for over-wintering habitat on the site.

Invasive plant surveys followed a more detailed protocol that categorized the number of occurrences as well as the size of the largest occurrence for each of the indicators found. Invasive plants were recorded during both the July and the August surveys each year.

Appendix C summarizes the annual survey schedule, species monitored by visit, and observation method. Protocols are outlined in more detail in the Volunteer Manual (TRCA 2014).

3.6 Data management and analysis

Survey data were maintained in a Microsoft Access database, and statistical analyses carried out using JMP 7.02, SAS Institute Inc. software (SAS 2007), with an alpha of 0.05 as the threshold for significance tests. Results that approached significance ($p<0.15$) are also discussed.

The raw dataset of species observations was quality assured in its entirety and compiled for the current analysis, following the data quality assurance process described in earlier reports (TRCA 2006, TRCA 2013).

3.6.1 Native Indicator species scoring (ISS)

Data for the 14-year period 2003 - 2016 were compiled into a series of seven 2-year temporal periods.

For each of the time periods, a Full ISS was calculated by monitoring site as follows:
1. The 2016 CC scores (Section 2.1, Appendix A) for all of the native indicator species found were summed.
2. This sum was divided by the sum of 2016 CC scores for the full native indicator set.
3. The result was multiplied by 100.

Fauna ISS, Avian ISS, Amphibian ISS, and Species of Conservation Concern, or SOCC ISS were calculated similarly, but the sum of CC scores for the subgroup was replaced as the divisor in step 2. Thus all ISS are reported on a 0-100 scale. The ISS as calculated is of most value in a relative sense, i.e. for objective comparison between sites, zones or other groupings.

We used the 2016 CC scores in step 1 because they are the most current reflection of the relative degree of conservation concern of the species monitored, and thus the most ideal for weighting purposes. Most of the indicator species have not seen score changes since the 2012 analysis. For those that have changed (Section 4.2) the new score reflects our current best understanding of conservation priority to inform forward planning.

3.6.2 Severity of Invasion scoring (SevInv)

The invasive species selected for monitoring are known to increase in abundance and expand in area very quickly, once established. Accordingly, a geometric scoring method was applied to provide a realistic estimate of the severity of invasion by the affected species on a site, as follows:

1. The occurrence category score from Table 1 (0-4) was multiplied by the maximum patch size category score (1-3) for the species found: the product was the SevInv score for the individual invasive indicator (0-12 scale).
2. Total SevInv was calculated as the sum of the individual species SevInv scores for the site (0-96).

SevInv scores were calculated for time periods 4 through 7, encompassing the years 2009 through 2016 during which invasive species monitoring was conducted. SevInv scores provide the ability to make objective comparisons between sites or groups of sites. The absolute value of the score is not the focus; ranges, differences and trends are informative.

A patch was defined as an area with consistent presence of the invasive species. It might be an area of dominance by that invader, even a monoculture or near monoculture, or it might be an area where the invader was consistently present, but not dominant. The edge of a patch was defined by the boundary beyond which the invasive plant was not observed. Surveyors were trained on how to distinguish/estimate patch boundaries with discussion covering each of the invasive indicator species. Instructions were also provided on the reverse of the field data sheet for reference as questions arose during surveys. Finally, surveyors were instructed that in the event of uncertainty, they should record what made sense to them based on the training and to add an explanatory comment to the data sheet.

Surveyors were trained to estimate patch size using their own measured pace length, by visualizing multiples of the size of the room in which the training was conducted, and by referencing the site aerial photo and ecological land classification map aids. As an example, for a site where a common buckthorn (*Rhamnus cathartica*) patch was clearly larger than 100 m^2 and it ringed a forest block, the patch was assigned to the < or > 1 ha category by estimating its average width and then referring to the site maps to assess whether it covered less or more than 10% of total site area, as delineated on the maps. In another example, garlic mustard (*Allaria petiolata*) was abundant throughout one forest vegetation community polygon. By referring to the ecological land classification map provided, the surveyor could similarly estimate the area of that community, and thereby categorize the patch size.

Table 1: Invasive species survey occurrence, patch size category and severity of invasion (SevInv) scoring

Species occurrence		Maximum patch size*		Species Severity of invasion score
Count description	Score A	Estimate description	Score B	
species not found	0		0	A x B (range 0 - 12)
few or scattered individual plants	1		1	
1 - 4 patches found	2	largest patch < 100 m^2	1	
5 - 10 patches found	3	largest patch > 100 m^2 < 1 ha	2	
>10 patches found	4	largest patch > 1 ha	3	

*The survey method did not provide for exact estimates (e.g. size =100 m^2). Instead surveyors were asked to decide whether the patch under observation was larger or smaller than the threshold.

3.6.3 Missing data

If surveys for one or more of the indicator species were incomplete for a time period, an ISS could not be calculated, resulting in data gaps (Table 2).

SevInv data were missing less often because all invasive species were surveyed during the same visit, and multiple surveys for the invasive species were conducted during each period (Table 2).

Missing data were independent of the data themselves and also independent of the urbanization zone, time period and landscape variables analyzed. They were considered to be missing completely at random (MCAR) and ignorable from the statistical perspective (Nakagawa & Freckleton 2008).

3.6.4 Station and observer effects in temporal analyses

Stations are represented in multiple time periods, and not every station is represented in every time period. In addition, observers changed over time. To account for potential station and observer effects in the temporal analyses, station and observer within station were included as random effects in models.

3.6.5 Calculation of means

For spatial comparisons, either the grand mean (i.e. the mean of all individual time period scores for all sites within the specified spatial group) or the mean of site means across time periods could be used. Preliminary analysis showed the difference in mean scores between the two approaches to be negligible, and the significance of differences between zones

(ANOVA; post-hoc Tukey-Kramer means comparisons) to be the same whether based on grand means or means of sites means.

The means reported herein are the means of site mean score across time periods for sites within the spatial grouping specified.

4.0 Results

4.1 Data collection

Volunteer recruitment grew over time and gaps in data collection sometimes occurred with volunteer turnover, resulting in differences in the number of sites with complete data between periods (Table 2).

Table 2: Data analysis time periods and number of sites with complete data (N) 2003 - 2016

Time Period	1	2	3	4	5	6	7
Date range	2003-2004	2005-2006	2007-2008	2009-2010	2011-2012	2013-2014	2015-2016
N for ISS	18	30	43	48	52	46	46
N for SevInv	na	na	na	47	46	44	46

4.2 Indicator species CC score changes

Annual updates of species scoring and ranking since 2012 have resulted in CC score changes by 2016 for 14 of the native indicator species (Appendix A). New scores resulted from updates in local occurrence and new population trend information for these species (TRCA 2016). Both increases and reductions in score occurred for species within the indicator set.

In the case of local occurrence, score reductions could result either from increased survey effort in areas where the species was not previously recorded, or movement of the species into new areas. Increases in local occurrence score, however, are more likely to record a true reduction in distribution, since they result from repeat surveys in areas previously inventoried (TRCA 2016).

Three species previously listed among the regional Species of Conservation Concern no longer have that priority, while the eastern meadowlark (*Sturnella magna*) became a species of regional concern. Appendix A summarizes the score changes and the rationale for updates, by species.

4.3 Regional biodiversity quality

All of the native indicator species were recorded at least once during the 2003-2016 period. In addition, all were found in both the rural and the urban zones. The mealy rosette lichen

(*Physcia millegrana*) remained the only native indicator recorded at least once on every site (Table 3).

Table 3: Frequency of observation for each of the indicator species 2003 - 2016, including the number of sites on which the species was found, and the total number of observation records.

Common name	Scientific Name	# sites	# observations
bobolink	*Dolichonyx oryzivorus*	3	8
bullfrog	*Lithobates catesbeiana*	5	12
green heron	*Butorides virescens*	5	14
porcupine	*Erethizon dorsatum*	6	22
eastern meadowlark	*Sturnella magna*	7	18
Virginia rail	*Rallus limicola*	8	20
wood duck	*Aix sponsa*	8	25
white oak	*Quercus alba*	10	96
western chorus frog	*Pseudacris triseriata*	13	30
narrow-leaved spring beauty	*Claytonia virginica*	15	40
pileated woodpecker	*Dryocopus pileatus*	15	39
winterberry	*Ilex verticillata*	15	40
ruffed grouse	*Bonasa umbellus*	16	25
northern leopard frog	*Lithobates pipiens*	18	53
riverbank wild rye	*Chamerion a. angustifolium*	19	96
Michigan lily	*Lilium michiganense*	20	100
star-flower	*Trientalis borealis*	22	86
turtlehead	*Chelone glabra*	22	97
American woodcock	*Scolopax minor*	26	136
barber-pole bulrush	*Scirpus microcarpus*	26	150
Christmas fern	*Polystichum acrostichoides*	27	145
American toad	*Anaxyrus americanus*	30	89
foam-flower	*Tiarella cordifolia*	30	149
grey treefrog	*Hyla versicolor*	30	154
wood frog	*Lithobates sylvatica*	31	173
marsh marigold	*Caltha palustris*	32	157
northern spring peeper	*Pseudacris crucifer crucifer*	32	275
savannah sparrow	*Passerculus sandwichensis*	32	99
swamp milkweed	*Asclepias i. incarnata*	33	156
eastern screech-owl	*Megascops asio*	35	102
green frog	*Lithobates clamitans*	35	247
mink	*Mustela vison*	35	105
scarlet tanager	*Piranga olivacea*	35	190
swamp sparrow	*Melospiza georgiana*	38	193
spotted Joe-Pye weed	*Eutrochium m. maculatum*	39	497
eastern chipmunk	*Tamias striatus*	40	137
hooded sunburst lichen	*Xanthoria fallax*	41	180
rough-speckled shield lichen	*Punctelia rudecta*	41	186
white trillium	*Trillium grandiflorum*	46	345
hammered shield lichen	*Parmelia sulcata*	47	270
ovenbird	*Seiurus aurocapillus*	47	282
zig-zag goldenrod	*Solidago flexicaulis*	47	309
white cedar	*Thuja occidentalis*	48	381
common greenshield lichen	*Flavoparmelia caperata*	49	204
white pine	*Pinus strobus*	49	373
eastern hemlock	*Tsuga canadensis*	50	407
candleflame lichen	*Candelaria concolor*	51	373
eastern wood-pewee	*Contopus virens*	51	557
Jack-in-the-pulpit	*Arisaema triphyllum*	52	390
mealy rosette lichen	*Physcia millegrana*	54	423

Mean ISS across the time periods (n=54 sites) are displayed in Figure 3 for the region as a whole and for the three urbanization zones.

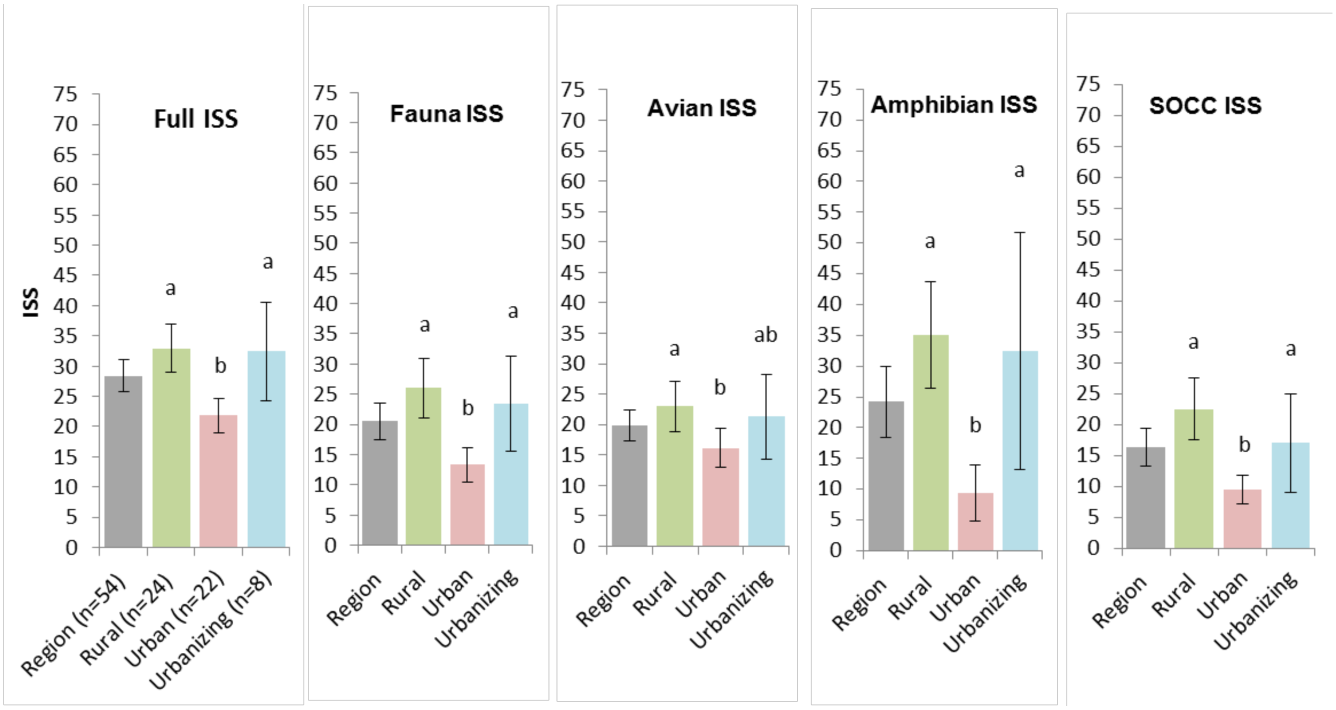

Figure 3: Mean of site mean ISS across seven 2-year time periods (2003-2016) for the Toronto region and its urbanization zones. Error bars show 95% confidence intervals for the mean. Zones with different letter labels were significantly different (all p<0.03). Zones with the same letter label were not (p>0.05).

4.3.1 Temporal changes in biodiversity quality

SOCC ISS declined significantly across the region and in the rural zone, while an apparent regional decline in Full ISS approached significance. Also in the rural zone, Avian ISS showed a significant decline. All other temporal differences were non-significant (Table 4).

Although the majority of individual sites did not record identifiable trends over the 14 years, 13 sites showed significant decline in one or more of the ISS groups and 5 had significant increases in at least one group. The greatest site level change was at the site that had recorded the highest ISS scores at the 10-year mark. Discussed as a high outlier at that time (TRCA 2013), this rural site recorded significant declines in Full, Fauna, Avian, and SOCC ISS over the 7 time periods (Fig. 4). Amphibian ISS did not show evidence of a trend. Appendix D lists the species found on this site by time period.

Table 4: Temporal trend and direction of the trend (Dir.) by indicator group across 7 time periods (2003-2016). Significant trends (p<0.05) are denoted **; trends approaching significance (0.05>p<0.15) are marked with * .

Response		Region (n= 283)	Rural zone (n= 122)	Urban zone (n=119)	Urbanizing zone (n=42)
Full ISS	Dir.	↓	ns	ns	ns
	R^2	0.93*			
Fauna ISS	Dir.	ns	ns	ns	ns
	R^2				
Avian ISS	Dir.	ns	↓	ns	ns
	R^2		0.86**		
Amphibian ISS	Dir.	ns	ns	ns	ns
	R^2				
SOCC ISS	Dir.	↓	↓	ns	ns
	R^2	0.91**	0.91**		

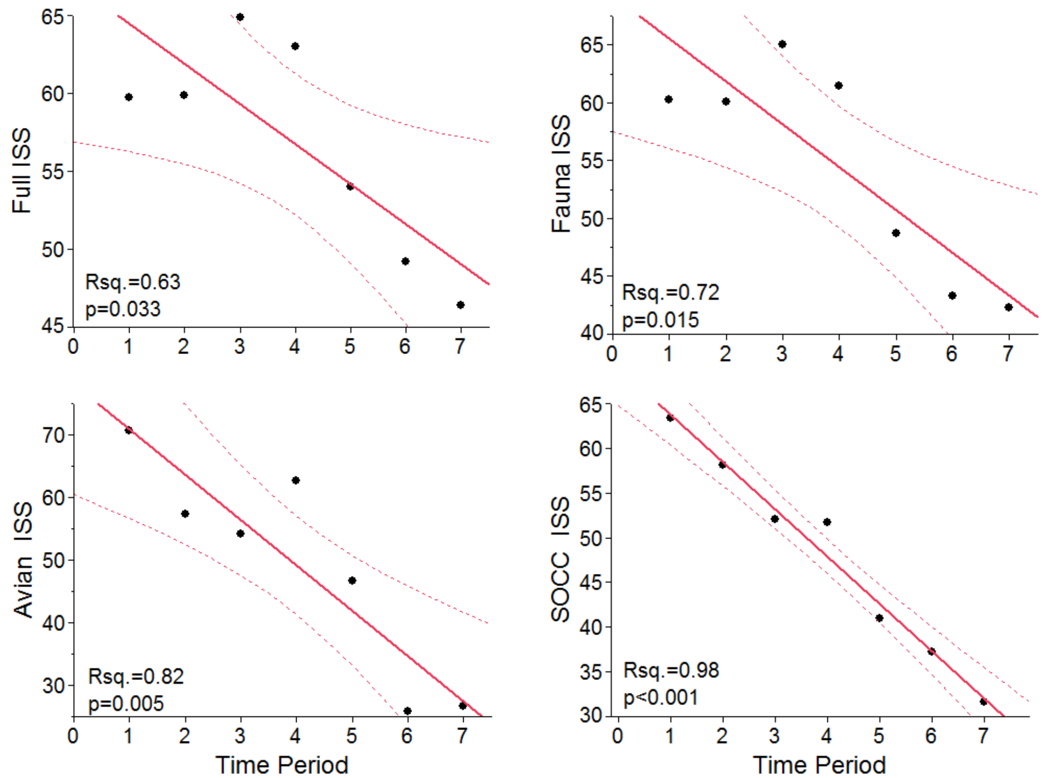

Figure 4: Decline in Full ISS, Fauna ISS, Avian ISS and SOCC ISS at previous high outlier site (site 2) across 7 time periods (2003 - 2016).

4.3.2 Biodiversity quality by watershed

Watershed comparisons consistently showed a significantly higher ISS in the Humber than in the Don watershed. ISS values for the other watersheds ranged between the values for these two; no other differences approached significance. A subsequent analysis by urbanization zone within watershed indicated that there was no significant difference between the urban zone portion of the Humber as compared to the Don (all Don monitoring sites are within the urban zone). In fact, no differences approached significance among any of the urban or urbanizing zones within watersheds.

In the rural zone, however, there were differences (Table 5). For Full ISS the rural Humber scored higher than the rural Etobicoke, with other watershed differences non-significant. For Fauna, Amphibian, and SOCC ISS, the rural Humber was higher scoring than both of the Rouge and the Etobicoke; a similar difference for Avian ISS approached significance.

Table 5: Watershed ISS means for rural zone sites, significant differences (S; $p<0.05$) and differences that approached significance ($0.05<p> 0.15$).

	Means of site-time period scores				Watershed pairs that differed significantly (S; *post hoc* Tukey HSD)		ANOVA R^2, p
	Rural Humber (n=63)	Rural Duffin's (n=26)	Rural Rouge (n=25)	Rural Etobicoke (n=8)	Humber-Etobicoke	Humber-Rouge	
Full ISS	38.8	29.8	29.9	20.4	S		0.92, 0.02
Fauna ISS	33.5	25.4	16.7	10.2	S	S	0.90, 0.002
Avian ISS	27.7	24.1	15.7	15.8	Approached significance	Approached significance	0.85, 0.094
Amphib. ISS	48.3	31.4	20.8	4.5	S	S	0.79, 0.004
SOCC ISS	29.9	19.4	14.9	5.8	S	S	0.91, 0.007

4.4 Severity of invasion

Because invasive plant indicator monitoring began in 2009**,** results are for periods 4-7 covering the years 2009 - 2016.

Total SevInv scores for individual site-time periods ranged from 0 to 40. Table 6 summarizes period 4-7 mean ISS, Total SevInv as well as SevInv for each of the top three scoring invasive indicators: common buckthorn (*Rhamnus cathartica*), garlic mustard (*Allaria petiolata*) and dog-strangling vine (DSV; *Cynanchum rossicum, C.nigrum*). For the ISS groups in Table 5, the significance of ISS differences between urbanization zones across the 4 time periods were consistent with differences across the full 7 time periods. ISS for the native flora indicators group (Flora ISS) was also calculated for periods 4-7. Rural and urbanizing zone mean Flora ISS for this period were nearly identical; the urban zone mean was lower and the difference approached significance in both cases (Table 6).

Table 6: ISS and SevInv scores and responses to zone for time periods 4-7 (2009 - 2016) for the rural, urban and urbanizing (Uz) zones.

	Grand means of site-time period scores*				Significant differences (S; *post hoc* Tukey HSD)			ANOVA R^2, p
	Rural (n=84)	Urban (n=72)	Urbanizing (n=27)	Region (n=183)	Rural - Urban	Rural - Uz	Urban - Uz	
Flora ISS	40.7	32.1	40.2	37.2	Approached significance		Approached significance	0.88, 0.11
Full ISS	33.2	22.3	30.5	28.5	S			0.90, <0.001
Fauna ISS	26.2	13.9	21.2	20.6	S			0.89, <0.001
Avian ISS	22.3	17.1	19.6	19.9				0.68, 0.17
Amphib. ISS	35.2	8.5	27.6	23.6	S		S	0.89, <0.001
SOCC ISS	22.0	9.6	14.5	16.0	S			0.89, <0.001
Total SevInv score	10.6	18.5	17.1	14.6	S			0.89, <0.001
C. buckthorn SevInv	4.3	4.9	6.3	4.9				0.89, 0.35
G. mustard SevInv	2.5	5.7	4.1	4.0	S			0.77, <0.001
DSV SevInv	2.5	5.1	4.4	3.8	Approached significance	Approached significance		0.94, 0.07

*periods 4-7 only; for sites with SevInv scores

4.4.1 Temporal changes in Severity of invasion

Although there were a small number of individual sites for which none of the invasive indicators were found during the first invasive plant monitoring period (2009 - 2010), all had SevInv scores higher than 0 by period 7. Regionally, total SevInv increased slightly period to period, but the trend was not significant (p=0.49). Within the zones no temporal trends were evident.

4.4.2 Response of SevInv to landscape predictors

Among the landscape variables, only road density was a significant predictor of total SevInv. The strongest relationship was for density within the 2 km distance (Table 7). In the rural zone only, and despite the narrow range of road density values, the relationship between SevInv and road density was significant at all three of the 500 m, 1 km, and 2 km distances.

Table 7: Response of Total SevInv to road density (2km). ↑ indicates increasing and ↓ decreasing SevInv with increasing road density. Significance is denoted "" and non-significance "ns".**

Response to Rd density (2 km)		Region	Rural zone	Urban zone	Urbanizing zone
Road density range (km/2 km)		9 - 230	9 - 119[a]	43 - 230	38 - 131
Total SevInv	Dir.	↑	↑	ns	ns
	R^2	0.89**	0.93**		

a 119 was an outlier; the second highest value in the rural zone was 36 km/2km

4.4.3 Severity of invasion by watershed

On a whole watershed basis, only the Humber and Don differed significantly in total SevInv (Table 8). Watersheds with a single site were excluded from this analysis.

Table 8: Regional watershed Mean total SevInv for watersheds having more than one site

Watershed	Etobicoke	Humber	Don	Highland	Rouge	Duffin's	L. Ont.	ANOVA R^2, p
% in urban zone	71	33	96	100	39	10		
N	12	65	28	8	27	28	8	
Mean Total SevInv	8.5	11.1	19.8	23.5	15.8	13.5	19.6	
Means w. different letter are significantly different	AB	B	A	AB	AB	AB	AB	0.89, 0.004

When the urbanization zone and watershed were considered together total SevInv was higher in the rural Rouge as compared to the rural Humber. No other differences approached significance. The power to detect differences may have been affected by the small number of sites in some watershed-zone groupings however (Table 9).

Table 9: Watershed mean SevInv differences by zone for watersheds having more than one site.

a) Rural zone

Watershed	Etobicoke	Humber	Rouge	Duffin's	ANOVA R^2, p
N	6	39	19	20	
Mean Total SevInv	6.8	8.2	16.5	10.7	
Means w. different letter are significantly different	AB	B	A	AB	0.93, 0.03

b) Urban zone

Watershed	Etobicoke	Humber	Don	Highland	Rouge	L. Ont.	ANOVA R^2, p
N	3	18	28	8	4	8	
Mean Total SevInv	11.3	15.4	19.8	23.5	14.3	19.6	0.80, 0.66
No significant differences were found							

c) Urbanizing zone

Watershed	Etobicoke	Humber	Rouge	Duffin's.	ANOVA
N	3	8	4	8	R^2, p
Mean SevInv	9.0	15.8	14.0	20.6	0.79, 0.53
No significant differences were found					

4.5 ISS response to SevInv

The response of ISS to SevInv was inconsistent, varying from a decline, through no significant relationship to an increase, with increasing SevInv. Regional Flora ISS increased with increasing total SevInv score. In the rural zone, ISS either declined with increasing SevInv, or there was no significant association. In the urban and urbanizing zones, where a relationship was significant or approached significance, the association of the affected ISS with SevInv was positive (Table 10).

Table 10: Association between ISS and Total SevInv score in the region and the urbanization zones. ↑ denotes increasing ISS and ↓ decreasing ISS with increases in SevInv score. Significant relationships are denoted **; those approaching significance are marked * .

ISS group		Region (n=183)	Rural (n=84)	Urban (n=72)	Urbanizing (n=27)
Full ISS	Dir.	ns	ns	↑	↑
	R^2			0.71*	0.94**
Fauna ISS	Dir.	ns	↓	ns	↑
	R^2		0.90*		0.93*
Avian ISS	Dir.	ns	↓	ns	ns
	R^2		0.77**		
Amphibian ISS	Dir.	ns	ns	ns	ns
	R^2				
SOCC ISS	Dir.	ns	↓	ns	↑
	R^2		0.90*		0.91*
Flora ISS	Dir.	↑	ns	↑	↑
	R^2	0.89**		0.75*	0.96*

4.5.1 ISS response to most commonly occurring invasive plant indicators

The three invasive plants found most often at TVM sites were common buckthorn, garlic mustard and dog-strangling vine (DSV). The associations between ISS and the SevInv score for each are summarized in Table 11. Where significant, or near significant, relationships existed they were negative regionally and in the rural and urban zones, with the exception of Flora ISS. For Flora ISS in all zones and for all ISS groups in the urbanizing zone, associations were either positive or non-significant.

Table 11: Association between ISS and the SevInv score for a) common buckthorn, b) garlic mustard and c) dog-strangling vine in the region and the urbanization zones. ↑ indicates and increase in ISS with increasing SevInv; ↓ indicates a decrease in ISS with increasing SevInv; no significant association is . Significance is denoted **; associations that approached significance are marked * .

a) Response		Region	Rural zone	Urban zone	Urbanizing zone
Full ISS	Dir.	ns	↓	ns	↑
	R^2		0.89*		0.91*
Fauna ISS	Dir.	ns	↓	ns	ns
	R^2		0.87**		
Avian ISS	Dir.	ns	↓	↓	ns
	R^2		0.74**	0.24*	
Amphibian ISS	Dir.	ns	ns	ns	ns
	R^2				
SOCC ISS	Dir.	ns	↓	ns	ns
	R^2		0.87*		
Flora ISS	Dir.	ns	ns	ns	ns
	R^2				

b) Response		Region	Rural zone	Urban zone	Urbanizing zone
Full ISS	Dir.	ns	ns	ns	↑
	R^2				0.97**
Fauna ISS	Dir.	ns	ns	ns	↑
	R^2				0.96**
Avian ISS	Dir.	ns	ns	ns	↑
	R^2				0.94**
Amphibian ISS	Dir.	ns	ns	ns	ns
	R^2				
SOCC ISS	Dir.	ns	ns	ns	↑
	R^2				0.93**
Flora ISS	Dir.	ns	ns	ns	↑
	R^2				0.98**

c) Response		Region	Rural zone	Urban zone	Urbanizing zone
Full ISS	Dir.	ns	ns	ns	ns
	R^2				
Fauna ISS	Dir.	ns	↓	ns	ns
	R^2		0.91*		
Avian ISS	Dir.	↓	ns	↓	ns
	R^2	0.67*		0.07*	
Amphibian ISS	Dir.	↓	↓	ns	ns
	R^2	0.90*	0.86**		
SOCC ISS	Dir.	↓	ns	ns	ns
	R^2	0.89*	0.90*		
Flora ISS	Dir.	↑	ns	↑	ns
	R^2	0.89*		0.78*	

4.6 ISS response to landscape predictors

The response of ISS to the landscape predictors is summarized in Table 11; there were significant relationships in all cases. For the region, when compared to the previous analysis that incorporated 5 periods of data (McKenzie *et al*. 2018), the strength of significant relationships were similar or slightly higher in most cases (Table 12a).

Analyses for the rural and urban zones (Table 12b, c) show differences between the two zones. The habitat landscape predictors were consistently significant predictors, at all 3 distances, for all groups in the rural zone, while there were very few significant predictors for the urban zone. Road density was primarily non-significant in the rural zone, with the exception of declining SOCC ISS with increasing road density at the 1 km distance. In the urban zone a negative road density effect on ISS was either significant or approached significance at the 500 m distance for all groups other than the Avian one; for the amphibians in the urban zone a significant negative effect was evident at the 1 km distance.

Table 12: Direction (Dir.) and strength (R^2) of the response of mean ISS to increasing values of landscape predictor variables in the region, the rural and the urban zones. R^2 values are shown for significant responses. Non-significant (n.s.) and relationships that approached significance (appr. sig.;0.05>p<0.15) are shown. Bold R^2 values highlight the distance at which each of the 3 main landscape effects had the strongest effect.

a) The region (n=54)

Response		Area NatCov			Area wetland			Road density		
		500m	1km	2km	500m	1km	**2km**	500m	1km	2km
Full ISS	Dir.	↑	↑	↑	↑	↑	↑	↓	↓	↓
	R^2	**0.41**	0.38	0.32	0.09	0.23	**0.24**	**0.34**	0.31	0.27
Fauna ISS	Dir.	↑	↑	↑	↑	↑	↑	↓	↓	↓
	R^2	**0.44**	0.41	0.38	0.16	0.33	**0.34**	0.28	0.27	**0.30**
Avian ISS	Dir.	↑	↑	↑	↑	↑	↑	↓	↓	↓
	R^2	**0.31**	0.29	0.24	0.09	0.20	**0.22**	0.12	0.11	**0.14**
Amphibian ISS	Dir.	↑	↑	↑	↑	↑	↑	↓	↓	↓
	R^2	**0.37**	0.35	0.34	0.12	0.25	**0.25**	0.28	0.31	**0.32**
SOCC ISS	Dir.	↑	↑	↑	↑	↑	↑	↓	↓	↓
	R^2	**0.50**	0.45	0.46	0.08	0.23	**0.26**	**0.29**	0.28	0.28

b) The rural zone (n=24)

Response		Area NatCov			Area wetland			Road density		
		500m	1km	2km	500m	1km	2km	500m	1km	2km
Full ISS	Dir.	↑	↑	↑	↑	↑	↑	ns	ns	ns
	R^2	**0.41**	0.34	0.20	0.32	**0.41**	0.31			
Fauna ISS	Dir.	↑	↑	↑	↑	↑	↑	ns	↓	↓
	R^2	**0.46**	0.39	0.33	0.30	**0.43**	0.36		appr. sig.	appr. sig.
Avian ISS	Dir.	↑	↑	↑	↑	↑	↑	ns	↓	ns
	R^2	**0.40**	0.38	0.30	0.27	0.32	**0.35**		appr. sig.	
Amphibian ISS	Dir.	↑	↑	↑	↑	↑	↑	ns	↓	↓
	R^2	**036**	0.25	0.22	0.16	**0.28**	0.17		appr. sig.	appr. sig.
SOCC ISS	Dir.	↑	↑	↑	↑	↑	↑	ns	↓	ns
	R^2	**0.55**	0.43	0.43	0.20	**0.31**	0.24		**0.17**	

c) The urban zone (n=22)

Response		Area NatCov			Area wetland			Road density		
		500m	1km	2km	500m	1km	2km	500m	1km	2km
Full ISS	Dir. R^2	↑ **0.14**	ns	ns	ns	ns	ns	↓. **0.23**	ns	ns
Fauna ISS	Dir. R^2	ns	ns	ns	↑ **appr. sig.**	ns	ns	↓ **appr. sig.**	ns	ns
Avian ISS	Dir. R^2	ns	ns	ns	ns	ns	ns	ns	ns	ns
Amphibian ISS	Dir. R^2	ns	ns	ns	↑ **0.19**	ns	ns	↓ appr. sig.	↓ **0.18**	ns
SOCC ISS	Dir. R^2	↑ **0.18**	↑ 0.12	ns	ns	ns	ns	↓ **0.15**	ns	ns

4.6.1 Best-fit landscape response models

McKenzie *et al.* (2018) presented best-fit multiple regression models for the responses of the ISS to landscape characteristics over the first 5 time periods. Repeating the analysis for the current 7-period dataset produced similar but not identical results. Once again the models were stronger for the rural zone than for the region or the urban zone (Table 13). There were again no significant models for the urbanizing zone, and in the urban zone, natural cover area within 500 m, was again the only consistently significant landscape predictor for all ISS groups. However, road density as a negative predictor of ISS increased in model leverage significance generally. Regionally and in the rural zone, for all groups other than Full ISS, an interaction term between NatCov area within 500 m and NatCov area within 1 km also improved model strength and reduced model error.

Table 13: Best-fit multiple regression models for the landscape variables in combination as predictors of the ISS' in a) the region (n=54), b) the rural zone (n=24) and c) the urban zone (n=22). Best-fit models were selected on maximum adjusted R^2 and minimum root mean square error (RMSE). Landscape predictors are listed in order of highest significance.

a) Region

Response	Adj. R^2	RMSE	Landscape predictors included and sign of the response
SOCC ISS	0.67	6.3	+NatCov in 500 m, -road density in 2 km, +wetland in 1 km, +NatCov in 500 m*NatCov in 1 km, +NatCov in 1 km
Fauna ISS	0.68	6.2	+wetland in 1 km, +NatCov in 500 m, -road density in 2 km, +NatCov in 500 m*NatCov in 1 km, +NatCov in 1 km
Full ISS	0.59	6.3	-road density in 500 m, +wetland in 1 km, +NatCov in 500 m
Amphibian ISS	0.58	13.9	-road density in 2 km, +wetland in 1 km, +NatCov in 500 m, +NatCov in 1 km, +NatCov in 500 m*NatCov in 1 km
Avian ISS	0.41	6.9	+NatCov in 500 m, +wetland in 1 km, +NatCov in 500 m*NatCov in 1 km, -road density in 2 km, +NatCov in 1 km

b) Rural zone

Response	Adj. R^2	RMSE	Landscape predictors included and sign of the response
Fauna ISS	0.83	4.8	-road density in 2 km, +wetland in 1 km, +NatCov in 500 m, +NatCov in 1 km, +NatCov in 500 m*NatCov in 1 km
SOCC ISS	0.78	5.5	+NatCov in 500 m, -road density in 2 km, +wetland in 1 km, +NatCov in 1 km, +NatCov in 500 m*NatCov in 1 km
Full ISS	0.64	5.6	+wetland in 1 km, +NatCov in 500 m, -road density in 1 km
Avian ISS	0.66	5.6	+wetland in 2 km, -road density in 1 km, +NatCov in 500 m, +NatCov in 500 m*NatCov in 1 km, +wetland in 1 km
Amphibian ISS	0.63	12.7	+NatCov in 500 m, - road density in 2 km, +wetland in 1 km, +NatCov in 1 km, +NatCov in 500 m*NatCov in 1 km

c) Urban zone

Response	Adj. R^2	RMSE	Landscape predictors included and sign of the response
Amphibian ISS	0.32	8.5	+wetland in 500 m, -road density in 1 km
Fauna ISS	0.26	5.3	+wetland in 500 m, -road density in 500 m
SOCC ISS	0.14	5.0	+NatCov in 500 m
Full ISS	no significant model (+NatCov in 500 m as sole predictor approached significance; p=0.09)		
Avian ISS	no significant model		

5.0 Discussion

5.1 Temporal trends in biodiversity quality

Statistically significant temporal trends have begun to emerge in the TVMP data for some groups; the declines in SOCC ISS regionally and of Avian and SOCC ISS in the rural zone are causes for concern. Declines affecting the rural zone impact the higher quality natural areas, i.e. those having the highest priority for conservation; across the region, SOCC declines demonstrate disproportionate impacts on those species already established as priorities for conservation by TRCA. Both trends are clear signals that action is needed.

5.1.1 The rural zone

The specific reasons for declining trends are not quantitatively documented through the TVM program's data collection process. However qualitative observation and established research suggest both causative factors and actions that can be helpful in curtailing these trends before those species found less consistently in the later monitoring periods are lost entirely.

Within the rural zone of the Toronto region, natural areas are protected from residential and industrial development through legislation. As a result, during the monitoring period, there has been very limited habitat area lost to such development; it can be ruled out as a direct causative factor for the declining biodiversity quality. There have, however, been other observable changes during this period with respect to the types and intensity of human disturbance. Primarily recreational, some of the increased impacts on natural habitats include:

- the proliferation of trail networks over time which continuously expands the area of trail impacts
- the expansion of permitted activities on trails from lower-impact "passive" to higher-impact "active" ones such as cycling and various types of racing (Korpilo et al. 2018)
- new off-trail recreational activities of a type that greatly increase impacts on wildlife through placement of infrastructure and promotion for high-intensity use (e.g. zip-lines, canopy tours, obstacle course competitions, etc.)
- increasing numbers of participants in existing recreational activities, including those traditionally considered "passive" or low-impact; strategies designed to widely promote such activities increase the number of participants further, thereby amplifying the effect
- increased infrastructure/development footprint within conservation lands
- the use of conservation lands for recreation types traditionally restricted to municipal parks or privately-owned properties zoned for the affected uses; examples include swimming/wading pools, golf driving ranges, public events
- increase in propensity for recreational users of natural areas to ignore regulations or limitations designed to protect wildlife and their habitats (e.g. encroachment, off-leash dogs, free-roaming cats, fence-cutting to access no-trespass areas, etc.)

Management of recreational activities within the natural heritage system needs to consider a variety of factors including:

1. The understanding that all human activity in natural areas has some level of impact on the natural ecosystem; the relationship between recreation use and impact has often been described as curvilinear, such that increases beyond minimal use have the greatest change in effect; once intensity of use is high, additional increases have a much lower additional effect (Hammit & Cole, 1998).
2. The impact of any activity extends well beyond its physical footprint; Lehvavirta *et al*. (2014) found pronounced effects on tree regeneration extending at least 80 m from recreational trails in Finland; in another study, Ballantyne et al. (2014) found that nearly 47 ha of 829 ha of endangered forest was lost to 46.1 km of recreational trails and their edge effects. These studies, and in fact most trail impact studies, considered vegetation only; there is a dearth of literature on fauna impacts. However, as far back as the 1990's, studies of bird communities documented a shift from specialist to generalist species near trails (Miller *et al*. 1998). The same authors also found that nest predation was higher near trails and that many bird species in the study area avoided nesting within 75 m of trails.

3. The addition of new recreational activity types that include the placement of infrastructure within natural areas (e.g. ziplines, canopy tours, climbing and exercise equipment) add impacts that may be orders of magnitude higher than traditional "passive" activities such as hiking, cross country skiing and nature appreciation.
4. Increasing participation in traditional activities increases the degree of impact; there is very likely to be a threshold beyond which the ecosystem cannot maintain integrity; such a threshold may not be recognizable until it is breached, and perhaps well after it is breached.
5. The actual and potential interactive effects between different activities with respect to ecosystem impact need to be considered.
6. The magnitude of effect on wildlife is influenced by the type, duration, frequency, intensity, location, and timing of the disturbance (Steidl and Anthony 2000).
7. The potential for conflict between different activities; e.g. the addition of cycling, group activities, racing, zip-lining, or canopy tours to hiking trails traditionally used for nature appreciation will inevitably introduce conflicts between these activities.
8. Beyond a low threshold of use, increasing the number of users and the mix of activities will impair the experience for the users themselves.

The studies cited above address walking/hiking use of trails only, while other studies note that cycling is a higher impact activity. For example, trails used for mountain biking had higher levels of soil erosion and exposed rocks and tree roots than high-use walking trails (Day and Turton, 2000). Zones of impact need to be quantified by type of use in order to better understand impacts. In addition, the cumulative effects of all activities in combination, and over time, must be understood, prevented, minimized and/or mitigated in a realistic manner if the persistence of many of the species still present today is to be ensured. Outdoor recreation is the 2nd leading cause of decline of U.S. threatened and endangered species on public lands (Losos *et al.* 1995). Our data suggest that the situation may be very similar here. Because our indicators include species not yet designated as threatened or endangered, corrective action can still be taken before that state is reached.

For the longer timeline (14 yrs.), as compared to the previous analysis at 10 yrs., road density had a higher significance as a predictor of ISS in the rural zone models, particularly for the fauna-based ISS groups.

Rural roads are experiencing increased traffic volume as residents of new residential developments commute in to the city (personal observation). This may explain the increased influence of road density. Previously, low-use roads may have had a lesser increase in impact on ISS as road density increased (within the range of densities in the rural zone), while higher traffic volumes may alter that picture. In any case, road density does now appear to be an important factor in the rural zone. The urban impacts conceptual model in Appendix E summarizes the negative impacts exerted on species and habitats by roads and outlines both planning related strategies to minimize impacts, and mitigation strategies to reduce the negative influences of existing roads.

In addition to negative impacts at the local scale, wider-scale dynamics will have effects that may or may not be possible to influence regionally. Climate change is an obvious example, as are habitat loss and habitat quality change in areas beyond regional boundaries that affect regional species for which the annual cycle requires such habitats. The best, but not sole, example of the latter would be migratory birds.

As the globe warms on average, predictions for the Great Lakes region emphasize not an overall warming trend, but rather an increase in volatility of weather patterns and of extremes in both temperature and precipitation (Environment Canada 2016). We are already experiencing these effects. Basic biology/physiology tells us that each species is adapted for a range of environmental conditions. One species may have a wider tolerance to extremes, and/or volatility than another, but every species will begin to show effects as its thresholds are surpassed; it may be unable to reproduce successfully, or even survive beyond a high stress threshold. We cannot say for certain whether the declining presence of some indicator species may be a result of changing climate/weather. Studies that could provide such detail are lacking, and would need to be carried out species by species to provide definite answers.

5.1.1.1 High outlier rural site

The significantly declining Full, Fauna, Avian and SOCC ISS of the previously high scoring outlier site (Fig. 4) provides an opportunity to explore potential causes. The discussion is necessarily qualitative, since impact monitoring data does not exist; observations with respect to changes occurring at this site have been made by multiple volunteers and by conservation authority staff. The urban impacts conceptual model is a useful guide (Appendix E). It provides a checklist of potential impacts to consider in the interpretation process. Despite an inability to demonstrate statistical relationships between potential impacts and the ISS', this discussion will elucidate some of the indirect ways in which human activity impacts the survival and persistence of other species.

The site is located in the rural zone. With respect to the landscape variables included in the best-fit rural model, neither area of natural cover, nor road density, nor wetland area have changed appreciably within 2 km of the site over the affected 14 year period. However, the previously rural standard dirt road immediately adjacent to the site was upgraded to an asphalt paved surface in 2004. It does not have shoulders nor a verge separating it from the wetland. Its alignment offers an alternate route from the north into the city of Brampton when the nearby regional roads designed for higher capacity traffic are busy. Once paved, although the posted speed-limit did not change, effective speeds as well as the volume of traffic were both observed to increase dramatically. Our simplified road density variable does not capture these changes. The site supported indicator species particularly sensitive to road effects. Subsequent to the paving, observers noted multiple porcupine road-kill events and porcupine was not observed on the site during the final monitoring period (Appendix D). All of the amphibian indicators are sensitive to roads, because of their need to move between overwintering and spring breeding habitats, and need to disperse following breeding. Several of the amphibian indicators have been abundant on this site since initiation of monitoring, and the amphibian ISS did not change over 14 years. Because the ISS captures presence/absence of species, not abundance, it is not sensitive enough to tell us whether any of the amphibian indicators have declined. The striped

(Western) chorus frog (Appendix D) was recorded only during the first monitoring period, but this observation was flagged as having uncertain status during the data verification process. We cannot draw conclusions with respect to its apparent disappearance from the site.

The previous report (TRCA 2013) noted that this site appeared to benefit from the fact that the wetland covered the area between the most likely public access points and the forest beyond; although conservation authority owned and thus permitting public access, practical access was limited by the need to wade through water to reach the forest. Since that time access has become easier due to the removal of a beaver dam that was causing flooding of the road. The drying out of an access point resulted in a nearby resident making a decision to improve access by mowing a path. Two potential impacts from this are an increase in disturbance by people accessing the natural area (it is unknown to what extent this has in fact occurred), and the introduction/dispersal of invasive species. During the first invasive monitoring period (2009-2010), garlic mustard was observed as few, scattered individuals within the site boundary (which has no formal trails) and as abundant along the mowed path beyond the boundary. In the subsequent two periods, it had expanded to a score of 4 within the site, indicating a finding of between 1 and 4 patches of garlic mustard dominance, the largest patch of a size greater than 100 m^2.

Appendix D shows declines among the birds. In addition to impacts on-site, this introduces the possibility of factors at a larger scale playing a part in the declining ISS, such as climate change/weather effects and changes in habitat availability or quality during non-breeding seasons for the species affected. The pileated woodpecker and ruffed grouse are non-migratory. Both would however be utilizing local habitat well beyond the boundaries of the site itself.

Clearly some of the negative influences on biodiversity quality at this site are not under the control of conservation land managers. However, site specific recommendations include mitigating the effect of the road on the site, eliminating the mowing and perhaps public education about how to minimize personal impacts on protected areas such as this.

5.2 Severity of invasion

By 2016, TVMP monitoring sites throughout the region were <u>all</u> invaded by one or more of the high priority invasive plants monitored. While a temporally increasing trend in Total SevInv score over the 4 time periods was not significant, the short duration of the monitoring combined with qualitative observation of expansion of these plants in the region suggest that, were monitoring to continue, an increase over time might become evident.

There is a possibility that the monitoring itself was one agent for the spread of some of the invasive plants, something that was not considered during original protocol development. This would be particularly of concern on sites that were not regularly visited by people other than the monitoring surveyors, and it should be taken into consideration when planning future monitoring work. Protocols involving the cleaning of boots to remove seeds and vegetation prior to entering a site and after moving through an invaded area, for example, may help to limit this effect.

The large significant difference in mean Total SevInv between the rural and the urban zone, largely due to garlic mustard and to DSV, is not surprising. While the fact that Fauna, Avian and SOCC ISS declined with increasing Total SevInv in the rural zone is likewise not a surprise, it is concerning, since the rural zone contains the highest biodiversity representation.

5.3 ISS response to landscape predictors

5.3.1 ISS Response to severity of invasion

The fact that the response of ISS to severity of invasion was not consistent among urbanization zones is interesting (Table 11). Intuitively we would expect native species diversity, and therefore ISS, to decline with increasing severity of invasion. This is in fact what occurred in the rural zone where mean ISS was higher. Fauna, Avian and SOCC ISS all declined with increasing severity of invasion. However, in the urban and urbanizing zones, the ISS responses to SevInv score were either not evident or were positive, increasing as SevInv increased. The inconsistency suggests that multiple mechanisms are at play, and/or that a key mechanism produces different results in communities with high versus low levels of native diversity. Cleland *et al.* (2004) review earlier work and discuss this idea. They conclude that resource utilization by the community is an important driver of the effect that introduction of an invasive species will have. Where native diversity is high, so too is resource utilization such that resources are not available for invaders and the community is more resistant to invasion. At intermediate levels of native diversity, available resources make the community less resistant to invasion and more susceptible to resulting impacts on sensitive species as that invasion occurs. Our results for the rural zone where ISS is higher than the urban zone, but reduced from ideal, fit with this hypothesis. Where native diversity is already low, space and resource availability is high and the community is easily colonized by both native and invasive plants. The urban zone results are in line with this idea, although only the native and invasive plants increased together as evidenced by coincidently increasing Full ISS, Flora ISS and SevInv. This suggests that source populations for the flora indicators remain in sufficient proximity within/to the urban zone, that they are able to take advantage of resource opportunities, and that this is not the case for many of the fauna.

The urbanizing zone presents a different result, where both flora and some of the fauna groups increased at the same time as did SevInv. Perhaps as the zone with the highest level of ongoing disturbance, combined with proximity to rural zone source populations of diverse species, opportunities are higher for colonization by native flora and fauna as well as invasive plants. Over time, the competitive advantage that the invasive species have may limit the establishment of native colonizers and thus limit native diversity.

5.3.2 Response to other landscape predictors

Because of the difference in direction of effect of SevInv when ISS scores were high, versus intermediate, versus low, it is not surprising that SevInv was not included in the best-fit models as an overall predictor of ISS (Table 13). All of the other main landscape predictors did appear in the selected models; regional responses were as expected, and in agreement with previous results (McKenzie *et al.* 2018, TRCA 2013). Area of natural cover and area of wetland positively predicted ISS, while road density did so negatively (Table 12, 13).

The updated landscape predictor models, now incorporating 7 periods of data were generally similar to the previous models, with slight differences. This time, models for all of the ISS groups increased in predictive strength (R^2) and had lower root mean square error (RMSE) than previously for the rural zone, but were weaker and had higher model error than previously for the urban zone (Table 13).

For the rural zone, and the region as a whole, models for all fauna groups were improved by the inclusion of an interactive effect of NatCov within 500 m and NatCov within 1 km, evidence supporting the importance of sufficient habitat area for breeding as well as the need for the larger surrounding habitat for dispersal and interaction among breeding sites/populations for fauna (i.e. meta-population dynamics). The lack of such extensive habitat in the urban zone and the consequential isolation of small breeding populations is one cause of the depauperate fauna representation that we now see.

In the urban zone, the models suggest once again, more strongly this time, that the major factors influencing the very low biodiversity quality here are primarily other than the landscape predictors analyzed. Urban matrix influences are the key concern, that is the influences of urban areas on nearby natural cover, in a large part driven by the activities undertaken by people within the natural cover that remains in this matrix. In addition to space, biodiversity needs protection from high levels of human visitation, from contaminants, from noise pollution, from invading species, from pets, etc.. Effective management of all of these is necessary for many native species to have the ability to survive and reproduce in the terrestrial natural cover and wetlands that have been maintained within the urban context.

5.4 Urban impacts review and urban impacts conceptual model

The conceptual model in Appendix E summarizes the known and hypothesized impacts of urban development on natural areas, highlighting the mechanisms of impact, the type and direction of resulting change, the effect on ecosystem condition, and the feasibility of reversing this result. Many effects, once established, are extremely difficult if not impossible to reverse, which highlights the importance of understanding them in advance and planning appropriately to eliminate, or at least to minimize them. The Economics of Ecosystems and Biodiversity (TEEB), an organization studying this subject from both a global and regional perspective, has published a series of informative reports. One of these highlights specific local and regional policy and management recommendations to reduce the impact of urbanization on biodiversity (Wittmer *et al*. 2011), while another focuses on water and wetlands (Russi *et al*. 2013). Alberti and Waddell (2000) and Alberti (2005, 2010) discuss urban impacts on ecosystem function in the context of efforts to sustain the natural services that healthy ecosystems provide to human residents, as do publications from the Baltimore ecosystem study (e.g. Cadenasso *et al*. 2008). Ditchkoff *et al*. (2006) consider the novel stresses experienced by wildlife as they attempt to survive and reproduce in urban areas. Venter *et al*. (2006) summarize threats to endangered species in Canada, and Machtans *et al*. (2013) conducted a first estimate of the number of birds killed by colliding with building windows in Canada. These authors ideas are incorporated into the urban impacts model.

6.0 Conclusion

The reduced biodiversity quality in the urban zone is a concern; although some conservation lands under natural cover have been preserved there, impacts from the surrounding urban land use reduce the quality of the habitat and the ability for it to support species of concern, and in fact most fauna species (Section 5.4; Appendix E). Key impacts that need mitigation include high intensity of recreational use, disturbance by off-leash dogs and free-roaming cats, off-trail activity, encroachment, dumping, introduction and dispersal of invasive species, noise pollution and roads as barriers or hazards to movement of fauna species. Prohibition of damaging activities is often already in place via bylaws or rules of behaviour for individual properties. Enforcement and other creative methods to induce residents and visitors to abide by the rules are needed, as is the establishment of areas out-of-bounds for human use to provide usable habitat for sensitive species.

Of even greater concern is the fact that clear impacts on biodiversity quality were recorded in the rural zone, including a significant decline in ISS for the Full group and the SOCC regionally, as well as for the Avian group and SOCC in the rural zone (Table 4; section 5.1.1). Where conservation lands in the rural zone were at one time lightly used for recreation, their proximity to a growing human urban population has resulted in quickly growing intensity of use. This has been exacerbated by the relaxation of rules that previously prohibited other than passive recreation and by a declining understanding among the general public of the value of regulations where they do exist. Without a change in the regional management approach to and effective public education of the value of conservation lands, biodiversity will continue to decline in the rural zone, and soon reach the minimal levels of the urban zone. Despite the strategic objective of protecting and enhancing regional biodiversity, it is declining.

7.0 Recommendations

The TVM program has been discontinued as a result of funding limitations, yet the long-term dataset remains of value, and its existence results from significant investment by the organization over the past two decades. It has been a key component of the Terrestrial Natural Heritage (TNH) Program that began in the late 1990s. Incorporating the development of the Terrestrial Natural Heritage System Strategy, the Conservation Concern scoring methodology for species, the regional scale landscape analysis methods, the region-wide application of field biological inventories, and the TVM monitoring the TNH program has been leading edge with respect to biodiversity assessment and conservation planning practice. Its comprehensive approach, real-world practical methods, and design for application in an urbanizing regions are major strengths.

TRCA terrestrial monitoring has transitioned to a more detailed, plot-based program, in operation since 2008. The archival TVM dataset provides a less detailed high-level view of overall ecological condition, and biodiversity quality over the 2003 - 2017 period.

The overlapping timeframes of the two programs provide an opportunity, to conduct an integrated analysis of data from both programs for the overlapping timeframe. Such an analysis would provide valuable information:

- through a calibration exercise, high-level indicators of ecological condition and biodiversity quality could be identified; such indicators could be reported in a consistent way over a longer time-period, and continuing into the future (in effect extending the time series for the current monitoring program)
- the exercise would provide an opportunity to test and assess potential new methods to analyze and interpret the plot monitoring dataset, in order to maximize the ability for monitoring reports to inform the conservation management work of the authority

The survey protocols and field aids, site information, 2002 - 2017 dataset, methods of quality assurance and data analysis, training presentations and program reports are being archived. An ArcMap geodatabase of the data will be available for future use.

Depending on the results of the integrated analysis above, it might also be useful to conduct an additional round of TVM protocol monitoring at one or more future intervals (perhaps 3 or 5 years), and thereby extend the dataset. The TVM indicator species approach, and the year-round coverage, mean that while the program did not monitor many species, it did include data collection for some fauna species that are not well-surveyed by the staff program (some of the frogs, porcupine), and provided data on species in overwintering habitat (porcupine, ruffed grouse, mink).

If such an effort were to be undertaken, it would not need to involve the recruitment of volunteers. Staff could carry out the surveys. With multiple sites visited in a day, and the extended time windows available for completing each survey, the number of staff involved would not be high.

There is also value in reviewing the methods developed to monitor and score the severity of invasion for the high priority invasive plants monitored under the TVM program, as potentially informative for other future invasive monitoring or assessments.

8.0 References

Alberti, M. 2010. *Maintaining ecological integrity and sustaining ecosystem function in urban areas*. Current Opinion in Environmental Sustainability 2010, 2:178–184

Alberti, M. 2005. *The effects of urban patterns on ecosystem function*. International Regional Science Review 28, 2

Alberti, M. and Waddell. 2000. *An integrated urban development and ecological simulation model*. Integrated Assessment 1: 215 - 227

Ballantyne M., Gudes O., Pickering C. 2014. *Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia.* Landsc. Urb. Plan. 7:4

Butchart, S., Walpole, M., Collen, B., van Strien, A., Scharlemann, J., Almond, R., Baillie,J., Bomhard, B., Brown, C., Bruno, J., Carpenter, K., Carr, G., Chanson, J., Chenery, A., Csirke, J., Davidson, N., Dentener, F., Foster, M., Galli, A., Galloway, J., Genovesi, P., Gregory, R., Hockings, M., Kapos, V., Lamarque, J., Leverington, F., Loh, J.,McGeoch, M., McRae, L., Minasyan, A., Hernández Morcillo, M., Oldfield, T., Pauly,D., Quader, S., Revenga, C., Sauer, J., Skolnik, B., Spear, D., Stanwell-Smith, D.,Stuart, S., Symes, A., Tierney, M., Tyrrell, T., Vié, J., Watson, R., 2010. Global Biodiversity: Indicators of Recent Declines. Science 328, 1164–1168

Cadenasso, M., S. Pickett, and M. Grove. 2006. *Integrative approaches to investigating human-natural systems: the Baltimore ecosystem study.* Natures Sciences Societes 14:4-14

Cleland E., Smith M., Andelman S., Bowles C., Carney K., Horner-Devine M., Drake J., Emery S., Gramling J., Vandermast D. 2004. *Invasion in space and time: non-native species richness and relative abundance respond to interannual variation in productivity and diversity*. Ecology Letters 7: 947–957

Cummings, H., S. Megens and D. Murray. 2010. *Overview of the Agriculture Sector in the Ontario Greenbelt and Comparison to the Rest of Ontario*. School of Environmental Design and Rural Development, University of Guelph http://www.hcaconsulting.ca/LinkClick.aspx?fileticket=SBB73wtMeKM%3D&tabid=83

Day, T. and Turton, S., 2000. *Ecological impacts of recreation along biking tracks and walking tracks*. Wet Tropics Management Authority and Rainforest Cooperative Research Centre. pp. 143–152.

Ditchkoff, S., S. Saalfield and C. Gibson. 2006. *Animal behaviour in urban ecosystems: Modifications due to human-induced stress*. Urban Ecosystems: 9

Environment Canada. 2016. *Climate data and scenarios for Canada: Synthesis of recent observation and modelling results.* http://climate-scenarios.canada.ca/files/Climate%20data%20and%20scenarios%20for%20Canada_EN_2016.pdf [accessed May 28, 2018]

Feest, A., Aldred, T., Jedamzik, K., 2010. Biodiversity quality: a paradigm for biodiversity. Ecol. Indic. 10, 1077–1082.

Hammitt W., Cole D. (1998) *Wildland recreation: ecology and management*. John Wiley and Sons, New York, 361p

Korpilo S., Virtanen T., Saukkonen T., Lehvavirta S. 2018. *More than A to B: Understanding and managing visitor spatial behaviour in urban forests using public participation GIS*. J. Environ. Manage. 207:124-133

Lehvavirta S., Vilisics F., Hamberg L., Malmivaara-Lämsä M., Kotze D. 2014. *Fragmentation and recreational use affect tree regeneration in urban forests*. Urban Forestry & Urban Greening 13:869–877

Losos E., Hayes J., Phillips A., Wilcove D., and Alkire C. 1995. *Taxpayer-Subsidized Resource Extraction Harms Species.* BioSci. 45: 446-455

McKenzie T., L. Normand, N. Iwanycki, G. Miller, P. Prior. 2018. *Assessing the utility of a novel terrestrial biodiversity quality indicator with 10 years of monitoring data*. Ecol. Indic. 85: 422–431

Miller S., Knight R. and Miller C. 1998. *Influence of Recreational Trails on Breeding Bird Communities*. Ecol. Appl. 8:162-169

Parks Canada. 2018. https://www.pc.gc.ca/en/pn-np/on/rouge [accessed May 24, 2018]

Province of Ontario. 2017. http://www.mah.gov.on.ca/Page187.aspx [accessed May 24, 2018]

Russi D., P. ten Brink, A. Farmer, T. Badura, D. Coates, J. Förster, R. Kumar and N. Davidson. 2013. *The Economics of Ecosystems and Biodiversity for Water and Wetlands*. IEEP, London and Brussels; Ramsar Secretariat, Gland.

SAS Institute. 2007. *JMP Statistics and Graphics Guide, Release 7*. SAS Institute Inc., Cary, NC, USA

Steidl, R., and Anthony R. 2000. *Experimental effects of human activity on breeding bald eagles*. Ecol. Appl. 10:258–268

Toronto and Region Conservation Authority (TRCA). 2007. *The Terrestrial Natural Heritage System Strategy*. Toronto and Region Conservation Authority http://www.trca.on.ca/dotAsset/26746.pdf

Toronto and Region Conservation Authority (TRCA). 2012. *Severity of Invasion by Invasive Plant Indicators at Terrestrial Volunteer Monitoring Program Sites 2009 - 2011*. www.trca.on.ca/dotAsset/143824.pdf

Toronto and Region Conservation Authority (TRCA). 2013. *Terrestrial biodiversity in the Toronto region 2003 - 2012: A decade of monitoring under the Terrestrial Volunteer Monitoring Program* https://trca.ca/app/uploads/2016/04/TerrestrialBiodiversityintheTorontoRegion2003-2012.pdf

Toronto and Region Conservation Authority (TRCA). 2014. *Terrestrial Volunteer Monitoring Program Volunteer Manual*. Toronto and Region Conservation Authority https://trca.ca/app/uploads/2016/02/TVM-Manual-2014.pdf

Toronto and Region Conservation Authority (TRCA). 2016. *Annual local occurrence and local rank update: terrestrial species and vegetation communities*. https://trca.ca/app/uploads/2016/02/Local-occurrence-update_2015.pdf

Toronto and Region Conservation Authority (TRCA). 2017. *Scoring and Ranking TRCA's Vegetation Communities, Flora, and Fauna Species*. Toronto and Region Conservation Authority https://trca.ca/app/uploads/2017/03/Ranking-Scoring-Protocol-Final.pdf

Venter, O., N. Brodeur, L. Nemiroff, B. Belland, I. Dolinsek, J. Grant. 2006. Threats to Endangered Species in Canada. Bioscience 56:11

Wittmer, H., A. Berghöfer, J.Förster, K. Almack. 2011. *TEEB in Local Policy: The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management*. Earthscan, London. www.teeb.org

Appendix A: Native indicator species, applicable analysis groups, 2012 and 2016 CC scores, and new score rationale

Common name	Scientific Name	Groups for analysis	CC score 2012	CC score 2016	Rationale for change (TRCA 2016)
American toad	*Anaxyrus americanus*	Full, Fauna, Amphibian	14	14	
American woodcock	*Scolopax minor*	Full, Fauna, Avian, SOCC	16	16	
barber-pole bulrush	*Scirpus microcarpus*	Full, Flora	10	10	
bobolink	*Dolichonyx oryzivorus*	Full, Fauna, Avian, SOCC	16	20	reduced local occurrence, declining continental pop.
bullfrog	*Lithobates catesbeiana*	Full, Fauna, Amphibian,	22	22	
Christmas fern	*Polystichum*	Full, Flora	14	13	updated local occurrence
eastern chipmunk	*Tamias striatus*	Full, Fauna	13	13	
eastern hemlock	*Tsuga canadensis*	Full, Flora	13	13	
eastern meadowlark	*Sturnella magna*	Full, Fauna, Avian, SOCC	13	18	reduced local occurrence, declining continental pop.
eastern screech-owl	*Megascops asio*	Full, Fauna, Avian	13	15	reduced local occurrence
eastern wood-pewee	*Contopus virens*	Full, Fauna, Avian	13	13	
foam-flower	*Tiarella cordifolia*	Full, Flora	11	11	
green frog	*Lithobates clamitans*	Full, Fauna, Amphibian	13	13	
green heron	*Butorides virescens*	Full, Fauna, Avian	14	14	
grey treefrog	*Hyla versicolor*	Full, Fauna, Amphibian,	22	20	updated local occurrence from road ecology surveys
Jack-in-the-pulpit	*Arisaema triphyllum*	Full, Flora	9	9	
marsh marigold	*Caltha palustris*	Full, Flora	13	13	
Michigan lily	*Lilium michiganense*	Full, Flora	14	13	updated local occurrence
mink	*Mustela vison*	Full, Fauna	14	14	
narrow-leaved spring beauty	*Claytonia virginica*	Full, SOCC, Flora	15	15	
northern leopard frog	*Lithobates pipiens*	Full, Fauna, Amphibian,	18	18	
northern spring peeper	*Pseudacris crucifer*	Full, Fauna, Amphibian,	20	20	
ovenbird	*Seiurus aurocapillus*	Full, Fauna, Avian, SOCC	19	21	reduced local occurrence
pileated woodpecker	*Dryocopus pileatus*	Full, Fauna, Avian, SOCC	15	15	
porcupine	*Erethizon dorsatum*	Full, Fauna, SOCC	21	21	
riverbank wild rye	*Chamerion a.*	Full, Flora	12	12	
ruffed grouse	*Bonasa umbellus*	Full, Fauna, Avian, SOCC	20	19	increasing continental pop. trend
savannah sparrow	*Passerculus*	Full, Fauna, Avian	11	13	reduced local occurrence, declining continental pop.
scarlet tanager	*Piranga olivacea*	Full, Fauna, Avian, SOCC	17	17	
spotted Joe-Pye weed	*Eutrochium m.*	Full, Flora	10	10	
star-flower	*Trientalis borealis*	Full, SOCC, Flora	14	15	reduced local occurrence
swamp milkweed	*Asclepias i. incarnata*	Full, Flora	13	13	
swamp sparrow	*Melospiza georgiana*	Full, Fauna, Avian	13	13	

Common name	Scientific Name	Groups for analysis	CC score 2012	CC score 2016	Rationale for change (TRCA 2016)
turtlehead	*Chelone glabra*	Full, SOCC, Flora	14	14	
Virginia rail	*Rallus limicola*	Full, Fauna, Avian, SOCC	15	17	reduced local occurrence, declining continental pop.
western chorus frog	*Pseudacris triseriata*	Full, Fauna, Amphibian,	23	23	
white cedar	*Thuja occidentalis*	Full, Flora	11	11	
white oak	*Quercus alba*	Full, SOCC, Flora	16	16	
white pine	*Pinus strobus*	Full, Flora	12	12	
white trillium	*Trillium grandiflorum*	Full, Flora	13	13	
winterberry	*Ilex verticillata*	Full, SOCC, Flora	15	15	
wood duck	*Aix sponsa*	Full, Fauna, Avian	15	14	updated local occurrence
wood frog	*Lithobates sylvatica*	Full, Fauna, Amphibian,	21	20	updated local occurrence through road ecology
zig-zag goldenrod	*Solidago flexicaulis*	Full, Flora	8	7	updated local occurrence
mealy rosette lichen	*Physcia millegrana*	Full	na	na	
candleflame lichen	*Candelaria concolor*	Full	na	na	
hooded sunburst lichen	*Xanthoria fallax*	Full	na	na	
hammered shield lichen	*Parmelia sulcata*	Full	na	na	
common greenshield	*Flavoparmelia*	Full	na	na	
rough-speckled shield	*Punctelia rudecta*	Full	na	na	

Appendix B: Invasive indicator plants monitored

Common name	Scientific Name
dog-strangling vine (DSV, swallowwort)	Cynanchum rossicum, C. nigrum
garlic mustard	Allaria petiolata
periwinkle	Vinca minor
common buckthorn	Rhamnus cathartica
glossy buckthorn	Rhamnus frangula
Himalayan balsam (ornamental jewelweed)	Impatiens glandulifera
common reed	Phragmites a. australis
European frog-bit	Hydrocharis morsus-ranae

Appendix C: Survey schedule, species surveyed by visit and observation method

Season	Month	Indicator Fauna/Trails	Indicator Flora/Lichens (visual ID)
Winter	January or February (one 1½ hr. early morning visit)	porcupine (visual ID) mink (visual &/or track/trail) ruffed grouse (visual &/or track/trail)	eastern hemlock white pine eastern white cedar
	March (one ½ hr. visit at dusk)	eastern screech-owl (response to call playback)	
Spring	April (two 1 hr. evening visits)	American woodcock (aural) spring peeper (aural) wood frog (aural) western chorus frog (aural) northern leopard frog (aural) American toad (aural)	
	May (one 2 hr. early morning visit)	pileated woodpecker (visual) wood duck (visual)	marsh marigold white trillium Jack-in-the-pulpit narrow-leaved spring beauty foam flower star flower
Summer	June (two 2 hr. evening fauna visits) July & August (one 2 hr. daytime flora visit each month)	eastern wood-pewee (response to song playback) ovenbird (response to song) scarlet tanager (response to song) swamp sparrow (response to song) Virginia rail (response to call) green heron (visual) bobolink (visual) savannah sparrow (response to song) eastern meadowlark (visual) green frog (aural) grey treefrog (aural) bullfrog (aural)	Michigan lily riverbank wild rye turtlehead swamp milkweed spotted Joe-pye weed barber-pole bulrush white oak common buckthorn glossy buckthorn dog-strangling vine garlic mustard common reed periwinkle Himalayan balsam European frog-bit
Fall	October (one 3 hr. daytime visit)*	eastern chipmunk (visual) trail mapping*	Christmas fern winterberry zigzag goldenrod mealy rosette lichen candleflame lichen hooded sunburst lichen rough speckled shield lichen common greenshield lichen hammered shield lichen

* trail mapping may be carried out on a separate fall visit, depending on the density of trails to be mapped and volunteer preference Invasive indicator plant species are highlighted with blue text.

Appendix D: Species observed by period on site 2

Species	Period 1 2003-2004	Period 2 2005-2006	Period 3 2007-2008	Period 4 2009-2010	Period 5 2011-2012	Period 6 2013-2014	Period 7 2015-2016
American toad			x				x
American woodcock	x	x			x		
Barber-pole bulrush					x		x
Candleflame lichen	x	x	x	x	x	x	x
Christmas fern	x	x	x	x	x	x	
Common greenshield		x	x	x	x	x	x
Eastern chipmunk		x	x	x	x	x	
Eastern hemlock	x	x	x	x	x	x	x
Eastern screech owl			x	x	x	x	
Eastern wood-pewee	x	x	x	x	x	x	x
Foam-flower	x	x	x	x	x	x	x
Green frog	x	x	x	x	x	x	x
Green heron	x		x	x	x		
Grey treefrog	x	x	x	x	x	x	x
Hammered shield lichen	x	x	x	x	x	x	x
Hooded sunburst lichen	x	x	x	x	x	x	x
Jack-in-the-pulpit	x	x	x	x	x	x	x
Marsh marigold	x	x					
Mealy rosette	x	x	x	x	x	x	x
Mink			x	x	x		x
Narrow-leaved spring beauty	x	x	x	x		x	
Northern leopard frog		x	x	x		x	x
Northern spring peeper	x	x	x	x	x	x	x
Ovenbird	x	x	x	x			
Pileated woodpecker	x	x	x	x			
Porcupine		x	x	x	x	x	
Rough speckled shield lichen		x	x	x	x	x	x
Ruffed grouse	x	x		x			
Scarlet tanager	x	x	x		x	x	x
Spotted Joe-pye weed	x	x	x	x	x	x	x
Star-flower			x	x	x		
Striped chorus frog	x*						
Swamp milkweed	x	x	x	x	x	x	x
Swamp sparrow	x	x	x	x	x	x	x
Virginia rail	x	x		x	x		x
White cedar	x	x	x	x	x	x	x
White pine	x		x	x	x	x	x
Winterberry	x	x	x	x	x	x	x
Wood duck	x	x	x	x			
Wood frog	x	x	x			x	x
# species	30	32	34	33	30	27	26

*observation flagged as uncertain during verification process

Appendix E: Urban impacts conceptual model; ↑ denotes an increase, ↑↑ a large increase; ↓ denotes a decrease, ↓↓ a large decrease; ∆ indicates a change other than quantity)

Characteristic drivers	Stressors on ecosystem	Ecological Effects	TVM Indicator measures	Duration of effect	Degree of effect	Ease of reversal	Strategy to minimize	Post-impact mitigation
Development - conversion of habitat	↓ habitat area for native species ↑ competition for habitat & resources (e.g. food) (intra and inter-species) ↑ energy expended to find suitable habitat not available for life processes ↓ reproductive success ↑ predation success for predators able to use the habitat	↓ abundance ∆ species composition ∆ food web structure ↓ or loss of area-sensitive species ∆ predator-prey relationships ↑ tolerant/urban-subsidized species ↓ native species diversity	SOCC indicator SR score, fauna SR score SOCC persistence & SR porcupine presence/absence	permanent	↑ with ↑ area converted	very difficult; not possible to natural state	compact development; conserve natural areas	maximize/restore natural habitat in parks; minimize landscaped/mowed parkland minimize hard-surfaces
Development - fragments habitat	↓ ability for native species to use habitat components ↓ dispersal ability, recruitment of young into pop. impacts some species more than others ↑ likelihood of inbreeding (isolates populations) ↑ predation success/ brood parasitism ↑ ability for exotic species to enter/establish	↓ abundance ∆ species composition ↓ sensitive species ↑ tolerant/subsidized species ↓ native species diversity ↑ invasion by exotics	amphibian SR score amphibian persistence severity of invasion score	permanent	↑ with ↑ degree of isolation/ distance between patches	very difficult; not possible to natural state	system approach to conservation; maintain effective connections	restore natural quality of existing corridors; expand where possible
High road density	↑ roadkill of sensitive species & groups ↑ food supply for scavengers ↑ toxic salt contamination; impacts sensitive native species ↑ impact of fragmentation & storm water ↑ noise pollution; ↓ breeding sensitive species, e.g. some birds pathway for invasion by exotics, e.g. *Phragmites*	↓ abundance ∆ species composition ↓ sensitive species ↑ tolerant/subsidized species ↓ native species diversity ↑ invasion by exotics	amphibian SR score porcupine pres./absence severity of invasion score	permanent	↑ with ↑ density, number, width, traffic volume, speed; varies with road surface, fencing, safe passages etc.	difficult; some mitigation possible	system approach to road network around conservation lands; maintain road-less connected habitat; install safe passages	integrate road ecology principles & safe passage development into road upgrade planning; minimize salt application - find alternatives; develop methods to recover salt at road edges
Altered hydrology	↑ speed, volume, & toxicity of storm water runoff; ↓ infiltration/water storage/availability to species, with water lost to system; exaggerates wet-dry cycles (↑ flooding, ↑ drought)	∆ vegetation communities/habitat ↓ sensitive species ↑ invasion by exotics	amphibian SR score & variability native indicator SR score	permanent	↑ with ↑ area converted	very difficult; not possible to natural state	water management best practices in urban planning/dev.	reduction of impervious surfaces; reversal of stream hardening, dam removal etc.

Recreation - hiking	↑ disturbance - to individual organisms, to habitat structure, ↑ soil compaction, introduction/dispersal of exotic species, noise pollution	Δ vegetation communities/habitat ↑ invasion by exotics	SOCC SR, fauna SR	effect outlasts driver	↑ with ↑ participation	moderate, difficult to reduce access once permitted	trail planning to avoid sensitive areas, public education & regulation	restoration and regulation; monitoring & decommissioning of trails where needed
Recreation - bicycling	↑ disturbance - to individual organisms, to habitat structure	↓ sensitive species ↑ invasion by exotics	SOCC SR, fauna SR	effect outlasts driver	↑ with ↑ participation	moderate; difficult to reduce access once established	trail planning to avoid sensitive areas, public education & regulation	restoration and regulation; monitoring & decommissioning of trails where needed
Recreation - motorized	↑↑ disturbance - to individual organisms, to habitat structure ↑↑ soil compaction/gouging/ponding, introduction/assisted dispersal of exotic species trail - kill of sensitive species, ↑↑ noise pollution;	↓↓ sensitive species, e.g. birds and other fauna ↓↓ biodiversity, community balance	SOCC SR, fauna SR	effect outlasts driver	↑ with ↑ participation	moderate, enforcement required	enforcement; security	restoration and regulation; monitoring & decommissioning of trails where needed
Increased temperature (release of waste heat)	range expansion of southern species, ↑ competition for native species habitat suitability reduced for species at limit of natural adaptive range	Δ vegetation communities/ habitat	presence/absence/ persistence of conifers native indicator SR score	permanent	↑ with ↑ industry, motorized transportation, heating, cooling system use;	very difficult; not possible to natural state	energy conservation	energy conservation enhancement
Landscaping, gardening	↓ native habitat & species; ↑ exotic species; ↑ nutrients; ↑ toxins; altered hydrology/runoff	↓ native species diversity ↑ introduction of exotics	SOCC SR, fauna SR severity of invasion score	effect outlasts driver	moderate, increases over time, eventually severe where invasive species are planted	very difficult; not possible to natural state	public education re native species to plant; best practices and regulation	same
Free-roaming pets	↑↑ predation (e.g. cats on birds/small mammals/herpetiles) ↑ disturbance/displacement of native species, (e.g. sensitive plants, ground-nesting birds) ↑ introduction/assisted dispersal of exotic species	↓ abundance ↓ native species diversity - sensitive species lost	presence/absence/ persistence of ovenbird presence/absence /persistence of ruffed grouse severity of invasion score	effect outlasts driver	moderate, increases over time	possible	prevention via bylaws & enforcement	habitat creation/ protection for affected species
Urban-subsidized species, e.g. raccoon, grey squirrel, European starling, house sparrow, ring-billed gull	↑↑ provision of food supply & shelter ↑ abundance, outcompete & replace more sensitive native species	Δ species composition Δ food web structure ↓ native species diversity	native indicator SR score	effect outlasts driver	high on sensitive native species (e.g. cavity-nesting birds)	very difficult	public education, avoiding feeding wildlife, secure bins for trash, building design to inhibit access (e.g. to vents, sheds & other unnatural shelter)	same