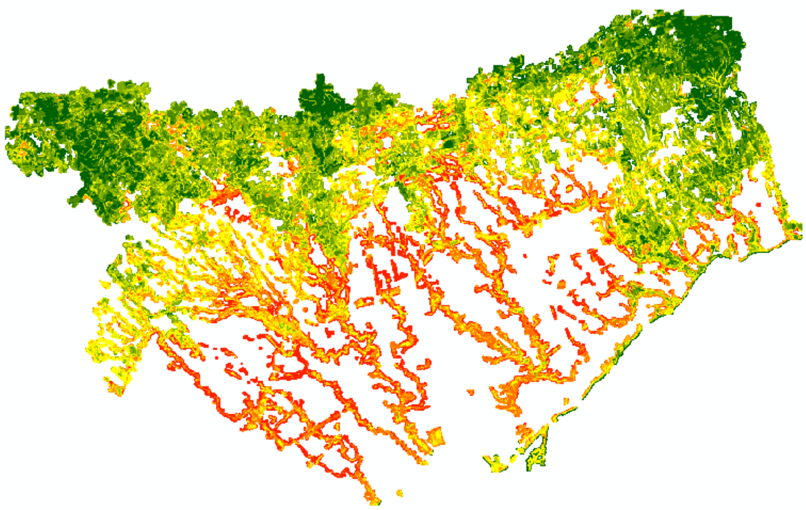
TRCA Terrestrial Ecosystem Climate Change Vulnerability Assessment

Part of the TRCA Terrestrial Natural Heritage System Strategy Update

April 2020



Toronto and Region Conservation Authority

Contents

List of Tables

1 Background and Overview

The *Terrestrial Natural Heritage System Update* (TNHS Update) is a TRCA initiative that aims to refine natural systems planning in TRCA jurisdiction to reflect improvements to the science and practice of natural systems planning since the original *Terrestrial Natural Heritage System Strategy* ("the Strategy") was published in 2007. Such improvements to natural systems planning include consideration of a broader range of factors that influence the function and resilience of natural systems such as the hydrological links between terrestrial and aquatic systems, the vulnerability of natural system components to climate change, and the contribution of the urban forest and other components of the urban matrix to the natural system. In addition to the availability of improved methods and new datasets with which to apply these methods, the boundaries of the TNHS derived from the Strategy require updating to reflect the implementation of its policies by different municipalities, as well as land use changes over the intervening years.

Climate change is already impacting natural systems in the Toronto Region and future projected climate change will likely intensify these impacts. Explicit consideration of the intrinsic vulnerabilities of natural systems to climate change in natural heritage system planning and management will help to increase the resiliency of natural systems to climate change-related impacts and maximize return on investments in restoration and related initiatives. In this regard, the *Terrestrial Ecosystem Climate Change Vulnerability Assessment* (CCVA) seeks to provide objective vulnerability criteria to be used as input into existing and future terrestrial natural heritage planning and management initiatives by TRCA and its municipal partners.

The methodology applied in this CCVA draws heavily on *Natural Systems Vulnerability to Climate Change in Peel Region* (Tu *et al.*, 2017). The framework used by Tu *et al.* for the Regional Municipality of Peel was developed through consultation with numerous academic and institutional subject matter experts, and was directed by a Core Advisory Team composed of representatives from TRCA, Credit Valley Conservation, the Ontario Climate Consortium, the Ontario Ministry of Natural Resources and Forestry, the Ontario Centre for Climate Impacts and Adaptation Resources, and the University of Waterloo.

1.1 Objective and Scope

The primary objective of this CCVA is:

> *To determine and map the relative degree of vulnerability of existing terrestrial ecosystems in the watersheds comprising the TRCA jurisdiction, including forests, wetlands, and meadows, to climate change stressors* (see definition below). *In so doing, the CCVA aims to provide information to existing and future ecosystem planning and management initiatives that will help to strategically increase the resiliency of terrestrial ecosystems to climate change stressors.*

The CCVA evaluates the relative vulnerability of the current terrestrial ecosystem to future climate change stressors, but does not seek to predict the vulnerability of terrestrial ecosystems at some particular future time, as land use planning and ecosystem management decisions will invariably change the current spatial distribution of vulnerability both positively and negatively.

Five Vulnerability Indicators (the best representatives within available datasets of the underlying Vulnerability Factors that are held to predict intrinsic vulnerability to climate change) are used to map the qualitative degree of vulnerability for different aspects of terrestrial ecosystem that contribute to overall climate change vulnerability. The additive vulnerability scores are based on the sum of the individual Vulnerability Indicator scores, and therefore it is assumed that all Vulnerability Indicators have equal weighting with regards to their contribution to additive vulnerability. This is a key assumption of the vulnerability framework outlined in Tu *et al.* (2017) that recognizes that the stress to ecosystems from climate change will necessarily always involve dynamic interaction between climate variables and elements of the natural system as well as interspecies interactions.

The geographic scope of the CCVA is limited to the extent of the natural system in the watersheds comprising TRCA jurisdiction. The natural system, as defined in the TNHS Strategy, comprises all areas of existing and potential natural cover, and is essentially coincident with all the non-urbanized lands in TRCA jurisdiction. In contrast to *Natural Systems Vulnerability to Climate Change in Peel Region*, urban areas, including the urban forest, were not considered to be within scope for this assessment. Other studies provide a more detailed assessment of natural systems climate change vulnerability within the urbanized areas and the urban forest (e.g. Green Infrastructure Ontario Coalition, 2016).

1.2 Key Definitions

The following key definitions are important to the interpretation and application of this methodology:

Climate Change Stressors: The types of climate stressors to the natural system anticipated to become more frequent and/or severe under projected future climate change[1], including both changes in seasonal average conditions and extreme or stochastic weather events. The specific stressors used were in the categories of average and extreme temperatures, annual total precipitation and maximum precipitation intensity, consecutive dry days, ice storms, and growing season length, following Tu *et al.* (2017; see Table 8 in report for more details).

[1] The reference scenario used to define the direction and magnitude of changes in select climate variables was 2041-2070 under the RCP 8.5 (high emissions) scenario (Auld *et al.*, 2016). As approximately one third of the geographic area evaluated in this report, which was completed for the Region of Peel (Auld *et al.*, 2016), overlapped with TRCA jurisdiction, and given that the CCVA generally uses qualitative as opposed to precise numerical criteria to define vulnerability, the Peel climate change assessment was felt to be a reasonable proxy for TRCA jurisdiction.

Vulnerability to Climate Change: Following the IPCC's definition (2014, p. 1775), this is the propensity or predisposition of terrestrial ecosystems to be adversely affected by climate change. The IPCC notes that the concept is complex and contains notions of "sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (p. 1775). Use of the term "terrestrial ecosystems" here is meant to encompass the full range of responses at the individual species and community level, as well as the biotic and abiotic processes that allow important ecosystem functions, and the services they may provide to society, to continue in perpetuity.

Natural System: The area of the TRCA watershed jurisdiction comprised of water resources, natural features and areas, natural hazards, and restoration areas of potential natural cover and buffers (TRCA, 2014).

Vulnerability Factor: A quality or characteristic of a natural component that is more or less vulnerable to a given climatic condition or event (Tu *et al.* 2017). "Such factors can be physical, chemical or biological aspects of the natural environment. Given that many of the impacts of interest result from a series of intermediate processes, an important part of understanding vulnerability is the elucidation of these... intermediate impacts..." (Tu *et al.* 2017, p. 28). The Vulnerability Factor is a primary factor producing underlying vulnerability, but may not be represented in existing datasets (e.g. area-to-depth ratio of water bodies, vegetation rooting depth and strength). The Vulnerability Factors are represented by Vulnerability Indicators. See Appendix E of Tu *et al.* for a list of Vulnerability Factors considered and detailed rationale.

Vulnerability Indicator: A metric or proxy variable representing one or more Vulnerability Factors. For example, the indicator "habitat patch quality", based on spatial metrics such as patch size, shape, and location, acts as a proxy for underlying Vulnerability Factors like habitat diversity, hydrological cycle regulation, and thermal regulation, amongst other variables, that may be difficult or impossible to measure directly. The indicators used in this study were those that were applied to the terrestrial system in Peel Region by Tu *et al.* (2017). The Peel Region assessment used a systematic screening process to select appropriate indicators based on criteria relating to importance, validity, and feasibility (see Table 6, p. 33). Appendix F of Tu *et al.* lists the Vulnerability Indicators used and the selection rationale.

2 Vulnerability Indicators

For this CCVA, the following five Vulnerability Indicators were used:

A. Ground surface temperature
B. Climate sensitivity of native vegetation
C. Habitat patch score
D. Soil drainage rating
E. Wetland hydrological stability

A more detailed description of each indicator, the data source, and scoring rationale is provided below in Table 1. For each indicator, vulnerability was scored as low, medium, or high vulnerability, corresponding to a vulnerability score of zero, one, or two, respectively, based on scoring criteria outlined in Table 1.

Table 1: Vulnerability Indicators used and explanation of data

Vulnerability Indicator	**Data Source**	**Range and Units**	**Scoring**
A. Ground surface temperature	NRCAN land surface temperature dataset (captured mid-afternoon in June of 2014)	13-47 (degrees Celcius)	Based on data percentiles (equal thirds) 0 – 13 to 27 ˚C 1 – 28 to 34 ˚C 2 – 35 to 47 ˚C
B. Climate sensitivity of native vegetation	TRCA ELC dataset (2017 update) Ranked list of ELC communities based on professional opinion of TRCA ecologists considering factors of hydrology, fertility, and their interaction or "dynamics")	No units, maximum of 3 vulnerable processes	Based on number of vulnerable processes (among hydrology, fertility, dynamics) 0 – no vulnerable processes 1 – one vulnerable processes 2 – two or more vulnerable processes * See further rationale below
C. Habitat patch score	TRCA natural cover layer (2013 update), patch scores from TRCA Landscape Analysis Model (LAM)	L1 to L5 (relative patch scores based on TRCA LAM)	0 – L1, L2 1 – L3 2 – L4, L5
D. Soil drainage rating	OMAFRA, Land Information Ontario (Soil Survey Complex dataset)	Well Drained, Imperfectly Drained, Very Poorly Drained, No Drainage (Urban)	0 – Well Drained 1 – Imperfectly Drained 2 – Very Poorly Drained, No Drainage (Urban)
E. Wetland hydrological stability	Multiple - TRCA ELC, natural cover, watercourse, LiDAR-derived DEM layers; MNRF wetlands layer; Oak Ridges Moraine Groundwater Program interpolated regional water table elevation)	Number of potential water sources (riparian = within 30 m of permanent watercourse; groundwater = <1 m depth to estimated water table)	Number of potential water sources 0 – Both riparian AND groundwater 1 – Riparian OR groundwater 2 – Precipitation only (no riparian on groundwater)

Each indicator was given equal weighting in the additive total vulnerability score, which was derived by simply summing all of the individual indicator scores within each aggregation unit (see section). No assumptions were made about the relative importance of any individual indicator. This approach is valid because the stress to ecosystems from climate change will necessarily always involve dynamic interaction between climate variables and elements of the natural system as well as interspecies interactions.

2.1 Vulnerability Indicator Scoring Rationale

The following subsection describes the scoring rationale presented in Table 1 for each Vulnerability Indicator in greater detail.

A. Ground surface temperature

The ground surface temperature measured by satellite remote sensing in mid-afternoon close to the summer solstice is a good proxy for the distribution of potential heat and drought stress throughout the natural system during summer and early fall. Higher air temperatures, for which ground surface temperature is a proxy, could lead to enhanced drying of soil and forest understories, plant heat stress, reduction in natural system thermal regulation, and loss of thermal refuges for heat-intolerant species. This in turn could lead to degradation or loss of local flora and fauna communities and reduced capacity of natural cover to provide localized cooling.

No specific numerical vulnerability thresholds emerged from the literature review for Peel, and any thresholds would inevitably also be dependent upon the presence of other vulnerability factors. Therefore, to determine vulnerability class thresholds, the data covering the area of the TRCA watershed jurisdiction was divided into three classes of equal abundance. This translated into a low vulnerability class consisting of cells reporting ≤27°C, a high vulnerability class of cells ≥35°C, and medium vulnerability class cells falling between these two thresholds.

B. Climate sensitivity of native vegetation

As certain species will be more impacted by increasing seasonal temperatures and increasing variability in precipitation than others, a list of all terrestrial ecosystems in TRCA jurisdiction grouped by Ecological Land Classification (ELC) community was generated by TRCA ecologists. These ecologists then scored each community for its vulnerability to disruption within three groups of functional processes: hydrological processes, fertility processes, and potential dynamic interaction between hydrology and fertility. ELC communities with no identified vulnerable processes were scored as low vulnerability, those with vulnerabilities identified for one process were scored as medium, and those with two or more vulnerable processes were scored as high vulnerability. The assumption is that shifts in mean climate along with increased frequency of extreme stochastic weather events such as droughts and ice storms may produce disturbances that shift communities towards a higher composition of non-native species, in turn impacting species-specific habitat provision, reducing biodiversity, and limiting the capacity of native vegetation communities to moderate the spread of invasive species.

C. Habitat patch score

Habitat patch score is a strong indicator of ecosystem vulnerability because of its interrelations with so many other vulnerability factors. For example, the degree of connectivity of a habitat patch with the surrounding natural system is a strong predictor of the ability of native species to find suitable habitat for the completion of lifecycle requirements. Habitat patch score is also likely to be positively correlated with regulation of erosion, water quality, and other elements of the hydrological cycle (e.g. attenuation of excess runoff and high evapotranspiration), as well as moderating air temperatures. Habitat patch score considers elements of patch size, shape, and influence of the surrounding matrix, and was determined using the TRCA Landscape Analysis Model (TRCA, 2017), run with TRCA's 2013 natural cover data layer. Each patch was classified on a scale between L1 (highest quality) and L5 (lowest quality), and these scores were aggregated into vulnerability scores as indicated in Table 1. See TRCA (2017), Appendix E, for further detail on the Landscape Analysis Model.

D. Soil drainage rating

The surficial soils within the natural system also interact with the biotic elements of the system to produce vulnerability to climate change. The approach applied here assumes that tight soils with poor drainage will produce shallower root networks and increased potential for localized inundation, contributing to higher relative vulnerability. However, it is noted that the interaction between soil drainage properties and changes in different climatic variables is very complex, and in certain respects soils with higher drainage ratings will be more vulnerable (e.g. to erosion resulting from extreme precipitation events).

The OMAFRA dataset used to classify this Vulnerability Indicator contained soils classified by drainage rating, considering both texture and slope, into six classes ranging from well drained to very poorly drained, as well as categories for urban land covers and open water. These drainage categories were classified into vulnerability scores as indicated in Table 1. As the original data for the OMAFRA layer was derived from soil surveys conducted in the 1950s and 60s, the extent of urban impervious areas was updated using TRCA's 2014 land cover layer. The age of the data introduces some uncertainty with respect to resolution, land cover and land use changes, but it remains the most comprehensive soils data layer available for the region.

E. Wetland hydrological stability

The stability of the hydrological regime of wetlands was inferred from a number of contributing data layers. The approach used in this analysis differed somewhat from that used by Tu *et al.* (2017) to evaluate wetland sensitivity to climate change. In particular, in this analysis it was assumed that wetlands assumed to be receiving inputs of water only from precipitation and local catchment runoff were more vulnerable than wetlands receiving additional water inputs from groundwater or from larger riparian systems.

For this assessment, two datasets were used to determine the wetland hydrological stability vulnerability score. The first was the TRCA permanent watercourse layer, which was updated in early 2018 to eliminate some reaches that were inferred based on drainage lines but could not be validated as watercourses through review of orthophotographs. A 30 m buffer was created around this layer, and wetlands within this 30 m buffer were assigned lower vulnerability scores than those falling outside of the buffer. The second dataset was the interpolated regional water table surface. This layer was obtained from the Oak Ridges Moraine Groundwater Program, and is interpolated at 100 m horizontal resolution from on hundreds of thousands of static and time series well records across TRCA jurisdiction. By subtracting this layer from TRCA's most recent regional digital elevation model, a "depth to water table layer" was created. Wetlands situated in areas with a depth-to-water-table ≤1 m were assumed to be less vulnerable than wetlands located in areas where depth-to-water-table was >1 m. As the depth-to-water-table value represents an annual average depth around which there is seasonal variation, areas with values ≤1 m are assumed to receive groundwater inputs on at least a seasonal basis if not perennially.

This method of characterizing wetland hydrological stability assumes that wetlands that are within 30 m of a permanent watercourse, or have a depth-to-water-table of ≤1 m, are receiving additional inputs of water (mainly surface water for the former, and groundwater for the former). These wetlands would therefore likely be less vulnerable to periods of drought or extended high temperatures than wetlands that rely only on precipitation and local drainage to supply atmospheric demand. Wetlands where soils remain dry for extended periods are more vulnerable to colonization by facultative upland vegetation and invasive species among other potential adverse impacts.

2.2 Deviation from Peel Region Methodology

The methodology applied in this assessment was in most ways identical to that used by Tu *et al.* (2017) for Peel Region, but differed in a few important respects. These differences are noted here along with a brief description of the rationale.

2.2.1 Urban extent

Whereas in Peel the vulnerability assessment was completed for the entire area of the Region of Peel, including urban areas, for this assessment the extent of analysis was limited to the extent of the Natural System in TRCA jurisdiction. This allows for greater differentiation of vulnerability within the Natural System itself, as many Vulnerability Indicators were characterized based on equal abundance percentiles, and these inevitably skew the spatial distribution of the higher vulnerability scores towards dense urban areas because of their higher temperature, poor drainage, and low habitat patch scores.

2.2.2 Aggregation scoring and scale

For Peel Region, vulnerability scores were aggregated into 30 ha average catchment sizes, as per TRCA's Integrated Restoration Prioritization methodology (TRCA, 2015). The decision to aggregate vulnerability scores at this scale was driven largely by the inclusion of the aquatic system and groundwater system in the scope of the analysis, and small subcatchments provided a natural common framework for all three systems analyzed in the Peel assessment. However, as the scope of this assessment was limited to the terrestrial natural system, the use of catchments as the basic aggregation unit was not justified. A 100 m grid size was settled on as the scale of aggregation because this represented the coarsest resolution within the input datasets.

2.2.3 Climate sensitivity of native vegetation

The lists of climate sensitive vegetation communities generated by TRCA ecologists were rated for vulnerability in categories of hydrology, fertility, and dynamics, as described in section 2.1. However, in this methodology framework, all wetland communities were rated as vulnerable in the hydrology category, meaning that, by default, all wetlands would be considered medium vulnerability or higher for this Vulnerability Indicator. This was felt to be a case of double-counting the hydrological vulnerability of wetlands, as a separate Vulnerability Indicator was already being used to assess this dimension of vulnerability. To address the double-counting issue, vulnerability rankings for wetland communities were counted out of a score of two (fertility, dynamics), whereas the scoring framework for upland communities was not altered. For both wetlands and uplands, communities with no identified vulnerable processes were scored as low vulnerability, those with vulnerabilities identified for one process were scored as medium, and those with two or more vulnerable processes were scored as high vulnerability. This did not cause any compression of scores for wetland communities, as there were no wetland communities that were rated as having vulnerable processes in all three categories.

2.2.4 Wetland vulnerability indicators

For the Peel Region assessment, wetland vulnerability was based on wetland community type according to categories of swamp, marsh, bog and fen, with an additional criterion that wetlands <30 m from a permanent watercourse were less vulnerable regardless of community type. The reasons for these methodological choices are outlined in detail in Tu *et al.* (2017). However, as additional data was available in TRCA jurisdiction to identify areas where there was a high potential for groundwater discharge (using the depth-to-water-table data layer from the Oak Ridges Moraine Groundwater Program), the Peel methodology was modified to reflect criteria other than community type. Community type is a less precise Vulnerability Indicator for wetlands, as only about 1% of the wetlands in TRCA jurisdiction (and similar proportions for Peel Region) are either bog or fen, and thus the only major division is between swamps and marshes, which can have varying hydrological stability depending on landscape position, among other factors.

3 Additive Vulnerability Scores and Intended Applications

3.1 Vulnerability Score Aggregation

The following methodology was used to aggregate and sum scores for the individual Vulnerability Indicators to produce an additive vulnerability layer: first, the original layers used for each of the five main Vulnerability Indicators were categorized into vulnerability scores of 0 (low), 1 (medium), and 2 (high). The scored Vulnerability Indicator layers were then aggregated from their original resolution into 100 m × 100 m cells, for all cells falling within the TRCA Natural System, by taking the majority vulnerability score within each cell.

The additive vulnerability layer was produced by first summing the maximum possible score within each cell based on the number of layers with data available for that cell. For example, a cell that had data available for all of the five Vulnerability Indicators would have a maximum possible score of 10 (a maximum possible score of 2 in each individual layer), whereas a cell that had data available for only three Vulnerability Indicators would have a maximum score of 6. Next, the actual score for each cell was divided by the maximum total score calculated for that cell to provide a measure of relative vulnerability. On this scale, the highest possible additive vulnerability score is 1, and the lowest possible additive score is 0. This accounts for the fact that data coverage for some Vulnerability Indicators was incomplete, particularly for the Climate Sensitive Native Vegetation indicator which requires ELC data to be present within a cell. This is an important caveat to interpretation of the vulnerability scores and mapping, as the additive vulnerability will not be determined from the same exact set of Vulnerability Indicators in all cells. However, all cells did have data coverage for at least Vulnerability Indicators A and D, and > 90% of cells had data coverage for Vulnerability Indicator C.

Finally, the process outlined above was repeated using the Integrated Restoration Prioritization (IRP) 30 ha average catchment size (see TRCA, 2015) as the basic unit of aggregation. Vulnerability Indicator scores were aggregated using the majority value within each catchment, and then summed within each catchment to produce additive vulnerability maps. The intent is that the additive vulnerability layer may eventually be incorporated into the existing IRP process to inform restoration planning after a consensus has been reached on the best approach for doing so. It is noted that, as at least some cells existed within almost all catchment units, additive vulnerability scores were generated for almost all 30 ha catchments, but that these scores may be misleading as the coverage of individual Vulnerability Indicator layers within each catchment is not the same. In particular, the additive scores for the highly urbanized catchments are often based on very limited areas of the Natural System, and this should be considered when applying the additive scores within these urbanized catchments.

3.2 Intended Applications of the CCVA

The maps and data layers produced through the CCVA may be used for a variety of purposes. One purpose may be as a communication tool to illustrate the wide variability in vulnerability to climate change that exists throughout the terrestrial ecosystems of the TRCA jurisdiction, and in so doing, illustrate how programs of ecosystem management and restoration could strategically reduce this vulnerability to climate change. Beyond general communication, it is not the intent of the CCVA to be applied independently of existing ecosystem planning processes. Rather, the CCVA aims to provide information that can be incorporated into existing ecosystem planning and management initiatives (e.g. IRP, forestry planning, compensation works, etc.). The Research and Knowledge Management team will be consulting with groups internal to TRCA to determine the relevance, applicability, and limitations of the CCVA to informing existing and future ecosystem planning and management initiatives, and best practices for incorporating the CCVA into these initiatives.

4 How to Access Data and Provide Feedback

The individual vulnerability indicator layers and additive vulnerability score layer are stored on the TRCA head office network and are available upon request from the Research and Knowledge Management team. Contact Namrata Shrestha (namrata.shrestha@trca.ca) or Neil Taylor (neil.taylor@trca.ca) for further details and access. Feedback on the utility, application, and limitations of the data is welcome. Data for both the individual and additive layers are available, with data aggregated both at the 100 m grid format as well as 30 ha average catchment size for use with Integrated Restoration Prioritization layers.

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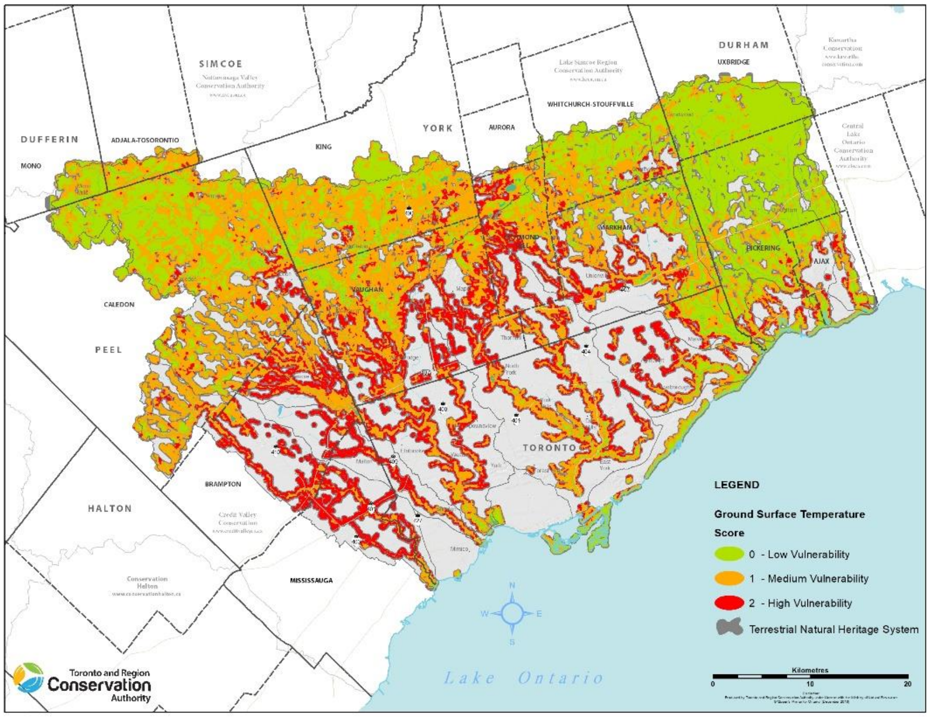
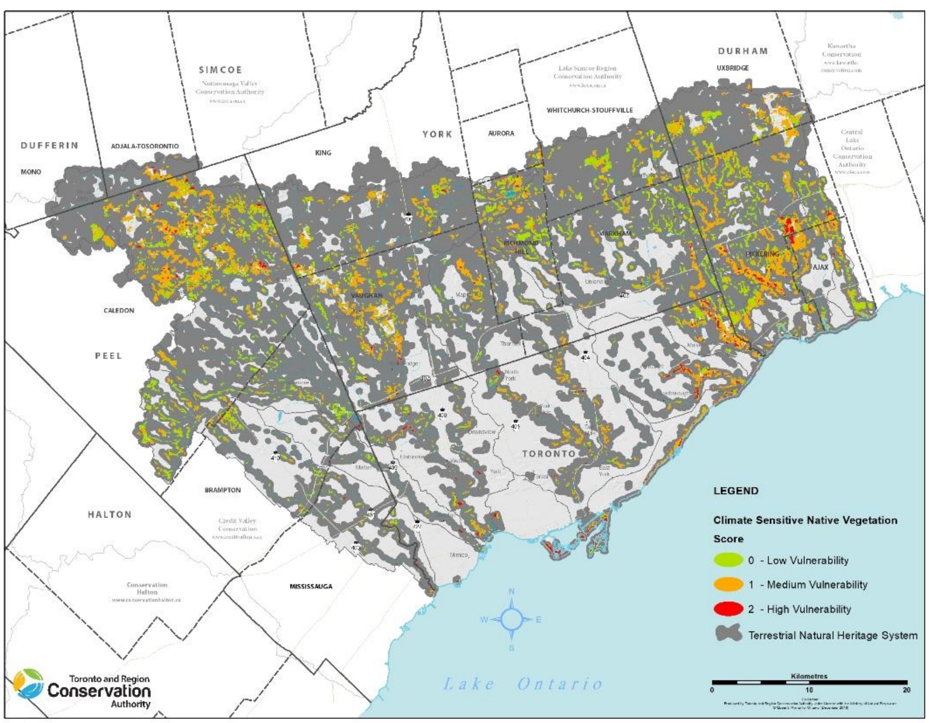
Appendix A: Maps of Vulnerability Indicator and Additive Vulnerability Scores

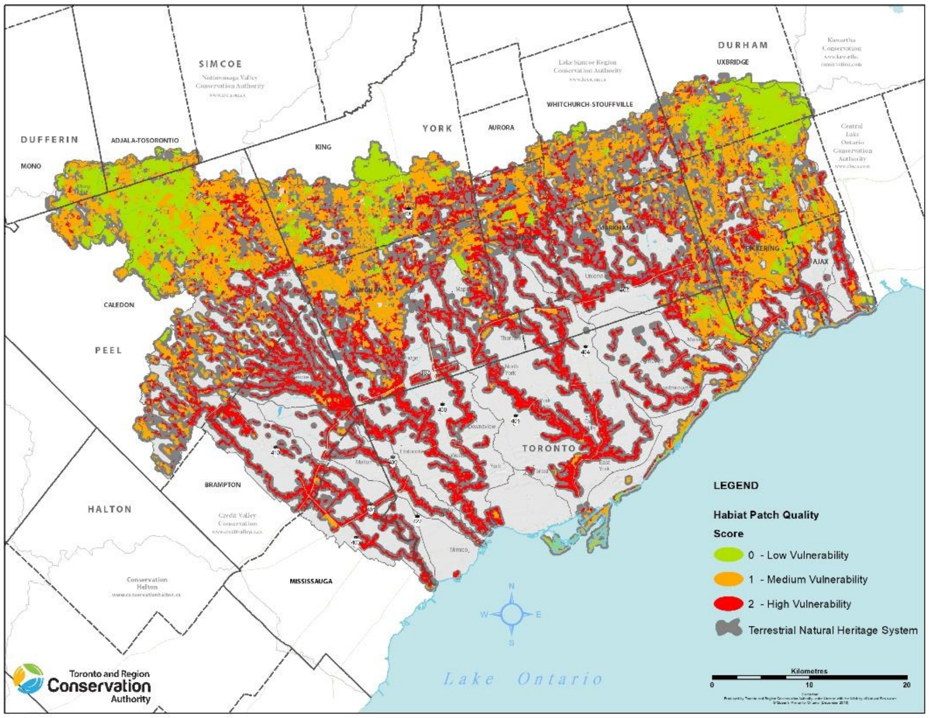
A1: Vulnerability scores for the ground surface temperature Vulnerability Indicator



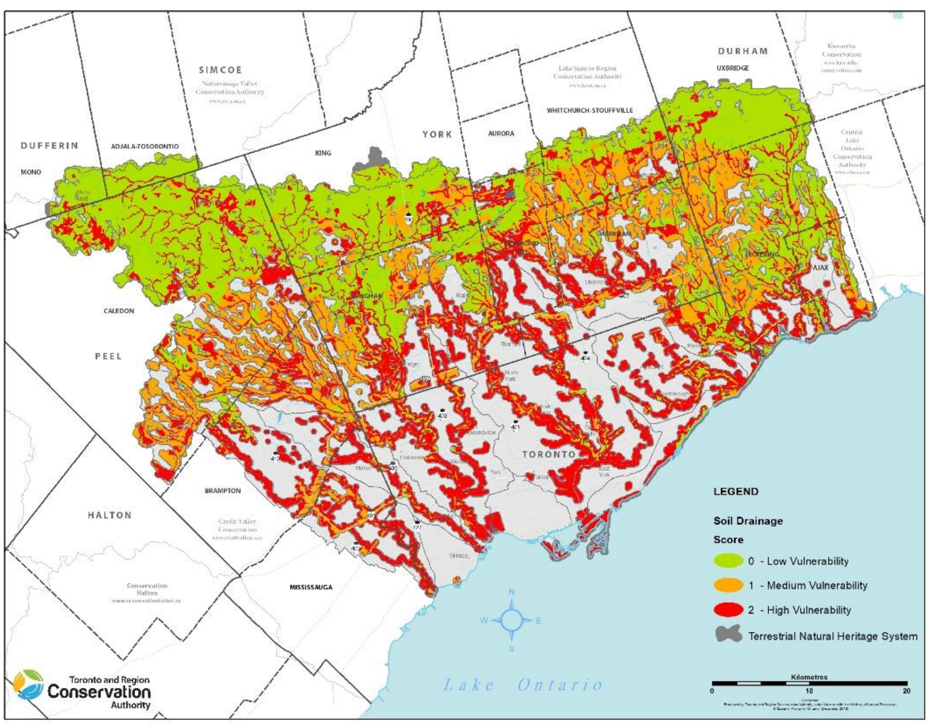
A2: Vulnerability scores for the climate sensitive native vegetation Vulnerability Indicator



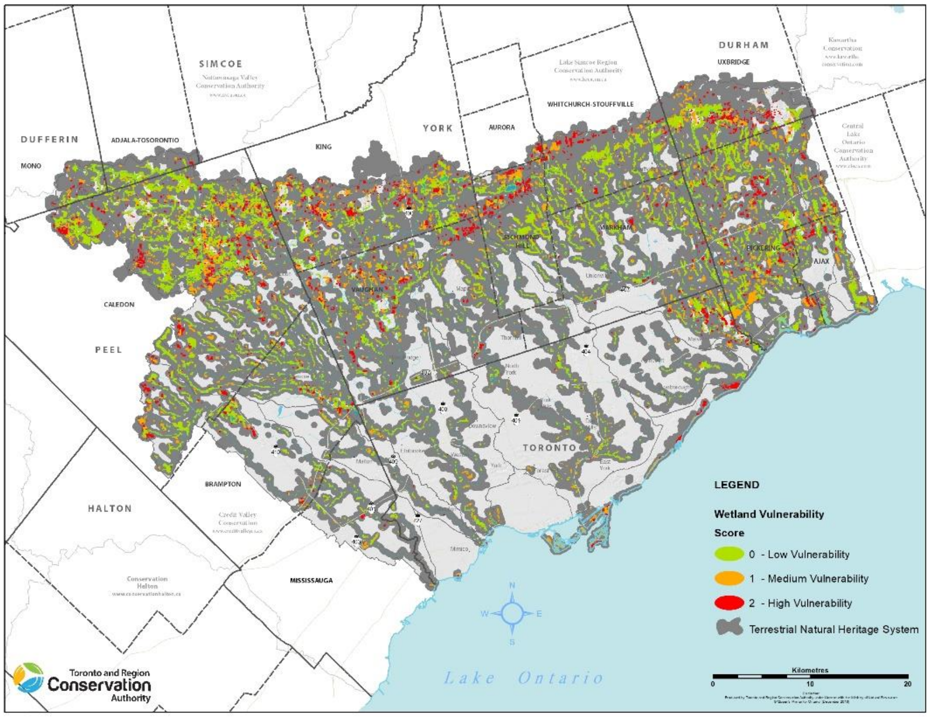
A3: Vulnerability scores for the habitat patch score Vulnerability Indicator



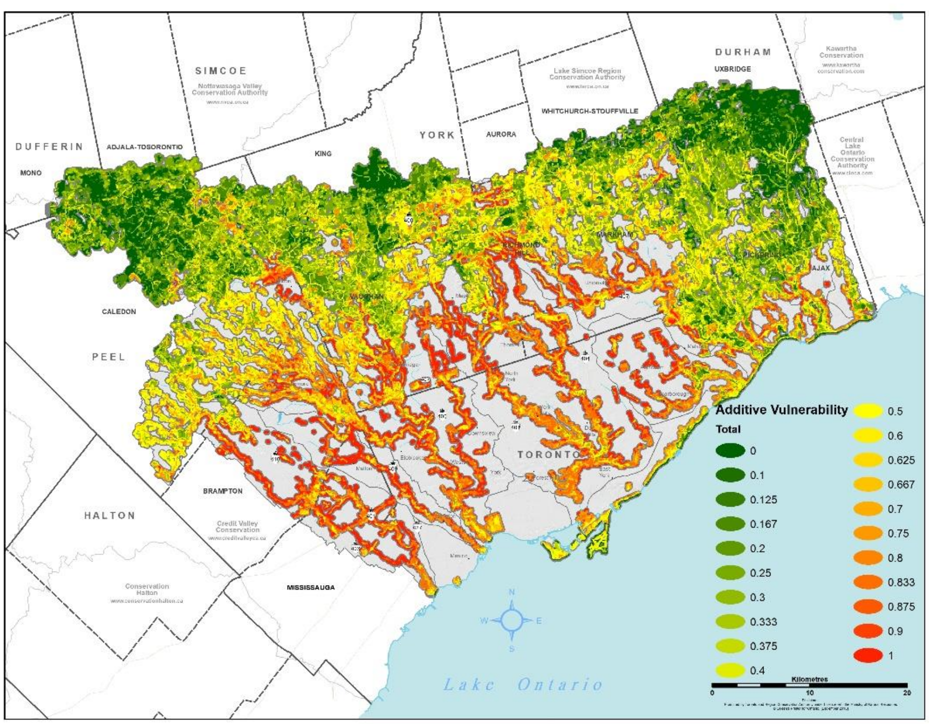
A4: Vulnerability scores for the soil drainage Vulnerability Indicator



A5: Vulnerability scores for the wetland hydrological stability Vulnerability Indicator



A6: Additive vulnerability scores for the TRCA terrestrial natural system (100 m grid unit)



A7: Additive vulnerability scores for the TRCA terrestrial natural system (IRP 30 ha average catchment unit); individual Vulnerability Indicator scores were also aggregated by IRP catchment