Credit Valley Conservation
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Technical Report: Ranking local species of conservation concern in the Credit River Watershed

FINAL
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SUMMARY

Many of the animals, plants, and other organisms that make up global biodiversity are experiencing population declines due to habitat loss, climate change, and other threats. Global, national, and subnational conservation status assessments (i.e. global G-ranks, national N-ranks, subnational S-ranks) are useful for identifying species whose populations are at a high risk of extinction across those geographic scales. Standardized methodologies exist for completing these assessments, including the NatureServe system used in Ontario by the Natural Heritage Information Centre. The ranks resulting from conservation status assessments have been incorporated into conservation policy worldwide. However, these assessments tend to overlook species that might be common at a broad scale but are of conservation concern in smaller areas – such as watersheds, counties, or ecodistricts.

Local species of conservation concern represent important components of regional biodiversity, can contain unique genetic lineages, and have important social and cultural values. In addition, some jurisdictions have regional policies that identify habitat for local species of conservation concern as protected. This is the case in the Credit River Watershed, where such a policy exists but does not provide a mechanism to identify which species qualify. For this reason, Credit Valley Conservation (CVC) wanted to create a system for identifying local species of conservation concern. These species are important components of the local natural heritage that both CVC and our municipal partners work to protect while fulfilling obligations outlined in the *Conservation Authorities Act* and *Provincial Policy Statement*.

Following a review of existing status assessment systems, CVC has developed a standardized method to assign local conservation status ranks (L-ranks) and identify local species of conservation concern at a watershed scale. In this report, we outline the theory used and decisions made during the development of the method and demonstrate its application using the fishes in the Credit River Watershed as a test case. In addition, we discuss potential applications of L-ranks by CVC as well as various issues to be considered by other groups that may want to apply the method.

The CVC method for assessing local conservation status is a modification of the NatureServe system for ranking species; however, our method is scaled more appropriately for smaller geographic areas and is easier to apply with limited data. We use three factors – index area of occupancy, intrinsic vulnerability, and short-term trend – to assign a rank to species on a scale from L1 (locally critically imperilled) to L5 (locally secure).

L-ranks assigned to fish species using our method proved to be more conservative than the provincial S-ranks, in that we identified almost three times as many local species of conservation concern than at the provincial level (14 L1 to L3 vs. 5 S1 to S3). All assessed provincial species at risk and species of conservation concern were identified as local species of conservation concern, although the ranks did not always exactly match. The additional fish species identified as L1 to L3 all had some combination of very restricted local ranges (e.g. Slimy Sculpin), high intrinsic vulnerability (e.g. Blacknose Shiner), and declining short-term trends (e.g. Brassy Minnow). While there may be different reasons why a fish species was ranked L1, L2, or L3, each of the 14 species identified as of local conservation concern

has a relatively high risk of extirpation from the Credit River Watershed. The loss of these species has the potential to alter the function of the local ecosystem in numerous ways, including disrupting food webs, nutrient cycling, sediment processes, and the regulation of carbon fluxes.

Our method was designed to be simple, objective, and broadly applicable – both across taxa and by other conservation organizations operating at local scales. L-ranks can be used to prioritize areas for conservation action that may be overlooked when local species of conservation concern are not considered, to assess the degree to which habitats for local species of conservation concern are already covered by current management plans and systems, and to identify areas for protection under regional policy. Finally, we emphasize that L-ranks are one tool that can be used to help guide conservation action, and that they should be considered in context with other information regarding species and habitats (e.g. provincial policy and legislation, determination of ecological integrity based on monitoring, etc.). CVC and other natural resource managers should consider all these pieces of information in a holistic manner when making decisions regarding action.

Table of Contents

1.0 INTRODUCTION

The health of ecosystems on which humans and all other forms of life depend is declining rapidly, as species are lost due to habitat destruction, climate change, and numerous other threats. Identifying which species and ecosystems are at the greatest risk of extinction helps conservation organizations to prioritize their work and maximize the impact of their actions. Several systems have been developed to assign conservation status ranks to species; the most widely used systems are those produced by the International Union for the Conservation of Nature (IUCN) Red List (IUCN 2012a) and NatureServe (Master *et al*. 2012). These systems use quantitative and qualitative information to assess species and ecosystems and assign ranks reflecting their probability of extinction, ranging from Least Concern to Critically Endangered (IUCN Red List) or Secure to Critically Imperilled (NatureServe). Conservation organizations use these ranks to target species and habitats for protection and restoration; many jurisdictions also tie conservation status ranks directly to species at risk policy and legislation.

While the IUCN and NatureServe systems were designed with global populations in mind, they are both also used to assess species and ecosystems at smaller geographic scales, including national and subnational units. For example, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) uses a modified IUCN Red List method to assess the conservation status of species at risk in Canada (COSEWIC 2015), and the Natural Heritage Information Centre (NHIC) uses the NatureServe method to assess the status of species in Ontario (NHIC 2014). When assessing species at these smaller geographic scales, the conservation status ranks produced represent the probability of extirpation from that area instead of extinction – with the exception of species that are only found within that area (i.e. endemic species).

The conservation status of species is rarely assessed within geographic areas smaller than states or provinces; however, ranks from smaller, local areas can provide important information to conservation managers working at finer scales. Identifying local species of conservation concern can help prevent globally common species from becoming rare, by initiating local action that reduces cumulative impacts on these species across their whole range – effectively providing a buffer of resilience. Local species of conservation concern can also contain unique genetic lineages, represent important components of regional biodiversity, and have important social and cultural values. Biologically defined local areas, such as watersheds, can represent more natural units of assessment and management than larger areas defined by political boundaries. Finally, some local jurisdictions have policies that protect local species of conservation concern – as is the case in the Region of Peel, where habitat for locally rare species[1] is protected as Significant Wildlife Habitat (North-South Environmental *et al*. 2009).

For these reasons, Credit Valley Conservation (CVC) intends to assign local conservation status ranks to the flora and

[1] The document cited refers to both locally rare species and species of conservation concern; we note that these are two different concepts, as a species may not necessarily be rare but still be a species of conservation concern. We have therefore chosen to assess the conservation status of local species, and not just their rarity, as described below.

fauna of the Credit River Watershed. Other groups that have assigned conservation status ranks in local jurisdictions have either used the NatureServe method directly or developed their own systems (e.g. Kaiser 2001; Magney 2004; Crain and White 2011; TRCA 2017). However, the NatureServe system would not be well suited for CVC's purposes without modification; the category thresholds for area of occupancy are too large to be applied at a local scale, and there are many ranking factors for which data are not available at the watershed scale. In addition, an evaluation of the independently developed systems mentioned above found that they considered only one factor or involved a number of subjective decisions.

CVC therefore chose to develop a novel method for assigning local conservation status ranks at a watershed scale. In particular, we aimed to develop a method that is: (i) simple and easily applied with available data; (ii) objective and based on quantitative factors; and, (iii) broadly applicable – both across taxa and replicable by other local conservation organizations. The resulting method is largely based on the NatureServe system; however, it includes modifications designed to incorporate a smaller geographic scale and to simplify the process. In this document we describe our approach and its development, demonstrate its use to assign ranks to one taxonomic group, and illustrate the application of the resulting ranks to various conservation planning and management activities.

2.0 METHODS

2.1 NatureServe's method

The NatureServe ranking method includes ten factors within three categories – rarity, threats, and trends (Table 1). Their ranking method follows a clear and detailed set of rules, depending on what data are available for each species; no

Table 1. *NatureServe ranking categories, subcategories, and factors, with the two minimum data requirement combinations (A and B) indicated (modified from Faber-Lagendoen* et al. *2012)*

Category	Subcategory	Factor	Minimum A	Minimum B
Rarity	Range / Distribution	(a) Range extent	1 of (a) or (b) + 1 of (c)-(f)	1 of (a)-(f) + 1 of (g)-(j)
		(b) Area of occupancy		
	Abundance / Condition	(c) Population size		
		(d) Number of occurrences		
		(e) Number of viable occurrences		
		(f) Environmental specificity [A]		
Threats		(g) Overall threat impact [B]		
		(h) Intrinsic vulnerability [C]		
Trends		(i) Short-term trend		
		(j) Long-term trend		

[A] Only used if information on area of occupancy or number of occurrences is not available
[B] Based on the IUCN threats calculator
[C] Only used if information on threats is not available

assessment includes data from all ten factors, and minimum requirements for data availability must be met. In particular, a species may be assessed using a minimum of two rarity factors or a minimum of one rarity factor plus one threats or trends factor. Species are scored for each factor by comparing their value for that factor to a defined scale. Thresholds for the scales were determined based on expert judgment, experience, and compatibility with the IUCN method (personal communication, D. Faber-Langendoen). For full details of the NatureServe factors and methodology for assigning ranks, see Master *et al*. (2012) and Faber-Langendoen *et al*. (2012).

A key feature of the NatureServe method is that it incorporates information on rarity, threats, and trends to assess conservation status and identify species of conservation concern. The rarity of a species may be best assessed using biological measures such as abundance and range extent (Gaston 1994), and some groups have used only these measures in their ranking of locally rare species (Kaiser 2001; Crain & White 2011). However, a species may be abundant or widely distributed but still be at risk of extinction or extirpation due to specific threats or significant population declines – for example, the Little Brown Bat (*Myotis lucifugus*), which was once one of the most common mammal species in North America and then experienced 95% population declines due to White Nose Syndrome. We have therefore chosen to model our ranking method after the NatureServe method by considering rarity, threats, and trends in our assessment. In addition, we aim to add credibility to our assessments by using this standard, internationally used system as the foundation for our method.

2.2 Selected ranking factors

CVC chose three of NatureServe's ten factors to use for our local conservation status assessment method – area of occupancy, intrinsic vulnerability, and short-term trend. These factors were chosen because they are ones for which CVC has data or for which data can be obtained with knowledge of the life-history of the species. In addition, this choice of factors includes one from each ranking category (i.e. rarity, threat, and trends) and satisfies NatureServe's minimum data requirements. However, our implementation of the ranking process using these factors differs in several ways from the NatureServe method. Details on the theory and scoring methodology for each factor used in our local conservation status assessment process are described in sections 2.2.1 to 2.2.3 below. The scoring process is outlined more fully in section 2.3.

2.2.1 Rarity: Index area of occupancy

The smaller the area occupied by a species, the greater the risk that a single threat event will lead to its extinction or extirpation. In conservation status assessments, area of occupancy is the factor used to assess this risk; it is most commonly measured based on the number of occupied grid squares of a standard size and is referred to as the index area of occupancy (IAO). The difference between IAO and the actual area of occupied habitat within a species' range is subtle but important. Because IAO is based on a standardized unit of measurement, it can be applied across species and compared to established thresholds for the purpose of assigning scores.

We selected the number of 2 x 2 km grid squares occupied by the species being assessed within the Credit River

Watershed as the measure of IAO. This is consistent with the measures of IAO used by NatureServe and IUCN Red List (Master *et al*. 2012; IUCN 2017). The recommendation to use 2 x 2 km grid squares is based on evaluations that show that using larger and smaller square sizes tends to result in underestimates and overestimates of extinction risk, respectively (IUCN 2017).

Some authors have suggested that estimates of occupancy used in conservation status assessments should be measured differently for species or ecosystems that live in linear habitats, such as streams or shorelines (e.g. Cheng 2013; Simaika and Samways 2016); suggestions include using smaller grid squares or biologically calibrated estimates of the area occupied. However, recent evidence supports the use of 2 x 2 km grid squares as the most appropriate size for status assessment of species in any habitat. Using a simulation exercise, Keith *et al*. (2018) found that estimates of occupancy performed best as a predictor of extinction risk for species when based on grid squares of 2 x 2 km in scenarios where the size of possible threat events ranged from <1 to >1000 km^2. This result held true for species with various distribution types (e.g. linear vs. patch) and for different types of threats (e.g. small, frequent threats vs. large, infrequent threats).

Based on this analysis as well as our desire to create a method that was generally applicable, we chose to use the standard grid square size of 2 x 2 km and therefore remain consistent with the current recommendations of the IUCN (IUCN 2017). In addition, we tested the use of 1 x 1 km grid squares with our data – see Appendix A, section iii, for a discussion of these results. While smaller grid squares or biologically informed methods might be more useful for defining the actual area occupied by a species, having a standard scale and method to be applied across taxa is more useful for defining an IAO that best reflects the risk of extinction or extirpation.

We also adopted the NatureServe category thresholds for scoring IAO – with one modification. We capped the categories at F (126-500 grid squares) vs. I (> 12,500 grid squares) (Table 2). Using F as our maximum category assigns species with an IAO between 504 and 2000 km^2 the highest possible score for occupancy. This capping also adjusts the points assigned to categories A through F, such that each category gets a larger point value in our system than in the NatureServe system. We ran a trial assessment using the full set of categories (i.e. up to I) and found that few to no species were ranked as locally secure (L5) while many were ranked as local species of conservation concern (L1 to L3). This is largely because the total area in the Credit River Watershed is approximately 1000

Table 2. *Scores for IAO, as they relate to thresholds for number of occupied 2 x 2 km grid squares, minimum area occupied, and point values in CVC's ranking method*

Score	Number of grid squares	Minimum area (km^2)	Points
A	1	4	0.92
B	2	8	1.83
C	3-5	12	2.75
D	6-25	24	3.67
E	26-125	104	4.58
F	126-500	504	5.50

km^2, and therefore no species can score higher than an F for IAO.

We acknowledge that the NatureServe occupancy thresholds are intended for use at multiple geographic scales – including global, national, and subnational. However, their method has not generally been applied to jurisdictions as small as the Credit River Watershed. Based on our trial assessment, we decided that the full set of occupancy thresholds introduced too much bias toward identifying species of conservation concern. The implications of our choice to cap the occupancy thresholds for other local organizations wishing to use our method are discussed in Appendix A, section ii.

2.2.2 Threats: Intrinsic vulnerability

Certain characteristics can make species more intrinsically vulnerable to extinction or extirpation. These are characteristics that would make it harder for a species to recolonize an area if its population there was destroyed or declined severely, such as low fecundity or poor dispersal ability. These characteristics are intrinsic properties of the species itself and are not a measure of external threats to the species; however, species with these characteristics may be more susceptible to external threats.

We selected four life-history variables that can contribute to high intrinsic vulnerability (Table 3). These variables were chosen based on a review of the literature on vulnerability and extinction risk (e.g. Laurance 1991; Gaston 1994; Bennett and Owens 1997; Foufopoulos and Ives 1999; Purvis *et al*. 2000; Reynolds *et al*. 2005; Sodhi *et al*. 2008; Hutchings *et al*. 2012) as well as a consideration of their applicability across different taxa.

Within each of these variables, we identified a set of species traits with specific, quantitative definitions for our test taxon. For example, under population growth, the traits identified that relate to higher intrinsic vulnerability include low fecundity (minimum eggs per year ≤ 100), slow to mature (mean age at maturity of ≥ 5 years), and long lifespan (mean lifespan of ≥ 9.5 years). A species that possesses at least one of these traits would receive a 'yes' for population growth in the vulnerability assessment, because their population growth traits are related to higher intrinsic vulnerability.

Table 3. *Life history variables that contribute to intrinsic vulnerability in fauna*

Life history variable	Contribution to intrinsic vulnerability
Body size	Large body size leads to higher energy and area requirements, and larger species are more susceptible to direct exploitation; small body size can limit dispersal ability and slow recolonization
Population growth	Slow population growth (e.g. through low reproductive output) leads to an increased risk of dying before reproducing as well as slow recovery times after a population decline
Exposure to risk	There is an increased risk of mortality for both juveniles and adults in species that migrate, with no parental care, and with exposed eggs
Ecological dependence	Species that depend on other species for food or habitat face a higher probability not being able to fulfill all their needs if they cannot locate those species, as well as an increased susceptibility to changes in those other species populations; species that depend on a very particular type of habitat are more likely to be affected by habitat limitation or loss

The process for identifying the particular species traits and quantitative definitions for fish is described in section 3.3 below. Taxon-specific definitions will be developed for other animal groups when they are assessed. Assessing plants will require some modification to the list of variables, for instance because body size is not a useful characteristic to assess intrinsic vulnerability in plants (although plant height and seed size are).

Our method for ranking species' intrinsic vulnerability is more detailed and more quantitative than that used by NatureServe, in which species are ranked somewhat subjectively as either "highly", "moderately", or "not" intrinsically vulnerable. We consider the greater attention to vulnerability in our method be appropriate, since we rely on intrinsic vulnerability as one of three factors used to assess species, whereas NatureServe only uses vulnerability as a factor when information on threats is not available (Table 1; Faber-Langendoen *et al*. 2012). Scoring for intrinsic vulnerability is based on the number of variables for which the species possesses at least one trait (Table 4).

Table 4. *Scores for intrinsic vulnerability, as they relate to the number of vulnerability life history variables possessed by the species, and the equivalent point values in CVC's ranking method*

Score	Number of variables	Points
A	4	1.10
B	3	2.20
C	2	3.30
D	1	4.40
E	0	5.50

2.2.3 Trends: local short-term trend

CVC has records of occurrence data over time for many taxonomic groups in the Credit River Watershed, largely as the result of work carried out by the Integrated Watershed Monitoring Program (starting 1999) and the Natural Heritage Inventory program (starting 2007). However, the nature of these programs and the data that they collect means that trends in species occupancy cannot be calculated using a regression with time as a continuous variable. This is because sampling is not carried out in the same places or with the same effort in every year, meaning estimates of IAO for a species will not be accurate on an annual basis.

We therefore chose to assess trends in species occupancy over time using a two-window approach. Using this approach, the data record is divided into two equal time windows and the average occupancy per year for each species is calculated for each time window. We determined the short-term trend for each species based on the percent change in average occupancy between the two time windows, with a correction to account for differences in sample effort (described in more detail below). While this approach to trend assessment is somewhat crude, it has the benefits of reducing the effect of variation in sampling effort between years as well as being more easily applied by organizations that do not have annual data. In regard to our test taxon, we note that CVC does periodically assess trends in fish presence (not occupancy) in a more thorough manner, using data from the long-term monitoring program. However, this same level of analysis is not applied to other taxa in the Credit River Watershed.

Score	Percent change	Point adjustment
A	Decline of ≥ 90%	-0.50
B	Decline of 80-90%	-0.40
C	Decline of 70-80%	-0.31
D	Decline of 50-70%	-0.22
E	Decline of 30-50%	-0.14
F	Decline of 10-30%	-0.07
G	Decline of 10% to increase of 10%	0.00
H	Increase of 10-25%	0.07
I	Increase of ≥ 25%	0.14
U	Unknown	.

Table 5. *Scores for short-term trend, as they relate to the percent change in IAO between two time windows, and the point adjustments based on those scores in CVC's ranking method (based on Table 8 in Faber-Langendoen* et al. *2012)*

We used the NatureServe thresholds and points for scoring trends (Table 5); the overall scoring procedure is discussed in the next section.

2.3 Scoring process

We used the NatureServe process for combining scores and assigning a final rank, with minor modifications as described below.

2.3.1 Factor scoring

Species being assessed receive category scores (e.g. A through E) and corresponding point values for IAO and intrinsic vulnerability (Tables 2 and 4). The points for occupancy and vulnerability range from 0 to 5.5, with lower values indicating species of higher conservation concern. The points for each score (e.g. A through E) are scaled so that each category is an even division of 5.5. For example, for a factor with ten categories score A would be worth 0.55 points, score B worth 1.10, and so on. The NatureServe scoring process involves five possible conservation status ranks – the points scale goes up to 5.5 to allow one point for each rank, plus an additional 0.5 points to account for historical, extinct, and extirpated species. For more detail on their scoring process, see Faber-Langendoen *et al*. (2012).

2.3.2 Subtotal and total scoring

The scores for occupancy and vulnerability are then combined using a weighting process to get a weighted average subtotal. Following NatureServe, we assign a greater weight to IAO than vulnerability. The heavier weighting of rarity factors (e.g. IAO) vs. threats factors (e.g. vulnerability) emphasizes both the importance of rarity as a predictor of extinction risk as well as the fact that IAO is based on actual data from the watershed whereas vulnerability is based on a hypothesis about how those traits affect extinction risk.

Using the NatureServe approach, the subtotal is calculated as (0.7 x occupancy score) + (0.3 x vulnerability score). The total score for each species is then calculated using a point adjustment based on their short-term trend (Table 5); species with a declining trend have points subtracted from their subtotal, whereas species with an increasing trend have points added. A final rank for each species is assigned based on where their total score falls on the scale presented in Table 6. Where the NatureServe system is commonly used to assign global, national, and subnational conservation status ranks (G-, N-, and S-ranks, respectively), we have termed the local conservation status ranks produced by our method as L-ranks.

It should be noted that while the points, weighted points, subtotals, and totals are presented or calculated using two decimal places, the final rank is assessed using the total as rounded to one decimal place. This is the same as the process followed by NatureServe in their assessment calculator, the intent of which is to remove the implied level of mathematical precision in using two decimal places (personal communication, D. Faber-Langendoen).

Species with ranks L1 to L3 will be considered local species of conservation concern, which is analogous to the definition of species of conservation concern using ranks at other geographic scales (e.g. S-ranks). Additional, non-numeric ranks can be used to indicate a qualitative status for a species. For example, LNA is used to indicate that the status assessment method does not apply to the species, because it is not a suitable target for conservation activities (e.g. non-native species, hybrids). We use the same definitions for these qualitative conservation status ranks as NatureServe (2018). An example of the scoring process is illustrated in Table 7.

2.3.3 Rank adjustments

In rare situations where the L-rank is higher than the S-rank (e.g. L4 vs. S3), the L-rank will be adjusted to match the S-rank. When this occurs, the issue will be discussed with staff at the NHIC so that are aware of the discrepancy and so that they can provide input on which factors in the provincial ranking may have led to the difference. The adjustment will be noted in the assessment report, with an overview of the factors that led to the L-rank being higher than the S-rank. This adjustment process is recommended by Faber-Langendoen *et al*. (2012) and is also used by NHIC in cases where the S-rank is higher than the N- or G-rank.

Another reason why a rank may be adjusted is in circumstances where the rescue effect applies – i.e. if individuals from populations from outside the assessment area are likely to move into the assessment area and thus reduce the risk of extirpation for the species. Consideration of the rescue effect is built into most conservation status

Final score range	L-rank	Rank description
≤ 1.5	L1	Locally critically imperilled
1.5 < score ≤ 2.5	L2	Locally imperilled
2.5 < score ≤ 3.5	L3	Locally vulnerable
3.5 < score ≤ 4.5	L4	Locally apparently secure
> 4.5	L5	Locally secure

Table 6. *Relationship between final scores and local conservation status ranks; final scores are based on a weighted combination of factor scores for IAO and intrinsic vulnerability, adjusted based on the score for short-term trend*

Table 7. *Example of scoring process and calculations, using the observed values for Brassy Minnow (*Hybognathus hankinsoni*); note that this species would receive a rank of L4 based on only the combined subtotal for occupancy and vulnerability (3.6 points), but that the decreasing trend moves it to the rank of L3 (3.3 points)*

Factor	Species value [A]	Score	Points	Weighting	Weighted points
IAO	24 grid squares	D	3.67	0.70	2.57
Vulnerability	2 variables (Body size: small; Exposure to risk: exposed eggs and no parental care)	C	3.30	0.30	0.99
				Subtotal	3.56
Trend	Decrease of 69% (T1 = 19 grid squares, 0.049 standardized grid squares; T2 = 7; 0.015)	D	-0.22	1.00	-0.22
				Total	3.34
				Final rank	L3

[A] Full details of the trait values for Brassy Minnow, and all other assessed species, are available in Appendix B

assessments; we chose to follow the COSEWIC (2015) guidelines on how to apply it. Details on how the rescue effect was considered and applied to our test taxon are provided in section 3.5.

3.0 TEST CASE: FISHES OF THE CREDIT RIVER WATERSHED

3.1 Data

We chose to apply our draft method to a single taxon to evaluate its ease of use and ability to accurately classify species. We selected fishes as our test case, based on the large amount of existing data on occupancy over time, the availability of life-history information, and the manageable number of species.

CVC has data on fish presence throughout the watershed from sampling carried out by our monitoring and inventory programs as well as by other organizations, including the Ministry of Natural Resources and Forestry and the Royal Ontario Museum. The majority of data were from electrofishing surveys (58%), with other survey types including seine nets, hoop nets, and minnow traps. We restricted the data used in the assessment to 20 years before present (1998 to 2017). This threshold was chosen in part because species not seen in the last 20 years are generally assigned a rank of SH – i.e. historical – using the NatureServe method (NatureServe 2018), and also because rigorous data collection via CVC’s monitoring program began in 1998. We also chose to exclude records from Lake Ontario from our assessment, as the nearshore and deeper areas of the lake represent a significantly different habitat type than the rivers, streams, ponds, and small lakes within the watershed. Furthermore, Lake Ontario has not been thoroughly or regularly surveyed by CVC as part of any targeted program.

A total of 25,561 records of fish species presence from 1998-2017 were extracted from the database. This number was reduced to 13,901 records once the data were reviewed and problematic records and records for taxa not being assessed were removed (e.g. non-native species, records from Lake Ontario or without geographic coordinates). In the final data set, each record represented a single fish species observed in a single location on a single date. Fifty-one native fish species were observed over the 20-year period. We chose to not assess managed non-native fish species (e.g. Brown Trout [*Salmo trutta*]; Rainbow Trout, [*Oncorhynchus mykiss*]); these species were assigned a rank of LNA.

3.2 Index area of occupancy

Each record was assigned to a 2 x 2 km grid square using GIS. The Credit River Watershed contains 311 2 x 2 km grid squares; almost two-thirds of the squares in the watershed (63.7%; 198/311) were surveyed for fish at least once in the 20-year period. IAO for each species was calculated as the total number of unique grid squares in which the species was observed over the whole period.

Species observed in only one or two grid squares in only one or two years were assigned a rank of LU (i.e. unrankable) by default. This excluded species from our assessment that were presumed to be vagrants and those not well sampled by our methods (e.g. Bowfin [*Amia calva*], found in one grid square in one year), but retained species that were assumed to be genuinely rare or restricted to a small amount of habitat (e.g. Logperch [*Percina caprodes*], found in two grid squares in twelve years).

3.3 Intrinsic vulnerability

We reviewed the literature to identify species traits and specific, quantitative definitions of those traits for fishes for the four life-history variables selected as indicators of intrinsic vulnerability (Table 8). In particular, research by Parent and Schriml (1995), Cheung *et al*. (2005), Olden *et al*. (2008), O'Malley (2010), and Glass *et al*. (2017) identified threshold values related to high vulnerability or risk of extinction in fishes. For example, Cheung *et al*. (2005) suggested that species with an age of first maturity of 5 years or greater have high or very high vulnerability, and Parent and Schriml (1995) identified species that mature at 6 years of age as having high probability of extinction. The set of life-history parameters needed to assess vulnerability (e.g. age of first maturity) for each species were obtained from the Ontario Freshwater Fishes Life History Database (OFFLHD) (Eakins 2019) and FishBase (Froese and Pauly 2018), using the package rfishbase and the R software environment (Boettiger *et al*. 2012; R Core Team 2018). Where the two databases provided different information, values from the Ontario Freshwater Fishes Life History

Database were selected as more locally relevant.

3.4 Trends

The short-term trend for each species was determined by comparing the average number of unique grid squares in which the species was observed per year in the second and first halves of the data period, after correcting for survey effort. The standardization was necessary because of a notable difference in effort between the two time periods – an average of 59 sampled grid squares per year between 1998 and 2007 versus 70 between 2008 and 2017. To make the adjustment, we divided the number of unique grid squares in which each species was collected in a year by the total number of grids sampled in that year. We then calculated the average standardized occupancy per year for each ten-year time period.

Table 8. *Quantitative threshold definitions for 10 species traits in four life history variable categories for fishes of the Credit River Watershed*

Life history variable	Species trait	Threshold definition	Data source [A]
Body size	Large body size	Max. total adult length ≥ 100 cm	OFFLHD
	Small body size	Max. total adult length ≤ 10 cm	OFFLHD
Population growth	Low fecundity	Min. eggs per year ≤ 100	OFFLHD
	Slow to mature	Mean age at maturity ≥ 5 years	OFFLHD
	Long lifespan	Mean lifespan ≥ 9.5 years	OFFLHD
Exposure to risk	Exposed eggs	Open substrate spawning guild [B]	OFFLHD
	No parental care	Non-guarding guild [B]	OFFLHD
	Migratory	Potamodromous, anadromous, or catadromous [C]	FB; CVC
Ecological dependence	Habitat specialist	Stenotherm	CVC [D]
	Higher trophic level	Trophic level ≥ 4 [E]	FB

[A] Data sources include the Ontario Freshwater Fishes Life History Database (OFFLHD; Eakins 2019); FishBase (FB; Froese and Pauly 2018); and, CVC staff (CVC)
[B] Based on the fish reproductive guilds as described by Balon 1990
[C] Some species found it the Credit River Watershed are classified as anadromous or catadromous but do not actually migrate to or from saltwater; these species are migratory nonetheless; CVC staff identified species not listed as migratory by FishBase
[D] Fish species that are stenotherms (i.e. require a very narrow water temperature range) were identified by staff from multiple conservation authorities in the development of the Golden Horseshoe Fish Index, using data from Lyons *et al*. 1996
[E] Using the FoodTroph value from FishBase; trophic levels of 4 and above are carnivores that eat other carnivores

The percent difference between the time periods (i.e. the trend) was calculated using the formula:

$$trend = \left(\frac{uT2 - uT1}{uT1}\right) X\, 100$$

where uT2 is the average number of standardized squares occupied per year between 2008 and 2017 and uT1 is the average number of standardized squares occupied per year between 1998 and 2007.

Two species were observed only in the second time period, and therefore had a calculated trend of positive infinity. For both of these species – American Eel (*Anguilla rostrata*) and Slimy Sculpin (*Cottus cognatus*) – it was assumed that the absence of observations in the first time period was due to issues of detectability and not a true absence from the watershed. We therefore gave these species a trend score of G, with a point adjustment of 0.

3.5 Rescue effect

The fish species with the highest probability of immigration into our assessment area are those whose range includes both Lake Ontario and the Credit River Watershed. We identified ten such species, using both professional judgment and by calculating the proportion of observations for each species in our complete data set that occurred in Lake Ontario. For those ten species that were identified as candidates for the rescue effect we then considered the factors outlined in the COSEWIC (2015) guidelines – primarily the status of the populations outside the watershed and the likelihood of immigration – when considering whether or not to apply the rescue effect and adjust the rank.

3.6 Results

The L-ranks for all fish species in the Credit River Watershed are presented in Appendix B, Table B1 while the full details of factor values, scores, and points for the assessed fish species are presented in Table A2. The number of occupied grid squares ranged from a minimum of one to a maximum of 136, with a median of 21. Creek Chub (*Semotilus atromaculatus*) was found in 136 grid squares over the 20-year period, while Slimy Sculpin was found in only one square.

The assessed fish species possessed characteristics from 0 to 4 vulnerability variables, with a median of two. The fish with the highest vulnerability scores had different combinations of traits in the four variables; for example, large-bodied, long-lived, migratory species (e.g. Northern Pike [*Esox lucius*]) and small-bodied, low fecundity species with no egg-guarding (e.g. Rainbow Darter [*Etheostoma caeruleum*]) both scored A or B for vulnerability.

The standardized occupancy of most species increased from the first time period to the second; trend values ranged from a decrease of 69% to an increase of 661%, with a median increase of 8%. Brassy minnow had the highest decreasing trend – a decline of 69%.

Three species had their L-ranks adjusted due to disagreement with the S-rank: American Eel (L3, vs. S1S2); Redside Dace (*Clinostomus elongatus*) (L3 vs. S1); and, American Brook Lamprey (*Lethenteron appendix*) (L4 vs. S3). Potential explanations for these discrepancies are discussed in section 4.3.

L-ranks were adjusted one step higher (e.g. L3 to L4) for eight species based on the potential for rescue effect (Table 9;

Table 9. *Fish species for which the rescue effect was considered, including: the proportion of observations (pObs) in our data from Lake Ontario (raw numbers in parentheses); whether or not the population in the watershed is connected to the Lake Ontario population; the status of the external population; whether or not the rescue effect (RE) was applied, and the resulting change in rank (if any)*

Common Name	pObs in Lake Ontario	Populations connected	External population status	RE applied	Rank change
Freshwater Drum	0.63 (12/19)	Y	S5	Y	L3 -> L4
Lake Chub	0.52 (27/63)	Y	S5	Y	L3 -> L4
Shorthead Redhorse	0.66 (53/80)	Y	S5	Y	L3 -> L4
Smallmouth Bass	0.58 (145/276)	Y	S5	Y	L3 -> L4
Gizzard Shad	0.82 (66/93)	Y	S4	Y	L3 -> L4
Yellow Perch	0.30 (58/195)	Y	S5	Y	L4 -> L5
Emerald Shiner	0.74 (212/300)	Y	S5	Y	L4 -> L5
Spottail Shiner	0.36 (35/98)	Y	S5	Y	L4 -> L5
American Eel	0.50 (6/12)	Y	END, S1S2	N	none
Slimy Sculpin	0.67 (8/12)	N	S5	N	none

Appendix B, Table B1). The rescue effect adjustment was not applied to two of the ten species that were identified as candidates. The rank for Slimy Sculpin was not adjusted as the existing population within the Credit River Watershed is separated from Lake Ontario by a significant distance. The rank for American Eel was not adjusted because it is a provincial species at risk.

Taking the scores for all three factors into account, as well as adjustments, we ranked two species as L1, two species as L2, and ten species as L3 – for a total of 14 species ranked as of local conservation concern (Appendix B). This is notably higher than the five species ranked as S1-S3 in the province of Ontario by the NHIC (Table 10). All assessed species classified as a species at risk were ranked L1 to L3 using our method.

In addition to the Redside Dace (L1) and American Eel (L2) – both species at risk – we identified two species of fish in the Credit River Watershed within the two ranks of highest conservation concern. Slimy Sculpin was ranked as locally critically imperilled (L1), while Greater Redhorse (*Moxostoma valenciennesi*) was ranked as locally imperilled (L2). While Greater Redhorse is considered provincially vulnerable (S3), Slimy Sculpin is considered provincially secure (S5). Some reasons for the high local conservation concern for Slimy Sculpin are discussed in section 4.2.1 below.

4.0 DISCUSSION

4.1 Overview

We developed a method for assigning local conservation status ranks to species in the Credit River Watershed that is simple, objective, and applicable across taxa. This method is a modification of the NatureServe system for ranking species; our method is scaled more appropriately for smaller geographic areas and is easier to apply with limited data. We use three factors – IAO, intrinsic vulnerability, and short-term trend – to assign a rank to species on a scale from L1 (locally critically imperilled) to L5 (locally secure). These L-ranks can be used to prioritize areas for action, to assess the

Rank	Rank description	Local	Provincial
1	Critically imperilled	2	1
2	Imperilled	2	2 [A]
3	Vulnerable	10	3 [B]
4	Apparently secure	28	22
5	Secure	9	44
X	Presumed extirpated	3	2
H	Possibly extirpated	6	1
U	Unrankable	15	3
NA	Not applicable	14	11

[A] We are including American Eel in the totals for S2, even though it has been assessed with a rank range of “S1S2”
[B] We are including Deepwater Sculpin in the totals for S3, even though it is ranked as “S3?”, which indicates that the rank is inexact

Table 10. *Number of fish species in the Credit River Watershed in each rank category using the method described in this document (Local) and as assessed provincially by the Natural Heritage Information Centre (Provincial)*

effectiveness of existing programs, and to protect habitat under regional policy.
We applied our method to fishes of the Credit River Watershed as a test case. In general, we found that our L-ranks were more conservative than provincial S-ranks, in that we classified almost three times as many species as of conservation concern. The assessed provincial species at risk and species of conservation concern were ranked as local species of conservation concern using our system, although their initial L-ranks did not match their S-ranks (see section 4.3).

The additional fish species identified as L1 to L3 all had some combination of very restricted local ranges (e.g. Slimy Sculpin, L1), high intrinsic vulnerability (e.g. Blacknose Shiner [*Notropis heterlepis*], L3), and declining short-term trends (e.g. Brassy Minnow, L3). While there may be different reasons why a fish species was ranked L1, L2, or L3, each of the 14 species identified as of local conservation concern has a relatively high risk of extirpation from the Credit River Watershed. The loss of these species has the potential to alter the function of the local ecosystem in numerous ways, including disrupting food webs, nutrient cycling, sediment processes, and the regulation of carbon fluxes.

Below, we highlight a few examples of L-ranks for particular fish species that illustrate how our system works objectively and provides locally relevant information (section 4.2), as well as discussing the rank adjustments for species whose L-ranks were higher than their S-ranks (section 4.3). In addition, we discuss potential applications of L-ranks at CVC (section 4.4), several further considerations regarding the development and use of this method (section 4.5), as well as next steps (section 4.6). Readers may wish to skim these sections depending on their interests and time.

4.2 Specific rank examples

4.2.1 A local rarity

Slimy Sculpin received the lowest score in our assessment and was assigned a rank of locally critically imperilled (L1). However, this species is considered provincially secure (S5) and is generally considered common (Eakins 2019). Slimy Sculpin has only been found in only one grid square in the watershed, and therefore received the lowest possible score for IAO. In addition, it has three vulnerability characteristics, making the species susceptible to local extirpation.

We considered that the low numbers of Slimy Sculpin in our data may have been due to issues of detectability, as it is a cryptic, benthic species. However, electrofishing has been identified as the most efficient way to survey for Slimy Sculpin (Gray *et al*. 2018). In addition, CVC staff note that the area where Slimy Sculpin has been detected in CVC surveys is the same area as the only record for the species from the watershed in the Royal Ontario Museum, despite extensive surveying of the watershed by museum staff over the past century. This mirrors what is known about the ecology of the species – their low mobility and high site fidelity have contributed to its selection as a suitable species for environmental monitoring (Gray *et al*. 2018).

While Slimy Sculpin is also present in Lake Ontario, its known occupied area in the Credit River Watershed is separated from the lake a significant distance as well as several barriers – making it a distinct population. We cannot say whether the Credit River Watershed population of this species is small and isolated due to natural or anthropogenic factors. However, in either case we suggest that this population is worthy of conservation attention and protection; if Slimy Sculpin is lost from that one grid square, it is lost from the entire watershed. In sum, the rank of L1 for Slimy Sculpin is a good example of how our method has identified a species of truly local conservation concern.

4.2.2 A species to watch

Brassy Minnow is ranked as locally vulnerable (L3) in our assessment, but as secure provincially (S5). While this species has not received much conservation attention in Ontario, it is a species of conservation concern in neighbouring jurisdictions – with ranks of vulnerable, imperilled and critically imperilled in Quebec, New York, and Vermont, respectively. The species has declined or disappeared from watersheds within these regions, all of which are at the edge of its range (NatureServe 2018; NY DEC 2018). This is of note, since Brassy Minnow exhibited one of the greatest percent declines in standardized average occupancy of any species that we ranked – a decline of 69% from the first to the second time window. In addition, the western population of Brassy Minnow is listed as a high-priority by COSEWIC and will be assessed in the near future (COSEWIC 2018). This suggests that our local conservation status assessment was useful in bringing attention to a species that has been generally overlooked in the watershed but may be in need of attention. This may include investigating potential reasons for the decline of Brassy Minnow in the watershed, as well as formulation a strategy for recovery of the species.

4.2.3 More widespread than we thought

Central Mudminnow (*Umbra limi*) received one of the highest total scores in our assessment and was ranked as locally secure (L5). This rank was based on the relatively large number of squares in which it was observed (70), the lack of any vulnerability characteristics, and a small increase in standardized average occupancy of 2% over the two time windows. While Central Mudminnow is also ranked provincially secure (S5), CVC staff were surprised to find that it received such a high L-rank as they did not consider the species to be particularly widespread. This may be partly due to its biology; Scott and Crossman (1998) refer to Central Mudminnow as small and "rather secretive", and its feeding habits involve burrowing into the sediment and staying still while they wait to ambush prey. In addition, as it has not generally been a species of interest, it's distribution within the watershed has not been assessed or reviewed. However, the data show that it is widely distributed within the Credit River Watershed and commonly observed. As such, the rank of L5 for Central Mudminnow is a good example of how our ranking method provides objective information that can add to professional experience.

4.2.4 A flagship species

Brook Trout (*Salvelinus fontinalis*) is a popular sport fish and is also considered an indicator of stream health. Trout Unlimited (2006) estimated that Brook Trout has severely declined within or been extirpated from the majority of its historical range in eastern North America. However, Brook Trout is ranked as secure both provincially (S5) and globally (G5) (NatureServe 2018); the current data on its range, occurrence, population size, and short-term trends put it in the highest category, despite concerns regarding historical declines and ongoing threats to the species. Our assessment assigned a rank of L4, or locally apparently secure, for Brook Trout based on its large IAO (74 squares), three vulnerability characteristics, and a small increase of 7% in standardized IAO over the two time periods. While our local rank is lower than the provincial rank (L4 vs. S5), our method also did not classify Brook Trout as a species of local conservation concern.

We considered that Brook Trout might have been ranked as a species of conservation concern (i.e. L3 or lower) if we had data that allowed for analysis of longer term trends, or if we had analyzed abundance instead of occupancy, as trend data from CVC's Integrated Watershed Monitoring Program show a significant decline in Brook Trout biomass between 1999 and 2016. However, Brook Trout would still be assessed as L4 if we substituted the biomass-based trend (-38% over 20 years) for the occupancy-based trend – its IAO would need to be much smaller and/or the declining trend would have to be more severe for it to be assessed as L3.

Brook Trout may not have been identified as a local species of conservation concern in our assessment, but it will remain the focus of study and management efforts due to its historical, social, ecological and economic importance. In addition, a recent survey of experts across the province identified the tributaries of Lake Ontario, including the Credit River, as one of the regions where Brook Trout has declined most severely and faces the most threats – including increasing threats due to climate change (Haxton *et al*. 2019). These concerns have led to a number of initiatives locally and provincially to provide additional direction on Brook Trout management. This species is a good example of how L-ranks should be considered within a larger context.

4.3 Rank adjustments

Three species had their L-ranks adjusted down in order to match their S-ranks: American Eel, Redside Dace, and American Brook Lamprey. The potential reasons for each of these mismatches are discussed below. In each case, CVC is satisfied that the adjusted L-rank is an appropriate assessment of the species' local conservation status.

4.3.1 American Eel

American Eel is a provincially Endangered species, ranked as S1S2 by the NHIC but ranked as locally vulnerable (L3) by our system. We note the total score for this species was 2.6, which is just above the threshold for L2 of 2.5 or lower. In our assessment, American Eel had a very small IAO (5 grid squares) and three vulnerability characteristics; however, it was only observed in the second time window and therefore received a short-term trend of zero. A decreasing short-term trend of 10% or higher would be enough to move American Eel to a rank of L2 using our method. The discrepancy between our rank and the provincial rank is likely mostly due to trends, as American Eel has had documented provincial declines of greater than 70% (COSEWIC 2012). Our short-term trend is difficult to compare to these provincial trends, which are based on data from much longer time periods – as is appropriate for a long-lived species like American Eel. In addition, the provincial trends are all based on data from areas significantly east of the Credit River Watershed.

4.3.2 Redside Dace

Redside Dace is also a provincially Endangered species, recently ranked as provincially critically imperilled (S1) by the NHIC but ranked as locally vulnerable (L3) by our system. This species requires cool, clear flowing streams with particular habitat conditions, and has suffered habitat destruction and degradation largely as a result of urban development. Populations of Redside Dace have disappeared from several watersheds across the Greater Toronto Area in recent years, but the species continues to persist in several subwatersheds of the Credit River.

Our rank of L3 for Redside Dace was based on its: small, but not tiny, IAO (11 grid squares); two vulnerability characteristics; and, 37% decrease in standardized IAO over the two time windows. We note that Redside Dace was consistently ranked L3 in every variation on the method that we tried (e.g. using the full NatureServe thresholds for IAO, smaller grid squares, etc.). CVC staff predict that the local IAO for Redside Dace will decrease if Redside Dace is re-assessed in the near future; threats to the species are ongoing, and it has declined to below detection levels at least two subwatersheds in the past eight years.

The discrepancy between our L-rank and the S-rank is likely due to the inclusion of two factors in the NHIC assessment not included in ours – threats and the number of viable occurrences. Redside Dace received a threat impact score of very high in its most recent COSEWIC assessment (COSEWIC 2017), which would provide it with a lower score (i.e. of greater conservation concern) in the threats category than it received for intrinsic vulnerability in our assessment. In addition, NHIC considered very few of the current occurrences of Redside Dace to be viable, which would have lowered the category score for occupancy.

4.3.3 American Brook Lamprey

American Brook Lamprey has been assessed as provincially vulnerable (S3) but was ranked by our system as locally apparently secure (L4). We note that the total score for this species in our assessment was 3.6, just above the threshold of 3.5 or lower for L3. Like Redside Dace, American Brook Lamprey in our assessment had a small, but not tiny, IAO (18 grid squares) and two vulnerability characteristics. In addition, American Brook Lamprey received a neutral trends score – with almost no change in occupancy between the first and second time windows.

The provincial rank of S3 for American Brook Lamprey was largely due to its threats score; like Redside Dace, it also received a score of very high in a threats impact assessment (Mike Burrell, personal communication). It therefore seems that the discrepancy between our L-rank and the S-rank was because of the use of threats vs. intrinsic vulnerability.

4.4 Applications for CVC

Local conservation status ranks will have numerous applications at CVC. First and foremost, habitat for species ranked L1 to L3 will meet the criteria for Significant Wildlife Habitat in Peel Region, according to the guidelines in the *Peel-Caledon Significant Woodlands and Significant Wildlife Habitat Study* (North-South Environmental *et al*. 2009). Once they have been identified, areas of Significant Wildlife Habitat are considered high functioning features in CVC's Natural Heritage System (CVC 2015). In addition, lists of locally significant wildlife (e.g. plants) could be used to identify other natural heritage features that receive protection under the *Provincial Policy Statement*, such as Significant Woodlands (OMNR 2010a; OMMAH 2014).

Like other types of Significant Wildlife Habitat or significant natural heritage features, the presence of a local species of conservation concern at a site involved in a development application may require actions to avoid or mitigate impacts of the development to that species. For example, the timing of work may be planned to avoid breeding windows, or the location of access roads may be routed to avoid key habitat features so that development may proceed in a responsible and sustainable manner. In some cases, proposed activities or development may need to be restricted or relocated completely. The precise ways in which CVC will recommend habitat protections for species ranked L1, L2, and L3 will be established by an internal working group.

We emphasize that the L-rank is only one piece of information about a species. Additional data, professional knowledge, and the context in which species are found should always be taken into consideration when making conservation decisions. For example, the listing of a species under the provincial *Endangered Species Act* and federal *Species at Risk Act* holds greater weight than an L-rank. Alternatively, a species may have high local interest for cultural or socioeconomic reasons, despite not being ranked L1 to L3. The status of a species as a resident, migrant, or visitor should also be taken into account.

Beyond policy-based protections, CVC will develop tools to protect, restore, and enhance habitat for local species of conservation concern – including management plans, recovery strategies, subwatershed plans, and restoration plans. As one example of how L-ranks may be used to inform this work, we can look at particular areas where fish species of conservation concern have been observed. Many of our L1 to L3 species (e.g. Greater Redhorse, Rosyface Shiner) were most frequently observed in the first two stream segments between the mouth of the river in Port Credit and the first major dam in Streetsville. This emphasizes the importance of these areas as habitat for species that move between the lake and river, and the limitations on these species imposed by the dam in Streetsville.

Moving away from lake-river interface, the West Credit River subwatershed is also an area of interest. Slimy Sculpin (L1) is found in this area, as is Banded Killifish (*Fundulus diaphanus*) (L3) and Brassy Minnow (L3). The West Credit River does not currently have a management plan, and the subwatershed study for the area was completed 20 years ago – suggesting that this may be an area of priority to focus on.

Alternatively, we can look at records of local species of conservation concern that occur within existing areas of interest. The Credit River – Hungry Hollow area, for which a management plan is currently in development and which has been highlighted in CVC's Natural Heritage System as Centre for Biodiversity, contains records of several L1 to L3 species – including Redside Dace and Brassy Minnow. Information on the locations of L1 to L3 species can be used to target areas for action in the Hungry Hollow – Credit River management plan.

Finally, we will also promote the use of L-ranks by groups across CVC and by our external partners as another factor to consider in site protection, restoration prioritization, land securement, and Natural Heritage Systems planning and evaluation. Local rarity has already been recognized as an important factor in some evaluation systems (e.g. the Ontario Wetland Evaluation System; MNRF 2014); however, there has been limited information available to date on which species are of local conservation concern. We aim to have L-ranks recognized as a valuable piece of information about the species that occur in the Credit River Watershed; these ranks will be incorporated into the policies and programs that work to characterize the health of our local ecological communities.

4.5 Additional considerations

Many issues were considered during the development of our local conservation status assessment method. Appendix A contains an in-depth discussion and review of the processes and analyses used, including the results of sensitivity analyses.

Topics covered in Appendix A include: other ranking factors; choice of occupancy thresholds; choice of grid square size; sampling effort and detectability; data biases; which species to assess; the effect of IAO on final rank; and, species on the edge

This discussion will be of interest to other local conservation organizations that may wish to apply the method in their own jurisdictions, as well as readers with an interest in the background and rationale for the choices that were made.

4.6 Next steps

Our local conservation status assessment method was tested on one taxonomic group during development. We have received and incorporated feedback on our method, both internally and externally, and plan to begin applying the method more broadly. Once this final version has been approved, we will assess and rank other taxa in the Credit River Watershed – starting with plants (2020), followed by birds (2021) and herptiles (2022). We anticipate that each taxon will provide unique challenges that will need to be addressed, and therefore expect that the local conservation status assessment method may be revised in later versions.

As one of our goals is to share this method with other conservation organizations, we will publish the final version and make it available for use by other groups (e.g. conservation authorities, municipalities) that may wish to identify species of conservation concern within their local area.

In addition to revisions to the method, we intend to periodically update the ranks for species that have already been assessed. We suggest that this reassessment should occur about every five years, which is consistent with the time frame used by other organizations and will allow for updated information on IAO and trends based on two full rounds of surveys at all monitoring sites. In reanalyses, the start and end points of the time windows for the trend analysis will therefore be shifted forward by 5 years. In addition, we would consider re-assessing a species sooner than five years should significant new occurrence data for that species be presented.

5.0 CONCLUSIONS

Identifying local species of conservation concern will help CVC in our mandate to protect, restore, and enhance the natural heritage of the Credit River Watershed. The method we have developed to assign local conservation status ranks is simple, objective, and broadly applicable. We have successfully used the method to identify local fish species of conservation concern in the watershed, and plan to apply it to additional taxa in the future. In addition, the method has been designed to be applicable by other conservation organizations wishing to identify local species of conservation concern in their jurisdictions. At CVC, L-ranks will contribute a source of useful information for prioritizing areas for action, assessing the effectiveness of existing programs, and protecting habitat.

This report has outlined the scientific details of the assessment method and documented the decisions made during its development. In regard to the fish species we used as our test case, we identified 14 species of local conservation concern – ten of which had not already been identified as provincial species of conservation concern or species at risk. The precise ways that CVC will incorporate information on these and other local species of conservation concern into policies and programs across the organization will be determined with consideration to our role and responsibilities as stewards of the natural heritage in the Credit River Watershed and technical advisors to the municipalities in our jurisdiction.

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APPENDIX A. Details of factors considered and sensitivity analyses conducted during the development of the local conservation status assessment method

i. Other ranking factors

During the process of developing our local conservation status ranking method, we considered using several factors to assess species in addition to the three that were ultimately selected. In particular, we considered using measures of: environmental specificity; spatial clustering; population trend information for a larger geographic area; threats; abundance; and, long-term trends. The decision making process used to exclude these factors is discussed below.

In addition, we considered using a flexible method of assessment where additional factors could be incorporated into the scoring procedure for species for which the information was available and left out when it was not. However, in the end, we decided that using only three factors best fit with our goal of creating a simple and easily applied method.

Measures of environmental specificity were omitted because existing methods for defining the environmental specificity of a species involve subjective decision making and/or require information not available for all species. For example, several groups have classified freshwater fish species as tolerant vs. intolerant, but these classifications are based on judgment as opposed to some measurable characteristic of the species. We tested a method (spatial clustering) to assign scores to species based on how close together in space all the records for a species were, given that some species may be found only in grid squares in a small area of the watershed. However, we found that doing the analysis at the geographic scale of the watershed meant that all species were identified as highly spatially clustered. Finally, we found that population trend data at the regional, provincial, or national scales are not available for most species.

Other status assessment methods, including the NatureServe method, commonly use the IUCN Threats Calculator to assess the types and strength of threats faced by species. We chose to focus on vulnerability instead of threats for several reasons. First, completing a threats calculator for each species would be time intensive and require the participation of multiple experts. For our purposes, assessing vulnerability using quantitative thresholds based on biological characteristics is easier and less subjective. Second, the threats experienced by different species in the same guild would be fairly consistent across the Credit River Watershed – resulting in low variation in threats scores across guilds. Third, our approach considers threats implicitly in both the choice of grid square size (see discussion in section 2.2.1) and the intrinsic vulnerability score. In sum, we concluded that adding threats to our method would not contribute much to the analysis.

We also considered using a measure of abundance instead of IAO as a factor to assess rarity. The NatureServe and IUCN Red List methods both use population size as one of their ranking factors; however, these factors are based on an estimate of the total number of mature individuals (or a surrogate measure used as an index of abundance) in the area of interest. While CVC's monitoring data contains some information on the number of individuals caught, these data have been inconsistently collected over time and do not permit accurate estimation of population size for fish in the watershed. In addition, the data from other sources (e.g. the Royal Ontario Museum) provide no information on abundance. Furthermore, estimates of abundance will not be possible for species in most other taxa (e.g. birds, herptiles, plants) due to the way the data are collected. As such, in keeping with our goal of developing a method that was generally applicable, we chose to use IAO instead of abundance. The relationship between occupancy and abundance is well supported in ecology (Gaston 1994; McGill 2007), including recent work in stream fishes (Miranda 2019).

As additional data on species occupancy in the watershed are collected over time, we may consider including a long-term trend factor to the ranking system in addition to the short-term trend. We limited the data for our test case assessment to a 20-year period, in part because of the 1998 starting date of systematic surveys in the watershed as well as the practice of considering a species record older than 20 years to be historical. Once CVC has collected a full three decades of data, in 2028, we will consider adding the long-term trend data to the assessment. This will provide an additional ten years of data to the trend calculations and would include more complete trend information for species whose populations are increasing in the short-term after a historical decline, or vice-versa. If the use of a long-term trend factor is implemented, we will consider weighting short-term trend more heavily than long-term trend as done in the NatureServe method (Faber-Langendoen *et al*. 2012).

ii. Choice of occupancy thresholds
As described in section 2.2.1, we chose to use the NatureServe categories and thresholds for IAO; however, we capped the thresholds at six (A through F) instead of nine categories (A through I). When making this decision, we assessed what would happen if the full set of NatureServe categories for occupancy was applied to our fish data. The result was that no species were classified as L5, only six were classified as L4, and the rest (46) were classified as species of conservation concern (L1 to L3). This bias toward assigning lower ranks and increasing the number of species of conservation concern was considered unacceptable.

The highest category for occupancy in our method (category F; Table 2) includes species that occupy between 126 and 500 2 x 2 km grid squares, or 504 to 2000 km^2. The lower end of this range is about half of the area of the Credit River Watershed, while the upper exceeds the total area in the watershed. This range also includes the total area of jurisdiction for many other agencies that might want to assign local conservation status ranks, including several of the 36 conservation authorities in southern Ontario.

However, other agencies wishing to use this method might find that the upper threshold of occupancy category F is smaller than the total area of their jurisdiction – including Toronto and Region Conservation Authority, which manages an area of approximately 3000 km^2. In these cases, we would recommend one of two approaches.

First, for jurisdictions that are significantly larger than 2000 km^2, we suggest using NatureServe category G as the maximum category for IAO, which includes 501 to 2,500 2 x 2 grid squares or an area of 2,004 to 10,000 km^2. This range should cover most of the jurisdictions in which it is reasonable to assess local species of conservation concern, including all ecodistricts and quaternary watersheds in southern Ontario (Wester *et al*. 2018; OMNR 2010b).

Second, for jurisdictions that are not much larger than 2000 km^2, we suggest that it may be reasonable to maintain the use of category F as the maximum category for IAO. The rationale for this approach is that it is highly unlikely that any species will be observed in every single grid square within a jurisdiction, so a maximum occupancy of 2000 km^2 would be adequate for most to all species being assessed. Other agencies wishing to apply this local conservation status assessment method should investigate both approaches for occupancy and assess which one is best suited to their needs.

iii. Choice of grid square size
As discussed in section 2.2.1, both NatureServe and IUCN recommend using IAO calculated with 2 x 2 km grid squares when assessing conservation status. This recommendation is based on studies that show the 2 x 2 km size works well to avoid over- or underestimates of species ranks as well as the fact that using a standard grid cell size helps ensure consistency and comparability of results across taxa and locations.

Nonetheless, NatureServe also provides categories for IAO using 1 x 1 km grid cells and suggests that this smaller cell size may be appropriate to use "*for species occurring in and confined to linear habitats (e.g. shorelines, streams) and for which one has relatively precise locations and a relatively complete inventory*" (Master *et al*. 2012, pg. 18). In addition to the case of species in linear habitats, we considered the suggestion that using a smaller grid cell size for IAO may be more appropriate for local conservation status assessment than 2 x 2 km cells, given that the tests of the suitability of these different grid cell sizes have all been done for species assessments at global, national, or subnational scales.

We therefore repeated the analysis of the fish data with 1 x 1 km grid cells instead of 2 x 2 km, using NatureServe's categories for IAO based on 1 x 1 km squares (found on page 19 in Master *et al*. 2012). These categories are equivalent in terms of the total area included in each category for both grid cell sizes; for example, category A includes species that are found in either one 2 x 2 km grid cell or anywhere between one and four 1 x 1 km grid cells – both with a maximum of 4 km^2. As with IAO for the larger grid squares, we capped the NatureServe categories at F (501 to 2000 1 x 1 km grid squares).

The change to grid square size resulted in changes to the number of occupied grid squares for most species, as well as changes to the trend in occupied squares over the two time periods. As a result, there were differences in the final ranks for the fish species assessed. In total, 28 of the 51 species (55%) were ranked as species of conservation concern using the 1 x 1 grid cells, vs. 14 of 51 species (27%) using the 2 x 2 grid cells. Using the smaller cell size resulted in an additional 14 species being ranked as species of conservation concern (L4s becoming L3s), as well as ten species that moved from L3 to L2. This included species such as Johnny Darter (*Etheostoma nigrum*) and Fantail Darter (*Etheostoma flabellare*) being ranked as L3 – despite that fact that both species were found in a relatively large number of grid squares in our data and are known as generally common species (Eakins 2019).

We note that the species whose ranks moved downwards (e.g. L4 to L3) were mostly influenced by changes to their score for IAO when using the smaller cell size and not by changes to the short-term trend. For example, Johnny Darter was observed in 32 2 x 2 km grid cells (or 128 km^2) and received a score of E for 4.58 points. Using the smaller grid cells, Johnny Darter was observed in a 52 1 x 1 km cells (or 52 km^2) and received a score of D for 3.68 points. This lower value for IAO is the factor that moved Johnny Darter from L4 to L3 in the re-analysis.

As noted in section 2.2.1, we stress that the estimate of IAO used in this assessment method is not meant to be a measure of the actual area of habitat occupied by the species, but is meant as an index. Going back to the example of Johnny Darter, it is unlikely that its true area of occupancy in the Credit River Watershed is either 52 km^2 or 128 km^2. Both of these are certainly overestimates, given that the streams and rivers where it lives make up only a small portion of the total area of each grid square in which it has been observed. However, as an index, an IAO of 52 km^2 provides a value that allows us to assess Johnny Darter and compare it to other species assessed using the same methods.

In sum, our exploration using 1 x 1 km grid squares to calculate IAO led us to the same conclusions as have been previously made by the IUCN – that the overall percentage of species being ranked as species of conservation concern using the 1 x 1 grid squares was an overestimate. We suggest that this is because not all grid squares in the watershed have been surveyed; as noted above, the recommendation from NatureServe for the use of 1 x 1 km grid squares suggests it is only appropriate in situations where a relatively complete inventory has been carried out.

iv. Sampling effort and detectability

One of the reasons that we chose to test our method with fishes was because of the quantity and quality of the data available. As mentioned in the methods, almost two-thirds of the grid squares in the watershed (63.7%; 198/311) were surveyed for fishes at least once in the 20-year period. In addition, this surveying included sites in all areas of the watershed; roughly equal numbers of squares were surveyed in the lower, middle, and upper watershed zones (68, 66, and 63 squares, respectively). Finally, the most common survey method used was electrofishing, which is known to have high detection rates for most stream fishes (Portt *et al*. 2006; Reid and Haxton 2017).

We would not recommend assessing the local conservation status of taxa that do not meet these three conditions: (i) a large proportion – we suggest 50% – of the 2 x 2 grid squares in the area of interest have been surveyed; (ii) survey effort has been distributed relatively evenly throughout the area of interest; and, (iii) survey methods have a reasonable probability of detection for most taxa being assessed. Failure to meet these conditions will mean that the data set may not accurately represent the occupancy of species in the area of interest. For organizations wishing to use this method that do not have data that meet these conditions, we recommend proceeding with caution and keeping the limitations of the data in mind.

Determining what qualifies as a reasonable probability of detection may be somewhat subjective, but the decision should be informed by knowledge of the biology of the species being assessed. In the case of our assessment, we noted that several of the fish species known from the watershed prefer lake and pond habitats (e.g. Black Crappie [*Pomoxis nigromaculatus*], Pumpkinseed [*Lepomis gibbosus*]), while others prefer deeper waters (e.g. Shorthead Redhorse [*Moxostoma macrolepidotum*]). To address concerns that these species may not have been well surveyed by our sampling methods – and therefore, that their ranks would be biased by artificially low IAO – we assessed the data in two different ways.

First, we calculated the proportion of observations of each species in our data that came from lakes and ponds vs. rivers and streams. Most of the species known to prefer lakes and ponds had higher numbers of observations in these habitats (e.g. Black Crappie, 117/140 observations in lakes and ponds); however, the number of lakes and ponds sampled provided enough data so that these species were still relatively commonly observed (e.g. Black Crappie in 17 grid squares) and received ranks of L4 or L5.

Second, we reviewed all species observed in five or fewer grid squares and asked whether the small IAO could be due to under-sampling. Many of the species found in a small number of grid squares could be classified as species living at the interface of Lake Ontario and the Credit River (e.g. Gizzard Shad [*Dorosoma cepedianum*], Logperch); this also includes those that prefer deeper water (e.g. Shorthead Redhorse). Our decision to retain these species in the list for assessment is discussed in Appendix A, section vi. For the remaining species found in five or fewer grid squares, our opinion was that this reflects their true distribution in the watershed. For example, Banded Kilifish is known to only exist in and around two ponds in the West Credit River subwatershed.

v. Data biases

Most data sets include some bias, even those that meet the standards for sampling effort discussed above. These biases should be accounted for when possible during analysis as well as acknowledged and considered when interpreting results.

There are two main sources of bias in our stream-fish data. First, sampling effort increased over the 20-year period as the monitoring program expanded. We chose to account for this by standardizing for sample effort in our calculations of trends in occupancy. Second, the locations of surveys were not randomly distributed and were often directed to known or suspected areas of occupancy for certain species of interest. For example, it is likely that all or almost all populations in the watershed of two high interest species – Brook Trout and Redside Dace – have been detected, which is not the case for most other fish species in our data.

It was not possible to account for this non-random sampling during this analysis; however, it is important to keep in mind during discussion and interpretation of the results. For example, the emphasis on surveying for Brook Trout may mean that, while its sampled IAO is close to the true number of occupied squares, other fish species will have underestimates of their true IAO. Having more accurate estimates of IAO for all species would not change Brook Trout’s rank, but may increase the ranks of other species, reducing the overall number of species of conservation concern.

In addition to the uneven sampling effort over time and non-random sample design seen in our fish data, additional factors that may introduce bias include sampling methods and the detectability of the species being assessed (both discussed in Appendix A, section iv).

Finally, we note that there are inherent biases that come with applying a one size fits all approach to species ranking. For example, two species may require different amounts of habitat to support a viable population size – one needing a larger area than the other. Using the same set of thresholds for IAO to assess both species would therefore assign a lower level of perceived risk than is actually the case for the species that requires more area to support their population. For that species, an IAO of ten grid squares may be just as risky as an IAO of one grid square for the species that needs less habitat.

While we acknowledge this issue, we note that one benefit of using more than one ranking factor (i.e. IAO, vulnerability, and trends) is to balance out potential biases such as the one described above. Furthermore, the alternative to a one size fits all approach – i.e. developing different sets of thresholds for different groups of species based on their biology – did not fit with our goal of developing an objective and easily applied method.

vi. Which species to assess

It can be difficult to define exactly which species should be included on the list for status assessment. Breeding vs. non-breeding populations, residents vs. migrants, visitor and vagrant species all complicate the issue. We have chosen to follow the process outlined in the *Guidelines for Application of IUCN Red List Criteria at Regional and National Levels* (IUCN 2012b), which excludes non-native species, recent colonizers, vagrant species, and visiting species that exceed an optional set filter.

The IUCN defines a vagrant species as one that is currently found only occasionally within the boundaries of a region, whereas they define a visitor as one that does not reproduce within a region but regularly occurs within its boundaries either now or during some period of the last century. The line between vagrant and visitor can be difficult to define, which is why the IUCN suggests developing a clear threshold or filter by which to identify these species.

We considered setting a filter to exclude fishes from our assessment that primarily occur only in large open lakes (i.e. Lake Ontario and areas directly influenced by water levels in the lake) and are only occasionally found in rivers and streams. However, it was difficult to know where to draw the line to define such species. For example, the majority of observations of Shorthead Redhorse in CVC's database between 1998 and 2017 were from Lake Ontario (66%; 53/80 records) and not the Credit River Watershed. In addition, all of the records for Shorthead Redhorse within the watershed were from the first segment upstream from the mouth of river at Port Credit. However, the range of this species encompasses most of Ontario – including streams in which it spawns (Scott and Crossman 1998).

It is possible that Shorthead Redhorse might move farther upstream in the Credit River if no barriers were in place to stop its movement. However, even if it wouldn't move any farther upstream, the fact that it does spend some time in the lower part of the river, presumably during spawning, implies that it should be considered a breeding species within the watershed and therefore qualifies for assessment. Similar arguments could be made for many of the fish species that were found primarily in the lake-river interface area (e.g. Emerald Shiner [*Notropis atherinoides*], Gizzard Shad).

Nonetheless, there were certain species in the data that were observed only once or twice and could reasonably be defined to be vagrants. We set the filter to identify these species as those that were observed in only one or two grid squares and only one or two years. This filter resulted in the removal of eight species from the data, including Bowfin, Trout-perch (*Percopsis omiscomaycus*), and Walleye (*Sander vitreus*). Note that this did not exclude species seen consistently in a small number of grid squares, such as Logperch, which was seen in only two grid squares but was observed in those squares in 12 of the 20 sample years.

Deciding which species to assess from other taxonomic groups will involve classifying species as residents, migrants, visitors, etc. within the Credit River Watershed. Some of this work has already been done, for example in the production of habitat utilization tables and watershed species lists. These classifications will be reviewed and updated as necessary. Species in need of classification will be evaluated using information from expert resources, including the NHIC and the Ontario Breeding Bird Atlas.

vii. The effect of IAO on final rank

The heavier weighting of IAO vs. vulnerability in our method led to some concerns that the final rank would be determined almost entirely based on the number of grid squares in which a species was observed. To address this concern, we evaluated the potential final rank outcomes based on different combinations of factor values. For each category of IAO there were at least two potential rank outcomes with different combinations of scores for vulnerability and trends. For example, species found in only one grid square can end up as either L1 or L2 with our method, while species found in 26 to 125 grid squares can end up as L3, L4, or L5. Full details on possible outcomes can be seen in Appendix C, Table C1.

viii. Species on the edge

Any conservation status assessment that operates on a geographic scale smaller than global faces the issue of ranking species that exist at the edge of their range within the study area. These species may be abundant and widely distributed throughout most of their range but, because the assessment area is on the periphery of their range, they receive ranks of high conservation concern (Glass *et al*. 2017). For example, many species at risk in the Carolinian zone of southwestern Ontario are more common across the border to the south, where this ecosystem is more prevalent.

We argue that these species are deserving of local conservation attention for a number of reasons. First, the effects of climate change include northward range shifts for many species – protecting and restoring their habitat ensures that they will have somewhere to move to (Gibson *et al*. 2009). Second, populations on the edge of ranges can be genetically distinct from core populations; maintaining this genetic diversity is important, especially as it relates to adaptation to local environments (Eckert *et al*. 2008; Glass *et al*. 2017). Finally, sudden and rapid population declines often begin within the core of a species' range (i.e. with the introduction of a pathogen or pest), making populations on the periphery an important reserve (Channell and Lomolino 2000).

APPENDIX B: Details of ranks, factor values, and scoring for fish species

Table B1. *Fish species present in the Credit River Watershed, including their final L-rank, S-rank, and notes about the final rank. The ranks of species at risk in Ontario are indicated in parentheses after their common name. Species present in the watershed, but not assessed for local conservation status, are included at the end of the table. This includes species with ranks: LX = presumed locally extirpated; LH = possibly locally extirpated; LU = locally unrankable; LNA = conservation status locally not applicable (e.g. because the species is non-native)*

Common name	Scientific name	L-Rank	S-Rank	Note
Slimy Sculpin	*Cottus cognatus*	L1	S5	
Redside Dace (END)	*Clinostomus elongatus*	L1	S1 [A]	L-rank adjusted to match S-rank
American Eel (END)	*Anguilla rostrata*	L2	S1S2 [B]	L-rank adjusted to match S-rank
Greater Redhorse	*Moxostoma valenciennesi*	L2	S3	
American Brook Lamprey	*Lethenteron appendix*	L3	S3	L-rank adjusted to match S-rank
Banded Killifish	*Fundulus diaphanus*	L3	S5	
Blacknose Shiner	*Notropis heterolepis*	L3	S5	
Brassy Minnow	*Hybognathus hankinsoni*	L3	S5	
Finescale Dace	*Chrosomus neogaeus*	L3	S5	
Logperch	*Percina caprodes*	L3	S5	
Northern Pike	*Esox lucius*	L3	S5	
Rosyface Shiner	*Notropis rubellus*	L3	S4	
Threespine Stickleback	*Gasterosteus aculeatus*	L3	S4	
White Bass	*Morone chrysops*	L3	S4	
Black Crappie	*Pomoxis nigromaculatus*	L4	S4	
Bluegill	*Lepomis macrochirus*	L4	S5	
Bluntnose Minnow	*Pimephales notatus*	L4	S5	
Brook Stickleback	*Culaea inconstans*	L4	S5	
Brook Trout	*Salvelinus fontinalis*	L4	S5	
Brown Bullhead	*Ameiurus nebulosus*	L4	S5	
Common Shiner	*Luxilus cornutus*	L4	S5	
Fantail Darter	*Etheostoma flabellare*	L4	S4	
Freshwater Drum	*Aplodinotus grunniens*	L4	S5	L-rank adjusted due to rescue effect
Gizzard Shad	*Dorosoma cepedianum*	L4	S4	L-rank adjusted due to rescue effect
Hornyhead Chub	*Nocomis biguttatus*	L4	S4	
Iowa Darter	*Etheostoma exile*	L4	S5	
Johnny Darter	*Etheostoma nigrum*	L4	S5	
Lake Chub	*Couesius plumbeus*	L4	S5	L-rank adjusted due to rescue effect
Largemouth Bass	*Micropterus salmoides*	L4	S5	
Longnose Dace	*Rhinichthys cataractae*	L4	S5	
Mottled Sculpin	*Cottus bairdii*	L4	S5	
Northern Hog Sucker	*Hypentelium nigricans*	L4	S4	
Northern Pearl Dace	*Margariscus nachtriebi*	L4	S5	
Northern Redbelly Dace	*Chrosomus eos*	L4	S5	
Rainbow Darter	*Etheostoma caeruleum*	L4	S4	

Common name	Scientific name	L-Rank	S-Rank	Note
River Chub	*Nocomis micropogon*	L4	S4	
Rock Bass	*Ambloplites rupestris*	L4	S5	
Shorthead Redhorse	*Moxostoma macrolepidotum*	L4	S5	L-rank adjusted due to rescue effect
Smallmouth Bass	*Micropterus dolomieu*	L4	S5	L-rank adjusted due to rescue effect
Spotfin Shiner	*Cyprinella spiloptera*	L4	S4	
Stonecat	*Noturus flavus*	L4	S4	
White Sucker	*Catostomus commersonii*	L4	S5	
Blacknose Dace	*Rhinichthys atratulus*	L5	S5	
Central Mudminnow	*Umbra limi*	L5	S5	
Creek Chub	*Semotilus atromaculatus*	L5	S5	
Emerald Shiner	*Notropis atherinoides*	L5	S5	L-rank adjusted due to rescue effect
Fathead Minnow	*Pimephales promelas*	L5	S5	
Golden Shiner	*Notemigonus crysoleucas*	L5	S5	
Pumpkinseed	*Lepomis gibbosus*	L5	S5	
Spottail Shiner	*Notropis hudsonius*	L5	S5	L-rank adjusted due to rescue effect
Yellow Perch	*Perca flavescens*	L5	S5	L-rank adjusted due to rescue effect
Atlantic Salmon (EXT) [C]	*Salmo salar*	LX	SX	
Bloater	*Coregonus hoyi*	LX	S4	
Lake Ontario Kiyi (EXT)	*Coregonus kiyi orientalis*	LX	SX	
Cisco	*Coregonus artedi*	LH	S5	
Lake Whitefish	*Coregonus clupeaformis*	LH	S5	
Least Darter	*Etheostoma microperca*	LH	S4	
Sauger	*Sander canadensis*	LH	S4	
Shortnose Cisco (END)	*Coregonus reighardi*	LH	SH	
White Crappie	*Pomoxis annularis*	LH	S4	
Bowfin	*Amia calva*	LU	S4	Classified as a vagrant in our analysis
Brook Silverside	*Labidesthes sicculus*	LU	S4	Only observed in Lake Ontario in our data
Burbot	*Lota lota*	LU	S5	Only observed in Lake Ontario in our data
Central Stoneroller	*Campostoma anomalum*	LU	S4	Classified as a vagrant in our analysis
Channel Catfish	*Ictalurus punctatus*	LU	S4	Classified as a vagrant in our analysis
Deepwater Sculpin (SC) [D]	*Myoxocephalus thompsonii*	LU	S3? [B]	Only observed in Lake Ontario in our data
Green Sunfish	*Lepomis cyanellus*	LU	S4	Classified as a vagrant in our analysis
Lake Sturgeon (THR)	*Acipenser fulvescens*	LU	S2	Classified as a vagrant in our analysis
Lake Trout	*Salvelinus namaycush*	LU	S5	Only observed in Lake Ontario in our data
Longnose Gar	*Lepisosteus osseus*	LU	S4	Classified as a vagrant in our analysis
Longnose Sucker	*Catostomus catostomus*	LU	S5	Classified as a vagrant in our analysis
Mimic Shiner	*Notropis volucellus*	LU	S5	One suspect record in our data
Trout-perch	*Percopsis omiscomaycus*	LU	S5	Classified as a vagrant in our analysis
Rainbow Smelt	*Osmerus mordax*	LU	S5	Only observed in Lake Ontario in our data
Walleye	*Sander vitreus vitreus*	LU	S5	Classified as a vagrant in our analysis
Alewife	*Alosa pseudoharengus*	LNA	SNA	
Brown Trout	*Salmo trutta*	LNA	SNA	

Common name	Scientific name	L-Rank	S-Rank	Note
Chinook Salmon	*Oncorhynchus tshawytscha*	LNA	SNA	
Coho Salmon	*Oncorhynchus kisutch*	LNA	SNA	
Common Carp	*Cyprinus carpio*	LNA	SNA	
Goldfish	*Carassius auratus*	LNA	SNA	
Koi	.	LNA	.	Hybrid; not ranked by NHIC
Rainbow Trout	*Oncorhynchus mykiss*	LNA	SNA	
Rosy Red Fathead Minnow	.	LNA	.	Hybrid; not ranked by NHIC
Round Goby	*Neogobius melanostomus*	LNA	SNA	
Rudd	*Scardinius erythrophthalmus*	LNA	SNA	
Sea Lamprey	*Petromyzon marinus*	LNA	SNA	
Tiger Trout	.	LNA	.	Hybrid; not ranked by NHIC
White Perch	*Morone americana*	LNA	SNA	

[A] Redside Dace has been recently assessed as S1 by the NHIC, this rank does not currently appear on the NHIC website, but will the next time it is updated; similarly, the correct current rank for American Eel is S1S2 even though this is not currently on the NHIC website (Mike Burrell, personal communication)
[B] The rank of "S1S2" for American Eel and "S3?" for Deepwater Sculpin indicates that there is some uncertainty around these ranks; see Master *et al*. (2012) for more information
[C] Atlantic Salmon is ranked as extirpated from Ontario because natural populations of this species were eliminated from the province; however, the MNRF carries out stocking programs and it is therefore present in the Credit River Watershed. Given that these populations are not self-sustaining, we have not considered Atlantic Salmon in this analysis and have given it a rank of LX
[D] Deepwater Sculpin – Great Lakes-St. Lawrence population, has been assessed by COSEWIC as SC, but has not yet been assessed by COSSARO

Table B2. *Full details of values, scores, and points (Pts) for 51 fish species under three ranking factors (IAO = Index Area of Occupancy, Vulnerability, Trend) as well as the calculations and adjustments used to produce the final rank. Under vulnerability, note that BS = body size, SPG = slow population growth, ETR = exposure to risk, and ED = ecological dependence, with a one in the column indicating that the species has at least one trait that qualifies under that variable. Under trend, note that a percent change (Pct. Chg.) of "." indicates that the species was not present in the first time window but was in the second time window; while the trend for these species was calculated as positive infinity, they were scored as a change of 0%. The process for calculating the final scores, including weighting the IAO and vulnerability scores (Wtd. IAO and Wtd. Vul.), is described in section 2.3. Rank adjustments were made either to match the provincial rank (S-rank) or because of the application of the rescue effect (RE).*

Common Name	IAO			VULNERABILITY							TREND			FINAL SCORES AND RANK							
	Grids	Score	Pts	BS	SPG	ETR	ED	Tot Vul.	Score	Pts	Pct. Chg.	Score	Pts	Wtd. IAO	Wtd. Vul.	Sub-total	Trend Adjust	TOT	Rank	Rank Adjust	Final Rank
Slimy Sculpin	1	A	0.92	1	1	0	1	3	B	2.20	.	G	0.00	0.64	0.66	1.30	0.00	1.3	L1		L1
Redside Dace	11	D	3.67	1	0	1	0	2	C	3.30	-36.6	E	-0.14	2.57	0.99	3.56	-0.14	3.4	L3	S-rank	L1
Greater Redhorse	2	B	1.83	0	1	1	0	2	C	3.30	84.0	I	0.14	1.28	0.99	2.27	0.14	2.4	L2		L2
American Eel	5	C	2.75	1	1	1	0	3	B	2.20	.	G	0.00	1.93	0.66	2.59	0.00	2.6	L3	S-rank	L2
Blacknose Shiner	5	C	2.75	1	0	1	1	3	B	2.20	630.9	I	0.14	1.93	0.66	2.59	0.14	2.7	L3		L3
Threespine Stickleback	5	C	2.75	1	1	0	1	3	B	2.20	145.7	I	0.14	1.93	0.66	2.59	0.14	2.7	L3		L3
Logperch	2	B	1.83	0	0	1	0	1	D	4.40	229.4	I	0.14	1.28	1.32	2.60	0.14	2.7	L3		L3
Northern Pike	23	D	3.67	1	1	1	1	4	A	1.10	27.3	I	0.14	2.57	0.33	2.90	0.14	3.0	L3		L3
Banded Killifish	3	C	2.75	1	0	1	0	2	C	3.30	219.1	I	0.14	1.93	0.99	2.92	0.14	3.1	L3		L3
Rosyface Shiner	5	C	2.75	1	0	1	0	2	C	3.30	118.9	I	0.14	1.93	0.99	2.92	0.14	3.1	L3		L3
White Bass	4	C	2.75	0	0	1	1	2	C	3.30	660.5	I	0.14	1.93	0.99	2.92	0.14	3.1	L3		L3
Finescale Dace	12	D	3.67	1	0	1	1	3	B	2.20	-1.8	G	0.00	2.57	0.66	3.23	0.00	3.2	L3		L3
Brassy Minnow	24	D	3.67	1	0	1	0	2	C	3.30	-68.5	D	-0.22	2.57	0.99	3.56	-0.22	3.3	L3		L3
American Brook Lamprey	18	D	3.67	0	0	1	1	2	C	3.30	0.4	G	0.00	2.57	0.99	3.56	0.00	3.6	L4	S-rank	L3
Freshwater Drum	3	C	2.75	0	1	1	0	2	C	3.30	-33.5	E	-0.14	1.93	0.99	2.92	-0.14	2.8	L3	RE	L4
Lake Chub	5	C	2.75	0	0	1	1	2	C	3.30	313.2	I	0.14	1.93	0.99	2.92	0.14	3.1	L3	RE	L4
Shorthead Redhorse	3	C	2.75	0	1	1	0	2	C	3.30	263.6	I	0.14	1.93	0.99	2.92	0.14	3.1	L3	RE	L4
Smallmouth Bass	16	D	3.67	0	1	1	1	3	B	2.20	8.2	G	0.00	2.57	0.66	3.23	0.00	3.2	L3	RE	L4

Common Name	IAO			VULNERABILITY							TREND			FINAL SCORES AND RANK							
	Grids	Score	Pts	BS	SPG	ETR	ED	Tot Vul.	Score	Pts	Pct. Chg.	Score	Pts	Wtd. IAO	Wtd. Vul.	Sub-total	Trend Adjust	TOT	Rank	Rank Adjust	Final Rank
Gizzard Shad	5	C	2.75	0	0	1	0	1	D	4.40	90.3	I	0.14	1.93	1.32	3.25	0.14	3.4	L3	RE	L4
Northern Pearl Dace	25	D	3.67	0	0	1	1	2	C	3.30	13.4	H	0.07	2.57	0.99	3.56	0.07	3.6	L4		L4
Brook Trout	74	E	4.58	0	1	1	1	3	B	2.20	6.9	G	0.00	3.21	0.66	3.87	0.00	3.9	L4		L4
Rainbow Darter	32	E	4.58	1	1	1	0	3	B	2.20	-6.3	G	0.00	3.21	0.66	3.87	0.00	3.9	L4		L4
Bluegill	9	D	3.67	0	1	0	0	1	D	4.40	-2.1	G	0.00	2.57	1.32	3.89	0.00	3.9	L4		L4
River Chub	21	D	3.67	0	0	1	0	1	D	4.40	-5.3	G	0.00	2.57	1.32	3.89	0.00	3.9	L4		L4
Spotfin Shiner	9	D	3.67	0	0	1	0	1	D	4.40	12.9	H	0.07	2.57	1.32	3.89	0.07	4.0	L4		L4
Black Crappie	17	D	3.67	0	1	0	0	1	D	4.40	114.1	I	0.14	2.57	1.32	3.89	0.14	4.0	L4		L4
Hornyhead Chub	19	D	3.67	0	0	1	0	1	D	4.40	163.1	I	0.14	2.57	1.32	3.89	0.14	4.0	L4		L4
Iowa Darter	22	D	3.67	1	0	0	0	1	D	4.40	58.4	I	0.14	2.57	1.32	3.89	0.14	4.0	L4		L4
Brook Stickleback	113	E	4.58	1	1	0	0	2	C	3.30	-13.1	F	-0.07	3.21	0.99	4.20	-0.07	4.1	L4		L4
Johnny Darter	32	E	4.58	1	1	0	0	2	C	3.30	-21.2	F	-0.07	3.21	0.99	4.20	-0.07	4.1	L4		L4
Northern Hog Sucker	30	E	4.58	0	1	1	0	2	C	3.30	-25.7	F	-0.07	3.21	0.99	4.20	-0.07	4.1	L4		L4
Northern Redbelly Dace	79	E	4.58	1	0	1	0	2	C	3.30	-16.6	F	-0.07	3.21	0.99	4.20	-0.07	4.1	L4		L4
Fantail Darter	34	E	4.58	1	1	0	0	2	C	3.30	-5.4	G	0.00	3.21	0.99	4.20	0.00	4.2	L4		L4
Mottled Sculpin	30	E	4.58	0	1	0	1	2	C	3.30	4.6	G	0.00	3.21	0.99	4.20	0.00	4.2	L4		L4
White Sucker	114	E	4.58	0	1	1	0	2	C	3.30	0.0	G	0.00	3.21	0.99	4.20	0.00	4.2	L4		L4
Stonecat	20	D	3.67	0	0	0	0	0	E	5.50	7.5	G	0.00	2.57	1.65	4.22	0.00	4.2	L4		L4
Largemouth Bass	62	E	4.58	0	1	0	1	2	C	3.30	40.9	I	0.14	3.21	0.99	4.20	0.14	4.3	L4		L4
Common Shiner	71	E	4.58	0	0	1	0	1	D	4.40	-13.7	F	-0.07	3.21	1.32	4.53	-0.07	4.5	L4		L4
Bluntnose Minnow	77	E	4.58	1	0	0	0	1	D	4.40	2.2	G	0.00	3.21	1.32	4.53	0.00	4.5	L4		L4
Brown Bullhead	52	E	4.58	0	1	0	0	1	D	4.40	3.4	G	0.00	3.21	1.32	4.53	0.00	4.5	L4		L4
Longnose Dace	61	E	4.58	0	0	1	0	1	D	4.40	-0.3	G	0.00	3.21	1.32	4.53	0.00	4.5	L4		L4
Rock Bass	57	E	4.58	0	1	0	0	1	D	4.40	9.4	G	0.00	3.21	1.32	4.53	0.00	4.5	L4		L4
Yellow Perch	19	D	3.67	0	1	1	0	2	C	3.30	126.5	I	0.14	2.57	0.99	3.56	0.14	3.7	L4	RE	L5
Emerald Shiner	9	D	3.67	0	0	1	0	1	D	4.40	30.5	I	0.14	2.57	1.32	3.89	0.14	4.0	L4	RE	L5

Common Name	IAO			VULNERABILITY							TREND			FINAL SCORES AND RANK							
	Grids	Score	Pts	BS	SPG	ETR	ED	Tot Vul.	Score	Pts	Pct. Chg.	Score	Pts	Wtd. IAO	Wtd. Vul.	Sub-total	Trend Adjust	TOT	Rank	Rank Adjust	Final Rank
Spottail Shiner	9	D	3.67	0	0	1	0	1	D	4.40	68.4	I	0.14	2.57	1.32	3.89	0.14	4.0	L4	RE	L5
Fathead Minnow	101	E	4.58	1	0	0	0	1	D	4.40	38.0	I	0.14	3.21	1.32	4.53	0.14	4.7	L5		L5
Golden Shiner	26	E	4.58	0	0	1	0	1	D	4.40	25.4	I	0.14	3.21	1.32	4.53	0.14	4.7	L5		L5
Pumpkinseed	103	E	4.58	0	0	1	0	1	D	4.40	26.8	I	0.14	3.21	1.32	4.53	0.14	4.7	L5		L5
Blacknose Dace	127	F	5.50	1	0	1	0	2	C	3.30	-3.9	G	0.00	3.85	0.99	4.84	0.00	4.8	L5		L5
Central Mudminnow	70	E	4.58	0	0	0	0	0	E	5.50	1.5	G	0.00	3.21	1.65	4.86	0.00	4.9	L5		L5
Creek Chub	136	F	5.50	0	0	1	0	1	D	4.40	-12.6	F	-0.07	3.85	1.32	5.17	-0.07	5.1	L5		L5

APPENDIX C: Possible outcomes for different combinations of factor values

Table C1. *Matrix of possible outcomes based on different combinations of factor values for IAO, vulnerability, and short-term trend. Points for IAO are based on the number of grid squares (Grids); points for vulnerability are based on the number of vulnerability characteristics (No. Char.), and points for trends are based on the percent change between two time windows (Dec. = decrease; Inc. = increase). Scaling and total scoring procedure are described in section 2.3. Note that the highlighted colour of the final point value indicates the corresponding final rank, where purple = L5, blue = L4, yellow = L3, orange = L2, and red = L1.*

IAO			VULNERABILITY				TRENDS									FINAL POINTS								
Grids	Points	Points Scaled	No. Char.	Points	Points Scaled	IAO & Vul. Subtotal	Dec. ≥90%	Dec. 80-90%	Dec. 70-80%	Dec. 50-70%	Dec. 30-50%	Dec. 10-30%	± 10%	Inc. 10-25%	Inc. ≥25%	Min	B	C	D	E	F	G	H	Max
126-500	5.5	3.85	0	5.5	1.65	5.50	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	5.0	5.1	5.2	5.3	5.4	5.4	5.5	5.6	5.6
	5.5	3.85	1	4.4	1.32	5.17	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.2	5.3
	5.5	3.85	2	3.3	0.99	4.84	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.9	5.0
	5.5	3.85	3	2.2	0.66	4.51	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.6	4.7
	5.5	3.85	4	1.1	0.33	4.18	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.7	3.8	3.9	4.0	4.0	4.1	4.2	4.3	4.3
26-125	4.58	3.206	0	5.5	1.65	4.86	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	4.4	4.5	4.5	4.6	4.7	4.8	4.9	4.9	5.0
	4.58	3.206	1	4.4	1.32	4.53	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.6	4.7
	4.58	3.206	2	3.3	0.99	4.20	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.7	3.8	3.9	4.0	4.1	4.1	4.2	4.3	4.3
	4.58	3.206	3	2.2	0.66	3.87	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.4	3.5	3.6	3.6	3.7	3.8	3.9	3.9	4.0
	4.58	3.206	4	1.1	0.33	3.54	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.0	3.1	3.2	3.3	3.4	3.5	3.5	3.6	3.7
6-25	3.67	2.569	0	5.5	1.65	4.22	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.7	3.8	3.9	4.0	4.1	4.1	4.2	4.3	4.4
	3.67	2.569	1	4.4	1.32	3.89	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.4	3.5	3.6	3.7	3.7	3.8	3.9	4.0	4.0
	3.67	2.569	2	3.3	0.99	3.56	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.1	3.2	3.2	3.3	3.4	3.5	3.6	3.6	3.7
	3.67	2.569	3	2.2	0.66	3.23	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4
	3.67	2.569	4	1.1	0.33	2.90	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.4	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.0
3-5	2.75	1.925	0	5.5	1.65	3.58	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	3.1	3.2	3.3	3.4	3.4	3.5	3.6	3.6	3.7
	2.75	1.925	1	4.4	1.32	3.25	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4
	2.75	1.925	2	3.3	0.99	2.92	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.4	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1
	2.75	1.925	3	2.2	0.66	2.59	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.7
	2.75	1.925	4	1.1	0.33	2.26	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.8	1.9	1.9	2.0	2.1	2.2	2.3	2.3	2.4

IAO			VULNERABILITY				TRENDS									FINAL POINTS								
Grids	Points	Points Scaled	No. Char.	Points	Points Scaled	IAO & Vul. Subtotal	Dec. ≥90%	Dec. 80-90%	Dec. 70-80%	Dec. 50-70%	Dec. 30-50%	Dec. 10-30%	± 10%	Inc. 10-25%	Inc. ≥25%	Min	B	C	D	E	F	G	H	Max
2	1.83	1.281	0	5.5	1.65	2.93	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.4	2.5	2.6	2.7	2.8	2.9	2.9	3.0	3.1
	1.83	1.281	1	4.4	1.32	2.60	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.7
	1.83	1.281	2	3.3	0.99	2.27	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.8	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4
	1.83	1.281	3	2.2	0.66	1.94	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1
	1.83	1.281	4	1.1	0.33	1.61	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8
1	0.92	0.644	0	5.5	1.65	2.29	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.4
	0.92	0.644	1	4.4	1.32	1.96	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.5	1.6	1.7	1.7	1.8	1.9	2.0	2.0	2.1
	0.92	0.644	2	3.3	0.99	1.63	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8
	0.92	0.644	3	2.2	0.66	1.30	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.4
	0.92	0.644	4	1.1	0.33	0.97	-0.50	-0.40	-0.31	-0.22	-0.14	-0.07	0.00	0.07	0.14	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.1