Habitat associations of Redside Dace informed by the Ontario Aquatic Ecosystem Classification

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HABITAT ASSOCIATIONS OF REDSIDE DACE INFORMED BY THE ONTARIO AQUATIC ECOSYSTEM CLASSIFICATION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Lamothe, K.A., Jones, N.E., Schmidt, B.J., and Drake, D.A.R. 2021. Habitat associations of Redside Dace informed by the Ontario Aquatic Ecosystem Classification. Can. Manuscr. Rep. Fish. Aquat. Sci. 3233: vi + 19 p.

Habitat associations are needed to inform the description of critical habitat for species listed under the *Species at Risk Act*. Often, species-habitat associations are derived from species occurrences in relation to site-level habitat features. The objectives of this study were to identify geophysical variables associated with the occurrence of Redside Dace (*Clinostomus elongatus* – Endangered) across its geographic range in Canada and to determine if particular habitat features differed between sites with local extirpations and those presently supporting populations. Redside Dace occurrence records were compiled from a database held by Fisheries and Oceans Canada at the Great Lakes Laboratory for Fisheries and Aquatic Sciences, which contains over 1,000 Redside Dace occurrences documented between 1926 and 2017. Occurrence records were manually geo-referenced to the Ontario Aquatic Ecosystem Classification, a hierarchical classification system for grouping Ontario rivers into larger spatial units, for extracting habitat variables. Variables of interest included channel slope, average July temperature, perennial turbidity, channel length, and base flow index. Results of this study suggest Canadian Redside Dace populations tend to occupy relatively steep (>0.1% channel slope), perennially clear, cool- to cold-water systems (mean July temperature ≤ 19 °C), supporting previous descriptions of the habitat associations of the species. The majority of Redside Dace extirpations since 1926 have occurred within the Greater Toronto Area among relatively large systems draining into Lake Ontario. Although no geophysical variables were identified in this study that clearly differentiated extant versus extirpated sites, this work adds to the literature on habitat associations for Redside Dace, ultimately informing recovery actions for the species.

RÉSUMÉ

Lamothe, K.A., Jones, N.E., Schmidt, B.J., and Drake, D.A.R. 2021. Habitat associations of Redside Dace informed by the Ontario Aquatic Ecosystem Classification. Can. Manuscr. Rep. Fish. Aquat. Sci. 3233: vi + 19 p.

On a besoin d'établir des associations espèce-habitat pour orienter la description des habitats essentiels des espèces inscrites sur la liste sur la liste de la *Loi sur les espèces en péril* (LEP). Souvent, les associations entre les espèces et les habitats sont dérivées des occurrences de ces espèces en lien avec les caractéristiques de l'habitat à l'échelle d'un site. Cette étude avait pour objectif de déterminer les variables géophysiques associées avec l'occurrence du méné long (*Clinostomus elongatus* – espèce en voie de disparition) dans son aire de répartition géographique au Canada, et de déterminer si certaines caractéristiques spécifiques de son habitat étaient différentes entre les sites où l'on a observé des disparitions de populations locales et les sites où se trouvent actuellement des populations. On a compilé les mentions d'occurrence du méné long dans une base de données gérée par Pêches et Océans Canada au Laboratoire des Grands Lacs pour les pêches et les sciences aquatiques, base de données qui contient plus de 1 000 occurrences de méné long documentées entre 1926 et 2017. Afin d'extraire les variables sur l'habitat, on a procédé manuellement au géoréférencement des mentions d'occurrence avec le système de classification des écosystèmes aquatiques de l'Ontario, un système de classification hiérarchique qui permet de grouper les rivières de l'Ontario en des unités spatiales plus larges. Les variables d'intérêt comprenaient notamment la pente des chenaux, la température moyenne en juillet, la turbidité pérenne, la longueur des chenaux et l'indice de débit de base. Selon les résultats de cette étude, il appert que les populations de ménés longs au Canada ont tendance à occuper des systèmes relativement abrupts (pente de chena de plus de 0,1 %), clairs à longueur d'année et à eaux fraîches à froides (température moyenne en juillet de ≤ 19 °C), ce qui vient confirmer des descriptions antérieures des associations entre l'habitat et l'espèce. La majorité des disparitions de populations de ménés longs depuis 1926 ont été observées à l'intérieur de la région du Grand Toronto dans des systèmes relativement importants se déversant dans le lac Ontario. Bien que cette étude n'ait permis de déterminer aucune variable géophysique permettant de différencier clairement les sites où l'on trouve actuellement des ménés longs et les sites où des populations ont disparu, ce travail s'ajoute à la littérature sur les associations espèce-habitat pour le méné long, ce qui permettra à terme d'orienter les mesures de rétablissement de l'espèce.

INTRODUCTION

Species-habitat associations are needed to inform the description of critical habitat for species listed under the *Species at Risk Act* (SARA). Knowledge of species-habitat requirements and habitat availability ensure that suitable habitats are protected and help identify habitats in need of restoration. As well, robust knowledge of species-habitat requirements is needed for determining the suitability of recovery actions, for example species reintroduction, a strategy increasingly identified for SARA-listed species (Swan et al. 2018; Lamothe et al. 2019). However, knowledge of habitat associations can be limited for SARA-listed species and is often based on relationships between species occurrence and point-based, site-level habitat measurements such as depth and water velocity. In some cases, these measures can be of limited utility by failing to capture the broader ecological processes that act on a species. As such, there is a continued need to quantify habitat associations for SARA-listed species across geographic scales (i.e., local, regional, global).

Redside Dace (*Clinostomus elongatus* Kirtland 1838) is a small minnow native to cool-water streams in eastern North America, listed as Endangered under SARA. The listing of this species was attributed to declining population trends and local extirpations (Table 1; Figure 1), likely caused by habitat degradation as a result of urbanization and agriculture within its restricted range (Committee on the Status of Endangered Wildlife in Canada [COSEWIC] 2017; Lebrun et al. 2020). Approximately 80% of the Redside Dace distribution in Canada occurs in the 'Golden Horseshoe' region of southern Ontario (Greater Toronto Area and Hamilton), where urban development poses an immediate threat of continued population declines and future extirpations. Given the sustained pressure from urbanization, characterizing, protecting, and restoring habitat are priorities for improving the survival and recovery of Redside Dace.

Habitat for Redside Dace is generally described as small, meandering, clear, cool-water streams in areas with suitable riparian vegetation (i.e., grasses, forbs, shrubs; COSEWIC 2017). Riparian vegetation provides habitat for terrestrial insects (e.g., Dipteran flies, chironomids), which are important prey items for Redside Dace (Daniels and Wisniewski 1994). As well, riparian vegetation, undercut banks, and submerged woody vegetation help maintain cooler water temperatures during the summer months, providing areas of thermal refuge. Redside Dace is generally found in streams with water temperatures less than 24 °C (McKee and Parker 1982; Redside Dace Recovery Team [RDRT] 2010). The present-day distribution of Redside Dace is primarily within the headwater streams of southern Ontario watersheds (Figure 1), which tend to be cooler with more stable base-flow than downstream reaches (Reid and Parna 2017). Lesser studied landscape characteristics of Redside Dace habitat include the influence of stream order, channel length, catchment area, and catchment slope.

The objective of this study was to identify habitat associations of Redside Dace in Ontario, focusing on geophysical variables that influence the productivity, structure, and composition of fluvial aquatic ecosystems (Melles et al. 2013; Jones and Schmidt 2017). Specifically, the goals were to determine: 1) the geophysical variables associated with the occurrence of Redside Dace in Ontario; and, 2) if extirpations of Redside Dace since 1926 have been associated with particular geophysical habitat features. Overall, the results of this study provide information on habitat associations for Redside Dace at extant and extirpated locations that can be used to inform future recovery actions for the species.

METHODS

The analysis involved three components: 1) determining the current and historical distribution of Redside Dace based on a database of field collection records; 2) relating the historical distribution of Redside Dace to underlying geophysical variables; and, 3) determining if differences exist between the geophysical variables associated with the present-day distribution of Redside Dace and locations where the species has been extirpated.

REDSIDE DACE OCCURRENCE RECORDS

Redside Dace occurrence records (n = 1,145 detections) for the period 1926 – 2017 were compiled from a database held by Fisheries and Oceans Canada at the Great Lakes Laboratory for Fisheries and Aquatic Sciences. The dataset was originally compiled to inform the provincial Redside Dace Recovery Strategy (RDRT 2010), and later the draft federal Redside Dace recovery strategy and recovery potential assessment (Lebrun et al. 2020). Occurrence records were contributed by Conservation Authorities, academic researchers, the Ontario Ministry of Natural Resources and Forestry, Fisheries and Oceans Canada, and other SARA-permit holders who captured Redside Dace. The compiled records resulted from the capture of Redside Dace using a variety of sampling gears, including seines, electrofishers, dip nets, and underwater video cameras.

Occurrence records of Redside Dace were spatially joined to interconfluence reaches identified within the Ontario Aquatic Ecosystem Classification (described below) using a manual geo-referencing process in ArcGIS. An interconfluence reach describes a section of stream between two inflowing tributaries of any size (Jones and Schmidt 2017). A manual process was taken to join occurrence records due to the imprecision of geographic coordinates among Redside Dace observations through time, particularly for earlier records. To provide a measure of confidence during the geo-referencing process, the linear distance of each occurrence record to the nearest interconfluence reach was calculated. Each occurrence record was then ranked from 1-3 based on the distance to the nearest interconfluence reach to provide a relative measure of confidence in the observation, where: 1 = observations < 20 m from the nearest reach (i.e., highest confidence); 2 = observations between 20 – 40 m from the nearest reach; and, 3 = observations >40 m from the nearest reach. When more than one Redside Dace observation was joined to an interconfluence reach, the most recent record with the greatest confidence was retained for further analysis.

The 1,145 Redside Dace occurrence records were joined to 305 unique AEC interconfluence reaches. Each identified AEC reach was categorized as having extant or extirpated Redside Dace populations as of 2020 based on a recent review of Redside Dace distribution by Fisheries and Oceans Canada (Table 1).

ONTARIO AQUATIC ECOSYSTEM CLASSIFICATION

The Ontario Aquatic Ecosystem Classification (AEC) is a multi-scale hierarchical classification system for grouping river systems across Ontario into larger spatial units (Melles et al. 2013; Jones and Schmidt 2017). The environmental data that underlie the AEC were derived from remote sensing, existing monitoring networks, and predictive models for delineated streams with a minimum drainage area of 1 km^2. The data occurs across four spatial scales (Figure 2; reach channel, reach contributing area, upstream channel for the catchment, and upstream catchment area; Jones and Schmidt 2017). For this analysis, several geophysical variables from the AEC were selected based on their hypothesized influence on Redside Dace habitat, including: channel length (m), Shreve order, base flow index, upstream catchment area (km^2), and Class Code (Table 2).

The Shreve method was used to assign stream orders to each reach (Shreve 1966). Shreve order begins at 1 in the headwaters, summing orders at stream confluences moving downstream (Figure 3). Base flow index was calculated as the reach base flow divided by the average rate of total stream flow, ranging between 0 and 1 (Neff et al. 2005). Class Code consisted of 20 distinct thermal, turbidity, and channel slope categories assigned to each AEC reach (Jones and Schmidt 2017). Thermal categories were based on modelled average July temperature over 30 years: cold (< 18 °C), cold-cool (18 < x ≤ 19.0 °C), cool (19.0 < x ≤ 20.5 °C), cool-warm (20.5 < x ≤ 22.0 °C), or warm (> 22.0 °C); see Jones et al. 2017 for details on thermal class differentiation. The binary turbidity categories were based on whether streams are perennially cloudy for most of the year or not, even during periods of low flow (Jones and Schmidt 2017). Finally, reaches were characterized as slow or fast, where slow corresponds to average reach channel slope ≤ 0.1% and fast corresponds to > 0.1% channel slope (Jones and Schmidt 2017). Therefore, the Class Code for identified reaches could be characterized as cold, clear, and fast (CDCF), cool, turbid, and slow (CLTS), or cool-warm, clear, and slow (CWCS), for example. It was hypothesized that Redside Dace would occupy relatively long, clear, fast, cold-cool areas with a relatively high base flow index and near the headwaters (i.e., low Shreve order; Figure 3).

STATISTICAL ANALYSIS

The frequency of unique Class Codes for reaches that contain extant Redside Dace populations (n = 230) were compared against interconfluence reaches where extirpation had occurred (n = 75). However, due to the spatial proximity of many occupied interconfluence reaches, it was necessary to reduce or remove Redside Dace observations to minimize spatial bias and pseudo-replication in the remaining analyses. Several approaches were attempted to reduce spatial autocorrelation and tested using Moran's *I*, but ultimately, the continuous habitat variables were averaged by waterbody name (e.g., Bronte Creek, Sixteen Mile Creek; Table 1), forming 71 unique observations.

Histograms were used to visually compare differences in average base flow index, upstream catchment area, channel length, and Shreve order of AEC reaches with extant versus extirpated Redside Dace populations. Ordination was used to visually compare differences in geophysical variables between reaches with extant versus extirpated Redside Dace populations. Using the aggregated data, non-metric multidimensional scaling (NMDS) was performed on a Gower dissimilarity matrix of base flow index, shape length, upper catchment area, and temperature class from the Class Code variable. Temperature Class was extracted from Class Code because there was almost no variation in Turbidity (n = 65 clear, n = 6 turbid) and Slope Classes (n = 71 fast, n = 0 slow) across retained, averaged observations. Furthermore, only one warm-water reach where Redside Dace was observed remained post-aggregation and was therefore removed prior to ordination, leaving 70 total observations.

RESULTS

A total of 1,145 Redside Dace occurrence records in Canada were compiled from between 1926 and 2017. Among the 1,145 compiled Redside Dace observations, 838 (73.2%) were less than 20-m from the nearest interconfluence reach, 152 (13.3%) were between 20- and 40-m from the nearest interconfluence reach, and 155 (13.5%) observations were greater than 40-m from the nearest interconfluence reach (Figure 4), suggesting reasonable confidence in the assignment of occurrence records to the AEC. A total of 305 unique AEC reaches were identified as containing Redside Dace based on the original 1,145 original observations, consisting of 230 reaches with extant populations as of 2017 (i.e., extant reaches) and 75 reaches with Redside Dace extirpations (i.e., extirpated reaches). Among the 305 occurrence records that were retained for analysis, 235 (77.0%) were less than 20-m from an interconfluence reach, 30 (9.8%) observations were between 20- and 40-m from an interconfluence reach, and 40 (13.1%)

observations were greater than 40-m from an interconfluence reach. Thirty of the 70 (42.9%) observations farther than 20-m from a reach were recorded before 1960 (Figure 4).

Spatial autocorrelation was observed in the continuous habitat variables (base flow index: Moran's $I = 0.25$, $p < 0.001$; upper catchment area: Moran's $I = 0.06$; $p < 0.001$; reach channel length: Moran's $I = 0.03$; $p = 0.007$). Reducing the data to 71 observations by averaging the observations by waterbody (see Table 1) retained some patterns of spatial autocorrelation in the base flow index (Moran's $I = 0.14$, $p < 0.001$), but not the upper catchment area (Moran's $I = 0.02$, $p = 0.079$) or channel length (Moran's $I = 0.02$, $p = 0.069$). Among the 71 unique observations were 53 extant waterbodies and 18 extirpated waterbodies. On average each waterbody contained 4.24 ± 4.81 SD unique AEC interconfluence reach segments occupied by Redside Dace (minimum = 1, maximum = 24). The shape of the frequency distributions of base flow index, upstream catchment area, Shreve order, and stream length were similar between the reduced dataset ($n = 71$ waterbodies; Figure 5) and the full set of identified unique AEC reaches currently or historically containing Redside Dace ($n = 305$; Figure 6), suggesting that a reasonable level of variation was retained after aggregation for both extant and extirpated locations.

Median values of base flow index, channel length, Shreve order, and upstream catchment area were larger among extirpated reaches and extirpated waterbodies than extant reaches (Figure 6) and waterbodies (Figure 5). However, NMDS analysis of the waterbody specific habitat variables (base flow index, channel length, temperature class, and upper catchment area) demonstrated no differentiation in habitat variables between extirpated and extant reaches (Figure 7), with a clustering of sites across temperature classes. Cold-water sites tended to be the shortest with the smallest upper catchment area and low base flow index (Figure 7).

Total identified reaches with Redside Dace occurrence records were most commonly characterized by cold-cool temperatures, clear water, and faster channel slopes (CCCF; $n = 103$; Table 3). Redside Dace was next most frequently observed in reaches characterized as cold, clear, and fast (CDCF; $n = 86$), followed by cool, clear, and fast (CLCF; $n = 73$; Table 3). Among the 103 reaches characterized as CCCF, 28 have experienced extirpations (27.2%). Reaches characterized as CLCF had the second most extirpations ($n = 25$; 25/73 = 34.2%). Among the total identified CDCF reaches identified, 15.1% have experienced extirpations ($n = 13/86$; Table 3).

DISCUSSION

The results of this study indicate that Redside Dace is most often found in clear streams with a relatively steep slope that are cool to cold, which is consistent with previous descriptions of Redside Dace habitat (COSEWIC 2017; Lebrun et al. 2020). Extirpations of Redside Dace have occurred within the Lake Ontario and Lake Erie drainages, with most occurring in the Greater Toronto Area (GTA). Interconfluence reaches with known Redside Dace extirpations were generally longer with larger upstream catchment areas.

The geographic extent of the GTA overlaps with a large proportion of Redside Dace distribution in Canada. The effects of agriculture north of the GTA, and urbanization within the GTA, likely have the greatest effect on aquatic habitat in the downstream river stretches. Historically, streams in the GTA drained forested catchments with significant overhead cover, producing colder outflows with higher base flows. However, upstream forested areas have been converted to areas of intensive agriculture (Elliott 1998) and urbanization has progressed east, west, and upstream over time. Redside Dace extirpations have occurred in areas lacking the effects of urbanization, where agricultural practices are widespread (e.g., Irvine Creek, Snow Drain), and in watersheds completely transformed by urbanization (e.g., Etobicoke Creek). Ultimately, the loss of forest cover, changes in base flow, and other in-stream habitat effects associated with agricultural practices in upstream watersheds is likely compounded in downstream reaches affected by urbanization, which helps to explain the concentration of extirpations within the GTA.

Previous research on Redside Dace populations within the GTA has demonstrated shifts in a variety of abiotic and biotic factors over time. For example, many non-native and invasive freshwater fish species have been introduced to watersheds supporting Redside Dace populations over the last 60 years (e.g., Allen and Mandrak 2019). Moreover, the flow regime of GTA systems has changed extensively. Reid and Parna (2017) investigated the long-term variability (1966 – 2013) in stream discharge across sites presently or formerly occupied (i.e., extirpated) by Redside Dace in the GTA. Their results suggested that flow alterations have occurred in areas with Redside Dace extirpations (Mimico Creek and Etobicoke Creek) and where populations were in decline (Lynde Creek and Rouge River), whereas the flow regime was less altered in areas where Redside Dace populations were more stable (Duffins Creek; Reid and Parna 2017).

Along with changes in flow regime, the loss of upstream forested catchments and riparian vegetation can lead to increases in local stream temperatures and reductions in water clarity. Results from this study indicate that Redside Dace populations in Canada are most often found in rivers with a mean July temperature less than 19 °C. Research into critical thermal maximum temperatures for Redside Dace suggests within-population differences by age and season (Leclair et al. 2020; Turko et al. 2020), where Canadian Redside Dace populations (Two Tree River) may be experiencing their thermal limit during the summer months (June – August; Leclair et al. 2020). Moreover, Redside Dace has an increased likelihood of mortality to increases in temperature during the summer months than winter months (Leclair et al. 2020), which is of concern given the loss of riparian cover for buffering temperatures across much of its distribution.

Another concern regarding the loss of upstream forested catchments and riparian vegetation is increased rates of erosion and siltation, leading to greater turbidity. The results of this study demonstrate that Redside Dace rarely occupy perennially turbid systems (n = 5 extant interconfluence reaches). This result is consistent with expectations given the reliance of Redside Dace on visual cues for locating prey and initiating reproduction (COSEWIC 2017), and supports previous research demonstrating a negative relationship between impervious land cover and Redside Dace abundance (Poos et al. 2012). Impervious land-cover increases run-off into streams during rain events, reducing water clarity (Poos et al. 2012), and leading to highly variable, unnatural flow events (Reid and Parna 2017).

Overall, the reliance of Redside Dace on perennially clear systems and relatively cold waters suggests that the growing brownification of freshwater ecosystems (e.g., Weyhenmeyer et al. 2016) and loss of thermal refuge habitat threatens the survival and recovery of extant Redside Dace populations. The results presented in this study provide an update to the current and historical distribution of Redside Dace in Canada, demonstrate the geographic bias of Redside Dace extirpations, and support previous efforts describing habitat associations for the species.

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Table 1. Drainage, location, waterbody, total number of interconfluence reaches identified within each waterbody, and the status of Redside Dace across Ontario waterbodies. A status of X indicates that the location no longer supports Redside Dace populations (i.e., local extirpation).

Drainage	Location	Waterbody	No. reaches	Status
Lake Erie	Irvine Creek	Irvine Creek	6	X
		Snow Drain	1	X
Lake Huron	St Josephs Island	Two Tree River	4	
	Unknown Stan J	Unknown Stan J	2	
	Gully Creek	Gully Creek	2	
	Meux Creek	Meux Creek	7	
		South Saugeen River	1	
	Saugeen River	Saugeen River	24	
Lake Ontario	Niagara region	Welland Canal tributary	1	X
	Bowmanville River	Bowmanville River	1	
	Pringle Creek	Pringle Creek	1	X
	Lynde Creek	Lynde Creek	9	
		West Lynde Creek	5	
	Carruthers Creek	Carruthers Creek	1	
		Carruthers Creek Tributary	3	
	Duffins Creek	Michell Creek	3	
		Duffins Creek	5	
		Ganatsekiagon Creek	5	
		Urfe Creek	2	
	Petticoat Creek	Petticoat Creek	1	X
	Rouge River	Little Rouge Creek	5	
		Rouge River	6	
		Morningside Creek	2	
		Robinson Creek	1	
		Little Rouge Creek Tributary	5	
		Bruce Creek	5	
Lake		Berczy Creek	6	

Table 1. Drainage, location, waterbody, total number of interconfluence reaches identified within each waterbody, and the status of Redside Dace across Ontario waterbodies. A status of X indicates that the location no longer supports Redside Dace populations (i.e., local extirpation).

Drainage	Location	Waterbody	No. reaches	Status
Ontario		Rouge River Tributary A	3	
		Rouge River Tributary B	2	
	Spencer Creek	Spencer Creek	5	X
		Flamborough Creek	1	X
	Fletcher Creek	Fletcher Creek	2	X
	Bronte Creek	Bronte Creek	18	X
	Highland Creek	Highland Creek	1	X
	Fourteen Mile Creek	Fourteen Mile Creek	9	
	Don River	Don River East	16	X
		Don River West	9	X
		Duncan Woods Creek	2	X
	Humber River	East Humber River	22	
		Humber River	14	
		Purpleville Creek	4	
		Cold Creek	1	
		West Humber River Tributary	8	
		West Humber River	2	
		Salt Creek	1	
		Black Creek	2	
		Humber River tributary	1	
	Etobicoke Creek	Etobicoke Creek	5	X
	Sixteen Mile Creek	Sixteen Mile Creek	9	
		Mill Pond	1	
		Sixteen Mile Creek West	3	
		Middle Sixteen Mile Creek	4	
		Middle Sixteen Mile Creek Tributary	2	

Table 1. Drainage, location, waterbody, total number of interconfluence reaches identified within each waterbody, and the status of Redside Dace across Ontario waterbodies. A status of X indicates that the location no longer supports Redside Dace populations (i.e., local extirpation).

Drainage	Location	Waterbody	No. reaches	Status
Lake Ontario		Middle Sixteen Mile Creek Hornby East Branch A	1	
	Credit River	Credit River Erin Branch	1	
		Credit River	11	
		Caledon Creek	1	
		Fletchers Creek	7	
		Churchville Tributary	2	
		Huttonville Creek	2	
		Levis Creek	2	
		Black Creek Tributary	1	
		Black Creek	2	
		Silver Creek	3	
		Snows Creek	1	
	Tecumseh Creek	Tecumseh Creek	1	X
	Sheridan Creek	Sheridan Creek	1	X
	Morrison Creek	Morrison Creek	3	X
	Mimico Creek	Mimico Creek	1	X
Lake Simcoe	South Holland Canal	South Holland Canal West	1	
		South Holland Canal East	1	
	Kettleby Creek	Kettleby Creek	2	

Table 2. Variables extracted from the Ontario Aquatic Ecosystem Classification. RCh = reach channel; RCA = reach contributing area; UCA = upstream catchment area.

Variable	**Type**	**Units**	**Scale**
Channel length	Continuous	m	RCh
Base flow index	Continuous	-	RCA
Thermal Class	Categorical 1 = cold 2 = cold/cool 3 = cool 4 = cool/warm 5 = warm	-	RCA
Turbidity Class	Categorical 0 = clear 1 = turbid	-	RCA
Slope Class	Categorical 0 = slow 1 = fast	-	RCA
Upstream catchment area	Continuous	km^2	UCA
Shreve order	Discrete	-	UCA

Table 3. Number of Redside Dace observations among all extirpated and extant interconfluence reaches. Data organized by Class Code, which consists of categorical variables related to average July temperature, perennial turbidity, and channel slope.

Class Code	**Average July temperature**	**Perennial turbidity**	**Channel slope**	**Extirpated reaches**	**Extant reaches**
CDCF	Cold	Clear	Fast	13	73
CDCS			Slow	0	1
CDTF		Turbid	Fast	0	5
CDTS			Slow	0	0
CCCF	Cold-Cool Transitional	Clear	Fast	28	75
CCCS			Slow	0	1
CCTF		Turbid	Fast	0	2
CCTS			Slow	0	0
CLCF	Cool	Clear	Fast	25	48
CLCS			Slow	1	3
CLTF		Turbid	Fast	1	0
CLTS			Slow	0	0
CWCF	Cool-Warm Transitional	Clear	Fast	5	7
CWCS			Slow	0	1
CWTF		Turbid	Fast	0	0
CWTS			Slow	0	0
WMCF	Warm	Clear	Fast	0	5
WMCS			Slow	0	0
WMTF		Turbid	Fast	0	0
WMTS			Slow	0	0
WBDY	Waterbody			2	5
None	None			0	4

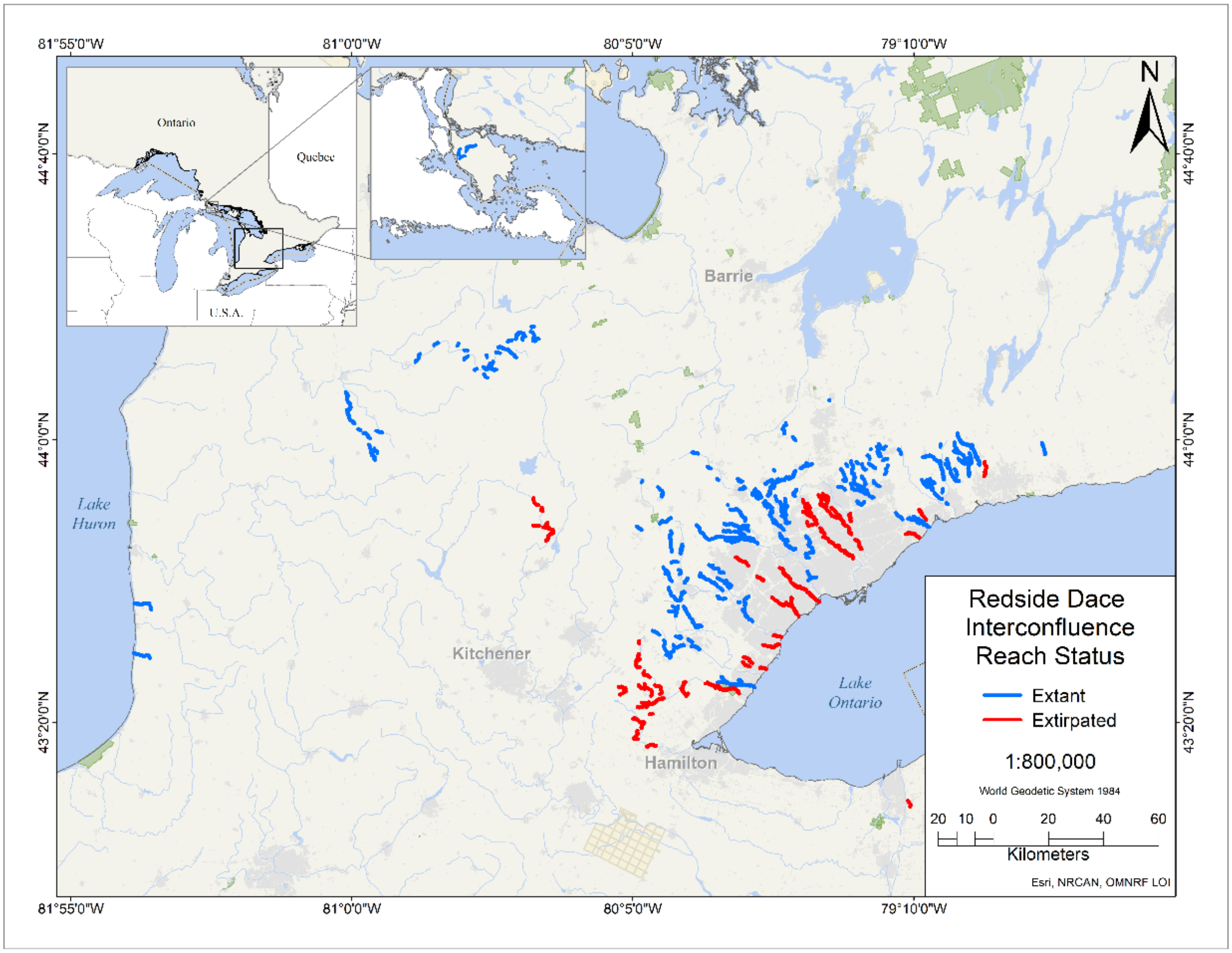

Figure 1. Map of the Ontario Aquatic Ecosystem Classification interconfluence reaches presently (blue) and historically (red) occupied by Redside Dace (Clinostomus elongatus) based on n = 1,145 species occurrence records up to 2017.

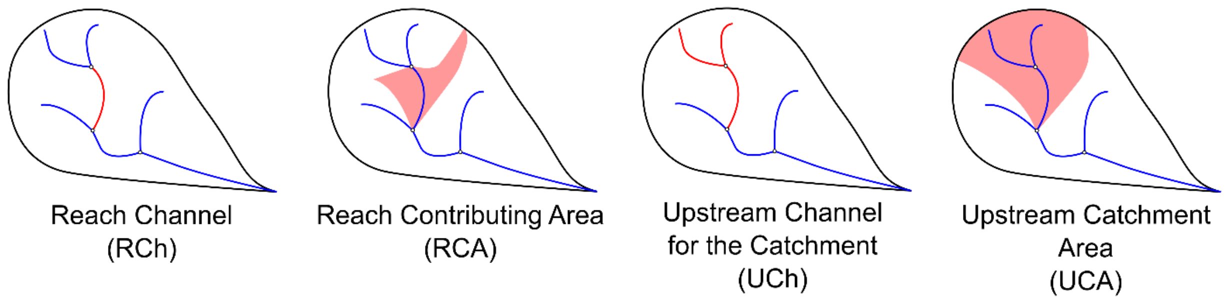

Figure 2. The four spatial scales of variables (shown in red) applied in the Aquatic Ecosystem Classification to group stream reaches, including: reach channel, reach contributing area, upstream channel for the catchment, and upstream catchment area (recreated from Jones and Schmidt 2017).

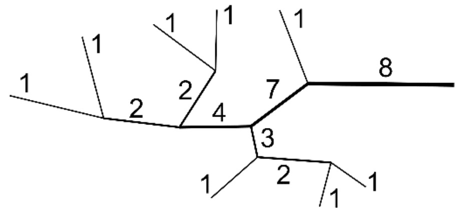

Figure 3. Diagram demonstrating the ordering of streams based on the Shreve method. Ordering begins at the headwaters and is summed at confluences moving downstream.

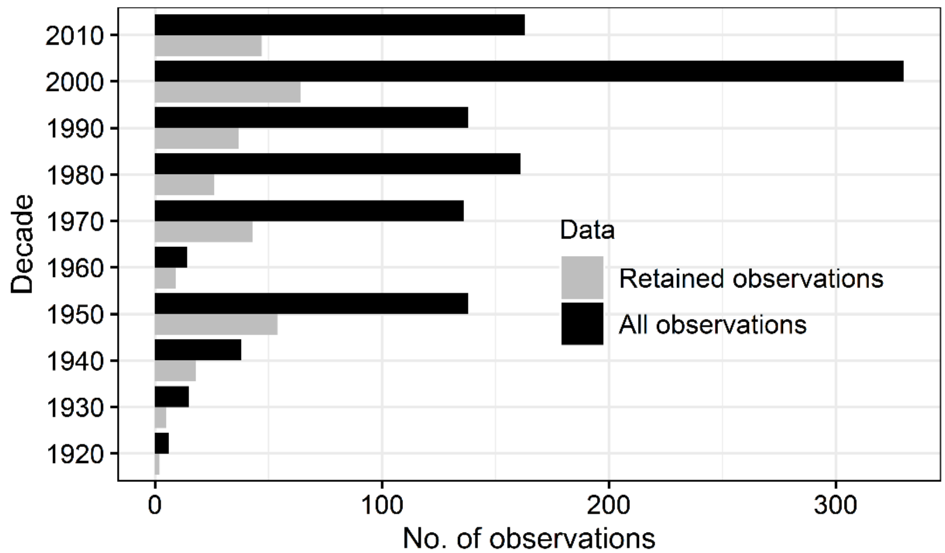

Figure 4. Decadal count of all recorded Redside Dace observations and after thinning observations by using only the most recent observations with the highest confidence (i.e., shortest distance to an interconfluence reach). Note that final decade includes observations from 2010 – 2017.

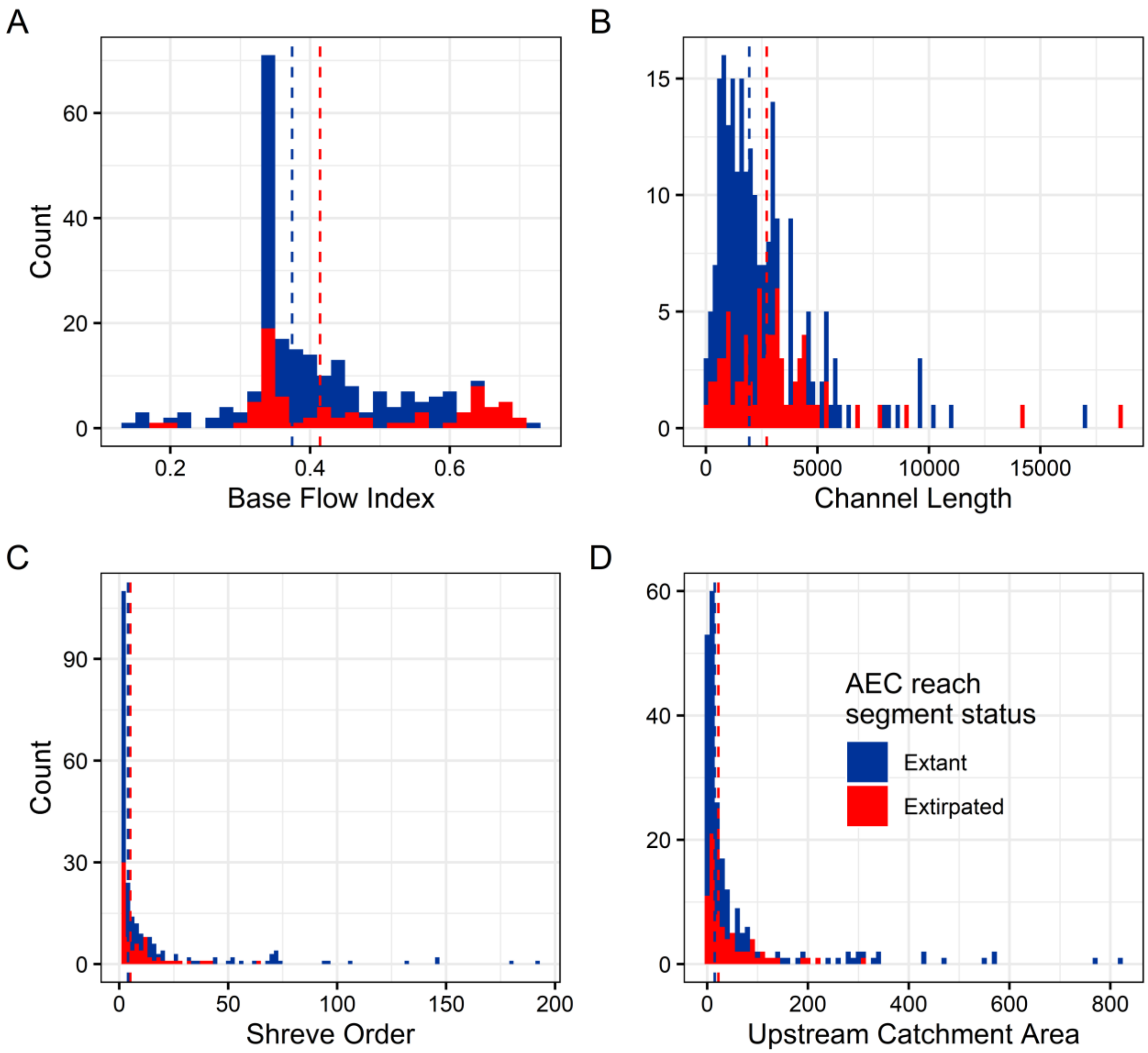

Figure 5. Histograms of A) base flow index, B) channel length (m), C) Shreve order, and D) upstream catchment area (km^2) for unique AEC reaches (n = 305) where Redside Dace are present (extant; blue) or historically observed (extirpated; red). Medians for extant and extirpated AEC reaches are presented in blue and red, respectively.

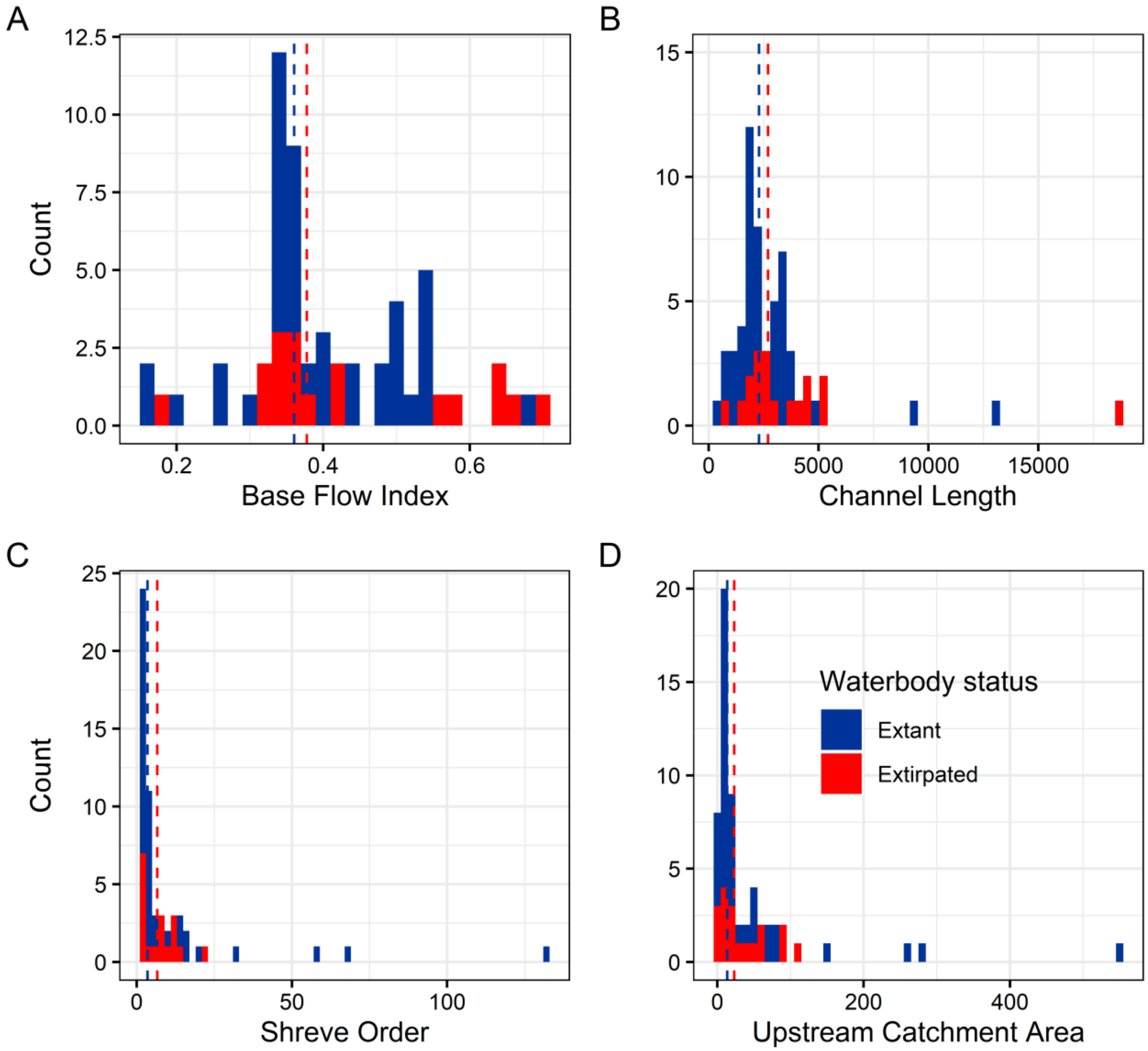

Figure 6. Histograms of average A) base flow index, B) channel length (m), C) Shreve order, and D) upstream catchment area (km^2) for interconfluence reaches grouped by waterbody (n = 71) where Redside Dace are present (extant; blue) or historically observed (extirpated; red). Medians for extant and extirpated waterbodies presented in blue and red, respectively.

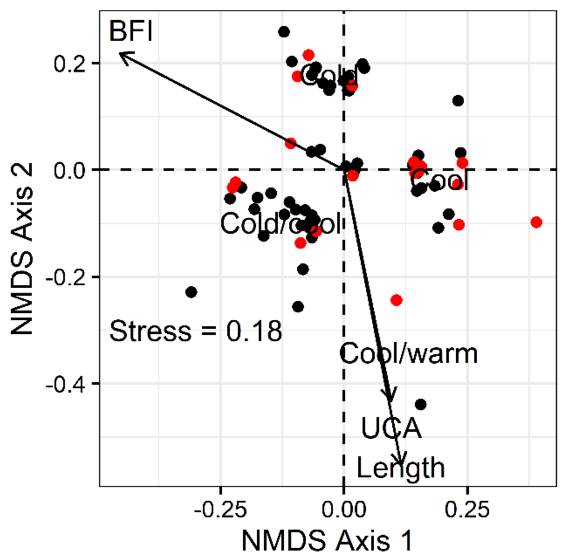

Figure 7. Non-metric multidimensional scaling (NMDS) plot with fitted upper catchment area (UCA; km^2), base flow index (BFI), reach channel length (Length; m), and temperature class variables (cold, cold/cool, cool, cool/warm). Red points = extirpated waterbody segments. Black points = extant waterbody segments.