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# *Estimating local and regional population sizes for an endangered minnow, redside dace* (Clinostomus elongatus), *in Canada*

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ABSTRACT

1. The Laurentian Great Lakes have undergone drastic declines in freshwater fishes, with 22 species having become extinct in the past century and many more currently at risk. One such species is the endangered minnow, the redside dace (*Clinostomus elongatus*), which is undergoing severe declines across its entire range.
2. Depletion and mark–recapture surveys were used to quantify population estimates of redside dace at several spatial scales (pool, reach and catchment) across several Great Lakes tributaries in Canada.
3. There was large variation in the local population estimates and the rate of occurrence of redside dace populations. In some cases, such as Gully Creek, a Lake Huron tributary, redside dace were widespread (9/10 of pools) but in low abundances (13.5 individuals per pool $\pm$ 5.09 ). In other cases, such as in the Don River, redside dace were highly localized (2/27 pools) but in relatively high abundance (99.2 individuals/pool $\pm$ 18.1).
4. Extrapolated population estimates at the catchment scale showed that three of the five study populations were below conservative estimates needed for long-term population viability.
5. Differences in redside dace populations were driven by adjacent land-use. Post-hoc analyses revealed strong negative associations between population estimates and impervious land-use (i.e. urbanization) at both the pool and sub-catchment level.
6. Immediate recovery actions that will focus on eliminating chronic and episodic impacts of adjacent land-use and improve connectivity are needed to help ensure redside dace, like many freshwater species in the Laurentian Great Lakes, remain a species at risk of – rather than facing – extinction.


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KEY WORDS: endangered species; biodiversity; freshwater ecology; Great Lakes; population estimate; urbanization; redside dace (*Clinostomus elongatus*)

## INTRODUCTION

The loss of freshwater fish diversity remains a global concern. Freshwater fishes are among the most imperilled taxa globally and the decline of freshwater biodiversity is comparable with species declines found in tropical rain forest communities (Ricciardi and Rasmusen, 2001). Twenty-two species and one subspecies of freshwater fishes have become extinct or extirpated in one or more of the Laurentian Great Lakes basins in the past century. These species include the global extinction of blue pike

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(*Sander vitreus glaucus*) and deepwater cisco (*Coregonus johannae*) and extirpation of deepwater sculpin (*Myoxocephalus thompsoni*; Mandrak and Cudmore, 2010). Of all the Laurentian Great Lakes, Lakes Erie and Michigan have suffered the greatest reduction in taxa (10 each), probably as a result of a higher level and longer history of human impacts (Mandrak and Cudmore, 2010).

Understanding population sizes of endangered species is critical for determining species trajectories, and for developing, implementing and prioritizing recovery actions. Population estimates are often the basis for assessing the conservation status of species, and used for determining population viability through space and time. Unreliable estimates of the distribution and abundance of species at risk of extinction can result in failure to list species that need protection, result in the inappropriate assignment of designations to species that do not need protection, or may suggest inaction when mitigation is needed (Hilton-Taylor *et al.*, 2000). However, owing to a paucity of data in many cases, endangered species lack adequate information on population distribution and abundance; therefore, trends in populations are often determined qualitatively and used as the basis for species listings (Lukey and Crawford, 2009). To alleviate the potential shortcomings of this approach, developing rigorous quantitative population estimates for endangered species remains an important first step to ensuring species protection and recovery.

Redside dace (*Clinostomus elongatus*) is a pool-dwelling, lotic minnow. Redside dace can be distinguished from other Canadian members of the minnow family (*Cyprinidae*) by their large mouth and protruding lower jaw, and large pectoral fins, which allow them to propel themselves into the air to capture terrestrial insects, their primary food source (Schwartz and Norvell, 1958; Daniels and Wisniewski, 1994; Scott and Crossman, 1998). Currently, redside dace are undergoing drastic decline across their entire geographic range. The global range of redside dace is discontinuous and includes tributaries to all five of the Great Lakes, Susquehanna River, Ohio River, and Upper Mississippi River drainages (Scott and Crossman, 1998). In Canada, redside dace are found only in Ontario and are in serious decline owing to major changes in land-use, especially urbanization (McKee and Parker, 1982). In the past 22 years, the conservation status of redside dace has changed from Special Concern (1987) to Threatened (2000) to Endangered (2007) (COSEWIC, 2007) as a result of declining distribution and abundance and changing assessment criteria. Urbanization and its resultant alterations in habitat are thought to be the most crucial among several factors influencing decline, especially in the Greater Toronto Area where 80% of its Canadian range resides (COSEWIC, 2007). Therefore, redside dace provides an excellent model organism for understanding the impacts of land-use change.

Standardized monitoring and assessment of population trends of redside dace through time are needed to allow for continuing assessment of conservation status and evaluation of recovery actions. Standardized, targeted surveys for redside dace did not occur in Canada before 1979, after which targeted surveys were conducted by government agencies (e.g. Fisheries and Oceans Canada, Ontario Ministry of Natural Resources, Royal Ontario Museum), non-government agencies, academia, and consultants. Unfortunately, these surveys were not undertaken in a standardized manner (e.g. different sampling methods and efforts were used), which makes data synthesis and trend analysis difficult (COSEWIC, 2007). Despite the need for such analyses, population estimates and trends of redside dace at local and regional scales remain a significant knowledge gap (RDRT, 2010).

There are many limitations to quantifying the population dynamics of endangered species. Endangered species are often elusive owing to both behavioural attributes (Novinger and Koon, 2000) and overall rarity, making them difficult to sample and count (Thompson, 2004). Redside dace, like many endangered species, are known to be regionally uncommon, but may be locally abundant (Koster, 1939; McKee and Parker, 1982). This makes evaluation of population estimates particularly difficult as sampling often entails many sites with zero captures, and a few sites with high abundances. Therefore, traditional study design (e.g. random site selection) may alter the estimation of redside dace abundance and require the sampling of many locations in order to find even a few sites containing the species. The objective of this study was to develop a systematic, standardized sampling methodology for a locally abundant and regionally rare freshwater fish species, redside dace, that can be used to identify spatial and temporal trends in population estimates required for conservation and assessment actions.

## METHODS

### Assessing spatial variation in population estimates of redside dace

Redside dace were sampled from eight reaches across five catchments where they were known to occur in

 

Canada (Figure 1). These included (from west to east) a Lake Huron tributary, Gully Creek, and four Lake Ontario tributaries: Humber River, Don River, Rouge River, and Duffins Creek (Figure 1). A reach was defined as an area of uniform in-stream habitat, based on stream gradient and surficial geology. All sampling was conducted using multiple pass (i.e. k-pass) depletion surveys using a 6-m bag seine (0.635 cm mesh). Despite potential increases in efficiency shown for other species at risk of extinction (Poos *et al*., 2007), seining was used over electrofishing because of concerns regarding harm to fish during or following their capture (Bohl *et al*., 2009). In an initial pilot study of electrofishing, there were high levels of harm at generally low electrofishing settings (e.g. 30 Hz, 150 V, 3 m $s^{-1}$ pulse rate; Poos unpublished data). All habitats (e.g. riffle, run, or pool) were isolated using block nets (0.32 cm mesh size) to ensure that fish did not accidentally move from a particular habitat or reach. Block nets were left in place until specific reaches had been completely sampled, thereby restricting movement into or out of each habitat type. All surveys were conducted after spawning, from July–September 2008.

As site selection may have an undue influence on population estimates, especially for endangered species (Thompson, 2004), an adaptive sampling approach was used that encompassed all stream habitats to develop the population estimates. For example, initially reaches that were generally known to support strong populations were targeted for sampling, especially where previous monitoring programmes had determined consistently high abundances within the vicinity (Reid *et al*., 2008; S. Jarvie, Toronto Region Conservation Authority, unpublished data). At a given reach, a minimum of 10 pools were sampled systematically from downstream to upstream. As redside dace are habitat specialists, preferring large headwater pools (McKee and Parker, 1982), sampling intensity was increased at these habitats. Each pool was surveyed until depletion of redside dace, with a minimum of three sample events conducted at each pool. Habitats such as riffles, glides, and runs were also sampled; however, as these habitats were considered non-resident habitat (i.e. used mostly during spawning), each riffle and run was sampled using only single-pass seine hauls and dip nets. If redside dace were not captured in these habitats, sampling was continued upstream. If redside dace were captured in these habitats, a minimum of two more seine hauls were completed to allow for comparable population estimates and probabilities of detection across habitat types. This sampling approach allowed maximum sampling intensity in pool habitats where redside dace would be more likely to occur, while also allowing continuous sampling throughout the reach.

Population sizes of redside dace were estimated at both local (i.e. pool, reach) and regional (i.e. catchment) levels using k-pass removal method estimates obtained using maximum likelihood (Zippin, 1956, 1958; Carle and Strub, 1978). In this

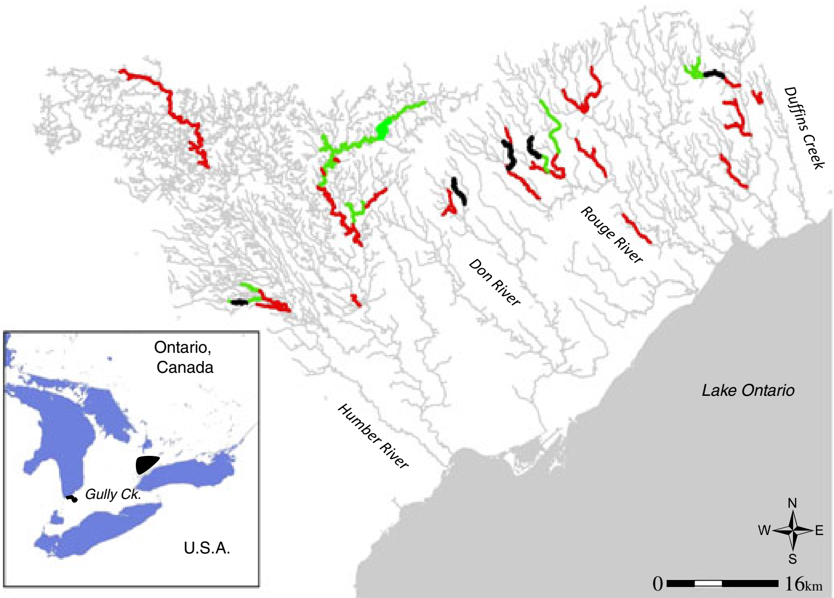


Figure 1. Distribution of sample locations of redside dace (black) in the Greater Toronto Area, Ontario in relation to optimal (green) and non-optimal (red) habitats. Shown inset are study locations relative to the Great Lakes and Gully Creek, a Lake Huron tributary. Note: Sampling was conducted between July and October 2008. Sample locations are approximate (individual pools not shown).

method, a closed population is repeatedly sampled. On each of a total $k$ sampling passes, the number of individuals are counted and removed from the population (Cowx, 1983). The Bayesian modification to the removal method was used, as it is less prone to violating model assumptions and provides lower bias (Carle and Strub, 1978). This approach weighs the likelihood function by a prior beta distribution for the probability of capture ($p$, with parameters $\alpha$ and $\beta$). If no prior information exists for $p$ (as is the case here), then a uniform prior of $\alpha = \beta = 1$ is used. Assuming the probability of capture is constant from sample to sample, the overall population size ($N_0$) can be estimated from the number of individuals successively removed. Given that the solution is solving for the smallest $N_0 \geq T$, where $d = \sum_i^k C_i$, $C_i$ is the number of redside dace captured in the $i$th removal, and $X = \sum_{i=1}^k (k-1)C_i$ ; the overall population size ($N_0$) is found iteratively using:

$$\frac{N_0 + 1}{N_0 - T + 1} \prod_{i=1}^{k} \frac{kN_0 - X - T + \beta + k - i}{kN_0 - X + \alpha + \beta + k - i} \leq 1$$

Once $N_0$ is solved iteratively, then the standard error is calculated as

$$SE_{\hat{N}_0} = \sqrt{\frac{\hat{N}_0 T (\hat{N}_0 - T)}{T^2 - \hat{N}_0 (\hat{N}_0 - T) \frac{(kp)^2}{q}}}$$

where $q = 1 - p$, is the probability of escape (Carle and Strub, 1978). Population estimates were standardized across reaches using density ($D$), which were corrected for sampling bias using the probability of detection ($p$) according to White's (2005) suggestion. Density estimates were calculated as

$$\hat{D} = \left( \frac{\hat{N}_{0reach}}{\bar{p}_{reach}} \right) \Big/ d$$

where $d$ is river distance (in metres). All analyses were completed using the R programming language v2.80 (R Development Team, 2009) using the fisheries assessment package FSA (Ogle, 2008).

### Assessing the efficacy of population estimates of redside dace from depletion surveys

Given the inherent uncertainty with developing population estimates for endangered species (Thompson, 2004), the efficacy of developing population estimates from depletion surveys was compared with mark–recapture estimates. For this, a mark–recapture study was conducted at a subset of the sampling locations in the Rouge River. At each site, redside dace were implanted with visual implant elastomer (VIE) tags, colour-coded for their location (i.e. specific pool). The application of VIE tags has been used previously in sampling endangered species (Philips and Fries, 2009) and has been shown to have good tag retention time and low mortality rates (Roberts and Angermeier, 2004; Stone *et al.*, 2006). Captured redside dace were injected with subcutaneous VIE tags adjacent to the anal fin on the ventral surface. All redside dace were held in oxygenated flow-through bins for 2–4 h to ensure post-tagging recovery and survival, and then returned to the river at the captured location. If redside dace were re-captured at a new location, they were tagged behind the existing tag with a new colour code for the recapture location. Therefore, individuals could be monitored for movement from site to site, but not for sample period (i.e. open population estimates were not possible).

Population sizes were quantified using the Petersen–Chapman method. The Chapman correction was applied to the population estimates as it has been shown to be an unbiased estimate when sample sizes are low (Seber, 1982). The Petersen–Chapman method has the following assumptions (Seber, 1982; Chao and Huggins, 2005): (1) all fish act independently; (2) tagging fish does not affect their catchability; and (3) fish do not lose their tags. Assuming that the population remained closed to the effects of mortality, recruitment, and migration between sample periods, the total population ($N$) was estimated as

$$N = \frac{(M+1)(n+1)}{(m+1)} - 1$$

where $M$ is the number of redside dace captured in the first sample and tagged, $n$ is the number of redside dace in the second sample, and $m$ is the number of redside dace marked and recaptured (Seber, 1982). All analyses were completed using the R programming language v2.80 (R Development Core Team, 2009) using the fisheries assessment package FSA (Ogle, 2008). Finally, given that most recapture sizes were generally above 0.1 but below 0.5, the binomial distribution was deemed most appropriate to calculate standard error (Seber, 1982). Standard error was determined as

$$SE_{\frac{m}{n}} = \sqrt{(1 - \frac{m}{M}\frac{\frac{m}{n}\left(1 - \frac{m}{n}\right)}{n - 1} + \frac{1}{2n}}$$

### Extrapolating population estimates to broader spatial scales for redside dace

Regional (i.e. catchment) population estimates are often needed to help prioritize areas in need of conservation actions for endangered species. Given the difficulties of sampling endangered species, it is often impossible to sample their known extent: extrapolation of population size is needed. Therefore, regional population estimates were quantified for redside, with the hope of providing management advice for conservation efforts.

To quantify population estimates of redside dace at the regional scale, the density estimates developed at the reach level were scaled to the remaining known extent of redside dace in each catchment. To determine the remaining extent of redside dace, fish sampling data were compiled from stream surveys in the sampled catchments. Data were collected from various government agencies including Fisheries and Oceans Canada (N.E. Mandrak, unpublished data), Ontario Ministry of Natural Resources (Reid *et al.*, 2008; L. Stanfield, unpublished data), and the Toronto and Region Conservation Authority (S. Jarvie, unpublished data), as well as the non-governmental agencies Ontario Streams (D. Forder, unpublished data) and Royal Ontario Museum (E. Holm, unpublished data). These records represent more than 300 000 fish collections records in the catchments sampled. As sampling at the reach level was conducted in areas of generally high habitat quality, regional population estimates were corrected for differences in habitat quality by segregating redside dace extent into optimal (i.e. comparable habitat quality) or non-optimal (i.e. reduced habitat quality) habitat types. In general optimal habitat was defined as a stream reach (i.e. segment) where redside dace were readily abundant (e.g. $\geq$ 5 individuals) within the past 20 years; the time period that the redside dace recovery strategy considers to be active record (RDRT - Redside Dace Recovery Team, 2010). As there were many cases where sampling was deficient, areas which met this criterion that were in close proximity (2 km) to one another and where no barriers existed were aggregated. In some cases, expert opinion was used to interpret habitat suitability where sampling was deficient and no (or sparse) historic sampling occurred. In these cases, habitat suitability (e.g. optimal/non-optimal) was assessed from aerial photos of grass meadow (as described in Andersen, 2002) and using recently developed habitat suitability indices (M.S. Poos, unpublished data). Each river segment was quantified separately based on the sampling data and the criterion above, and whether barriers existed. Non-optimal habitats were defined as a stream reach where redside dace occurred in low abundance (< 5 individuals, i.e. the above criterion) or occurred historically. These definitions of optimal and non-optimal habitat are deliberately inclusive to provide an estimate of overall redside dace population size, and are not meant to coincide with current regulatory initiatives (e.g. Endangered Species Act, Species at Risk Act), which are beyond the scope of this work.

Uncertainty was incorporated within the regional population estimates in three ways. First, uncertainty in sampling (i.e. incomplete detection) in the reach-level density estimates ($D$) were corrected using the probability of capture ($p$) to reduce the effects of sampling bias and previous criticisms of extrapolating naïve abundance estimates (see above, and White, 2005). Second, as population sizes could not be assumed to be equivalent in non-optimal habitats, and that pool- and reach-level population estimates were developed in areas of optimal habitat quality, variability was incorporated into catchment-level estimates. For example, population estimates were reduced in non-optimal habitats by 0%, 25%, 50%, and 75%. Although these thresholds were arbitrarily defined, they allow for comparisons of population sizes across a spectrum of different habitat and population scenarios, which may be useful for informing species management. Finally, uncertainty was incorporated into the population estimates by bounding the estimates using the 25% and 75% quantiles of the mean pool-level density estimate. These bounds ensured that catchment population estimates explicitly incorporated spatial and sampling variability.

## RESULTS

In total, 993 redside dace were captured across 100 pool locations and roughly 7 km of continuous stream in five catchments (Table 1). Probabilities of capture were generally high, ranging from 0.584 on Gully Creek to 0.785 on the Don River (Table 1). On average, redside dace accounted for 15% of the total fish community composition, with typical communities consisting of widespread and tolerant species such as blacknose dace (*Rhinichthys atratulus*; mean = 22%, range: 0–50%), white sucker (*Catostomus commersoni;* mean = 5.4%, range: 0–37%), creek chub (*Semotilus atromaculatus;* mean = 24.5%, range: 0–100%), and common shiner (*Luxilus cornutus*; mean = 7.6%, range = 0–74%). Redside dace were not captured in non-pool habitats (e.g. riffles or runs), although sampling was conducted during post-spawning periods. Only individuals larger than 32 mm were captured, indicating year 1+ individuals (Schwartz and Norvell, 1958; Scott and Crossman, 1998).

There was large variation in the rate of occurrence of redside dace among catchments. Overall, redside dace were found in 39% of the headwater pools sampled. In some areas, such as Gully Creek, redside dace were captured in 90% of pools; whereas in other areas such as the Don River, redside dace were captured in only two pools (e.g. rate of occurrence of 7.4%; Table 1) despite extensive sampling (Table 1). The remaining catchments had relatively similar rates of occurrence, including the Humber River (40%), Rouge River (50% in Leslie Tributary, 31% in Berczy Creek), and Duffins Creek (50%).

Population estimates for individual pools varied considerably (Figure 2). For example, when redside dace were found, the majority of pools had generally high population sizes (overall mean = 27 individuals/pool) while, in some cases ($n = 5$), redside dace population estimates exceeded 50 individuals per pool (Table 1; Figure 2). Pool-level population estimates were highest in the Don River (93.2 individuals/pool), followed by Duffins Creek (36.7 individuals/pool; Figure 2). The Humber River had the highest population density of redside dace (0.289 individuals m$^{-1}$), followed by the Don River (0.277 individuals m$^{-1}$), Gully Creek (0.247 individuals m$^{-1}$), Rouge River (Leslie Tributary = 0.118, Berczy Creek = 0.135 individuals m$^{-1}$, respectively), and Duffins Creek (0.081 individuals m$^{-1}$; Table 1).

At the catchment level, there was large variation in the extrapolated population estimates of redside dace based on the extent of optimal and non-optimal habitats. For example, Gully Creek had limited optimal habitat (only 3 km), which yielded catchment population estimates of only 462–741 individuals (min = 129, max = 1171; Table 2). In comparison, the Humber River had considerably more optimal habitat, with roughly 133.5 km, with extrapolated population estimates ranging between 21 530 and 38 582 individuals. Population estimates varied considerably in the remaining catchments: in the Rouge River 4499–9180 individuals, in Duffins Creek 1207–2398, and in the Don River 402–1607 (Table 2).

There was close agreement between the population estimates from the depletion surveys and mark–recapture techniques. In total, approximately 85% of the pools where redside dace were found had similar population estimates using the two different estimation methods (Figure 3).

## DISCUSSION

Redside dace are among the most imperilled fish species in Canada and the Laurentian Great Lakes. Declines in redside dace populations have occurred in 15 of 26 Canadian populations, with five populations known to be extirpated, and another five populations thought to be extirpated (COSEWIC, 2007). Despite extensive sampling in Canadian catchments in the past three decades, there have been no quantitative population estimates of redside dace at local or regional levels (COSEWIC, 2007). At a local scale, the mean pool-level population estimates varied considerably from 13.5 ± 5.09 individuals per pool in Gully Creek to 99.2 ± 18.1 individuals per pool in the Don River. As the sampling conducted in this study represents the most extensive to date (i.e. ~ 1000 individuals sampled and 7 km of stream), catchment-level population sizes were developed to help identify and prioritize conservation efforts. Regionally, the catchment population estimates ranged from a minimum of 463 individuals (Gully Creek) to 52 507 individuals (Humber River; Table 2). In the worst-case scenario, population sizes in Gully Creek

Table 1. Summary of sampling data for the redside dace (*Clinostomus elongatus*) at various catchments across its Canadian range

| Catchment | Distance ($d$) sampled (m) | Pools with redside dace (pools sampled) | Probability of capture ($p_{reach}$) | Density (individuals m$^{-1}$) | Mean population estimate per pool (± 95% CI) | Relative abundance (range) |
|---|---|---|---|---|---|---|
| Gully Creek | 491 | 9 (10) | 0.584 | 0.247 | 13.5 ± 5.09 | 19.6% (2–44%) |
| Humber River | 426 | 4 (10) | 0.612 | 0.289 | 30.3 ± 6.3 | 13.8% (4–25%) |
| Don River | 678 | 2 (27) | 0.785 | 0.277 | 99.2 ± 18.1 | 16.5% (15–18%) |
| Rouge River: Leslie Trib. | 2625 | 15 (30) | 0.751 | 0.118 | 20.3 ± 5.8 | 12.9% (5–21%) |
| Rouge River: Berczy Creek | 600 | 4 (13) | 0.718 | 0.135 | 22.7 ± 5.6 | 10.6% (1–19%) |
| Duffins Creek | 2105 | 5 (10) | 0.608 | 0.081 | 36.7 ± 12.3 | 29.8% (5–38%) |

 

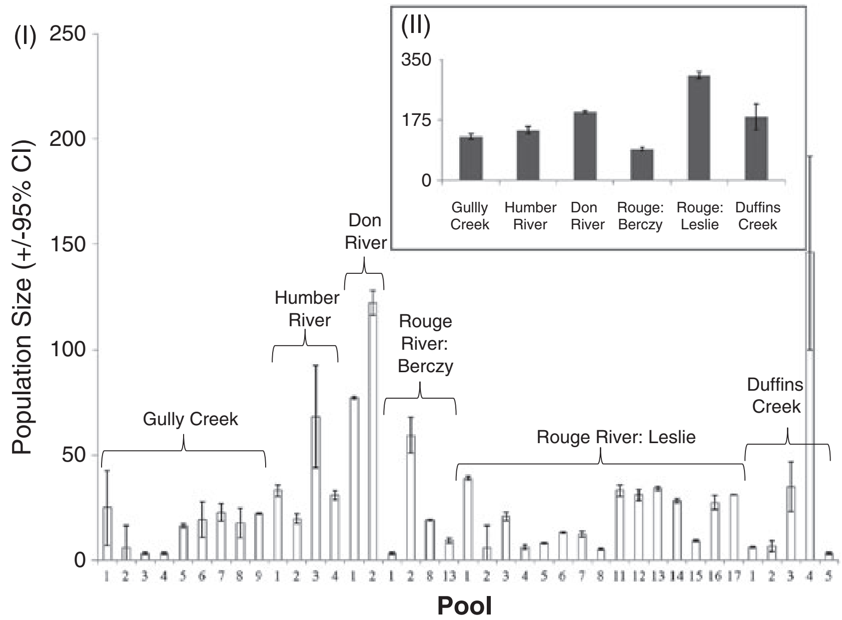


Figure 2. Variability in spatial population estimates for redside dace (*Clinostomus elongatus*) at various scales including: (I) pool-level; and (II) reach-level (shown inset top right; see Figure 1). Shown are depletion population estimates across various pools at a sampled reach July to September 2008. Estimates are shown ± 95% confidence intervals. Pools without redside dace are not shown.

and the Don River were estimated as only a few hundred individuals remaining across a relatively small area (Table 2), further emphasizing conservation concern for the species in these localities.

Developing local and regional population estimates for endangered species, such as redside dace, can help identify populations that may be moving towards extinction. Recently, Velez-Espino and Koops (2008) used a demographic-based population viability analysis to assess the minimum viable population size for the long-term persistence of redside dace. Assuming that redside dace mature at age 2, their estimates suggested that a breeding population size of 2952 (lower and upper bounds: 2421–3305) was required, at a minimum, to have a probability of persistence above 95% within 100 years. If redside dace mature at age 3, then 4295 (lower and upper bound: 3651–4711) breeding individuals were required for population persistence. Given the regional estimates of redside dace populations, it appears that three of the five catchments sampled (Don River, Duffins Creek, and Gully Creek) have population sizes below the minimum requirements for population persistence. Assuming similar densities of redside dace per catchment as found here, and that redside dace mature at age 3 – as McKee and Parker (1982) suggested for Canadian populations – an additional 7.2, 10.7 and 7.6 km of optimal habitat would need to be added to the Don River, Duffins Creek, and Gully Creek, respectively, for redside dace to approach long-term viability.

Table 2. Basin-wide population estimates for the redside dace (*Clinostomus elongatus*) in several catchments across Canada

| | Potential extent of redside dace | | Extrapolated basin-wide population estimate given: | | | |
|---|---|---|---|---|---|---|
| Catchment | Non-optimal habitat[1] | Optimal habitat[1] | 0% reduction in non-optimal habitats (range)[2] | 25% reduction in non-optimal habitats (range)[3] | 50% reduction in non-optimal habitats (range)[3] | 75% reduction in non-optimal habitats (range)[3] |
| Gully Creek | 1.5 | 1.5 | 741 (206–1,171) | 648 (180–1025) | 556 (155–878) | 463 (129–732) |
| Humber River | 77.1 | 56.4 | 38 582 (24 569–41 542) | 33 011 (21 021–35 543) | 27 415 (17 474–29 546) | 21 530 (13 927–23 548) |
| Don River | 5.6 | 2.4 | 1607 (1218–1711) | 1205 (913–1283) | 803 (609–856) | 402 (305–428) |
| Rouge River | 52.9 | 24.9 | 9180 (3887–14 443) | 7620 (3151–11 439) | 6059 (2566–9 533) | 4499 (1861–6754) |
| Duffins Creek | 19.6 | 10 | 2398 (423–2466) | 2001 (353–2058) | 1604 (283–1650) | 1207 (213–1242) |
| Total: | 156.3 | 95.2 | 52 507 (30 304–61 333) | 44 485 (25 619–51 348) | 36 463 (21 087–42 462) | 28 441 (16 434–32 703) |

[1]Area measurements were not possible given limitations in the river data; therefore estimates are shown as river distances (km of river).
[2]Catchment-scale population estimates were extrapolated using reach-level density estimates corrected for incomplete detection using the probability of capture (*P*). Ranges were bounded using the 25 and 75% quantiles.
[3]As habitats may not be consistently optimal (as in the reach-level sampling locations), in areas where habitat was considered non-optimal, population estimates were reduced by 25%, 50% or 75%.

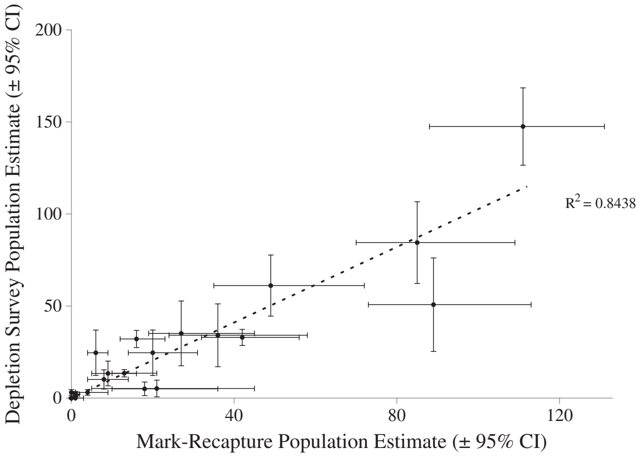


Figure 3. Comparison of pool-level population estimates for redside dace (*Clinostomus elongatus*) obtained using depletion and mark–recapture estimates at two locations in the Rouge River: (a) Berczy Creek; and (b) Leslie Tributary. Estimates are shown ± 95% confidence intervals.

Understanding causative mechanisms for the loss of freshwater biodiversity remains paramount for developing appropriate recovery actions. The decline of redside dace, like many freshwater fishes, is thought to be primarily driven by habitat alteration caused by changes in adjacent land use (Ricciardi and Rasmussen, 2001). A post-hoc assessment at the pool and reach levels demonstrated a highly significant negative relationship between the population estimates and impervious land-use, at both the pool ($R^2 = 0.86$, $P = 0.01$) and sub-catchment scales ($R^2 = 0.86$, $P = 0.003$; Figure 3). Mechanisms of how impervious land may influence freshwater fishes are diverse; however, one fundamental concern is related to shifts in stream hydrology (Roy *et al.*, 2005; Wenger *et al.*, 2008). Perhaps it is not surprising that one of the lowest catchment-level population estimates of redside dace was in the Don River. The Don River remains Canada's most degraded river system with over 80% of its 360 km$^2$ catchment as urban land-use (Rumman *et al.*, 2005; TRCA, 2009). Episodic floods in the Don River have increased by 302%, on average, from pre-urbanization levels (Poos, unpublished data); representing considerable impacts to habitat suitability. Efforts to reduce the variability in flow, for example through implementation or retrofit of low-impact residential development, will only help the long-term viability of redside dace.

Understanding how adjacent land-use may influence population sizes of freshwater species can allow early mitigation of potential threats. Previous research suggests that by 2100, land-use change will outpace other macro-ecological drivers (e.g. climate change, invasive species) affecting freshwater systems (Sala *et al.*, 2000). A comparison of the occurrence and estimated population sizes of redside dace suggests a wide range of potential chronic versus episodic impacts associated with land-use change. For example, in Gully Creek redside dace were widespread (e.g. high rate of occurrence), but generally low in abundance; compared with populations in the Don River, which were highly localized (low rate of occurrence across potentially occupied sites), but highly abundant where found. In both cases, it appears that these differences were due to adjacent land use. For example, unlike urbanization in the Don River, Gully Creek is one of a few redside dace catchments dominated by agriculture (e.g. cash crop, livestock). The impacts of agriculture compared with urbanization present different challenges for managing freshwater fishes (Newcombe and Jensen, 1996; Wenger *et al.*, 2008). Like many agricultural systems, sedimentation and suspended solids are a known concern in Gully Creek (ABCA, 2009; RDRT, 2010). As such, chronic, and not episodic, deleterious effects may be causing the high rate of occurrence and low population sizes of redside dace found in Gully Creek. Shifts in turbidity and velocity have been shown to reduce the foraging success of the closely related rosyside dace (*Clinostomus funduloides*; Zamor and Grossman, 2007; Hazelton and Grossman, 2009) as well as for other fishes (Newcombe and Jensen, 1996); and it is likely that similar consequences are occurring for redside dace. Interestingly, the remaining populations in the Humber and Rouge rivers, which remain above the population viability threshold, were neither highly widespread (occurrence between 31 and 50% of pools) as in Gully Creek nor were they highly aggregated in specific pools (e.g. from $20.3 \pm 5.8$ to $36.7 \pm 12.3$ individuals per pool; Table 2) as in the Don River. Such results emphasize the importance of delineating potential impacts of adjacent land-use and population sizes of freshwater species across both local and regional scales.

Delineating local and regional population sizes for endangered species is an activity filled with uncertainty. In some instances, such as with the pool- and reach-level population estimates, there is less uncertainty with the estimates themselves because the methods are well known (e.g. Zippin, 1956, 1958), and the data have been independently corroborated using mark–recapture data. Although in reality it is likely that some of the assumptions of the closed population models were violated, it is unlikely that these altered the results. For example, unequal catchability between marked and unmarked fish may arise owing to the behaviour of individuals in the vicinity, learning by animals already caught (e.g. trap/net shy) or unequal opportunity to be caught because of position of the net (Eberhardt, 1969). Nonetheless, the consistency between the depletion and mark–recapture estimates ($R^2 = 0.8438$; Figure 4), and the generally high detection probabilities (mean = 0.676; Table 1), suggest that these violations did not alter the pool- and reach-level population estimates. However, it should be noted that greater uncertainty exists in developing population estimates at broader scales, which requires broader extrapolation. Decisions on how best to scale-up population estimates remain challenging as validating these estimates is impossible. In this study, a range of potential scenarios were used to develop the catchment-level population sizes. Regardless of the scenarios presented or the population viability threshold selected (i.e. maturation at age 2 or 3; Velez-Espino and Koops 2008), there were no discrepancies in the evaluation of catchments moving towards extinction (Table 2). In addition, it is likely that, if anything, our catchment-level population estimates were over-estimates as the definitions of optimal and non-optimal habitat were purposely inclusive (e.g. included historical occurrences and adjoining populations) and the catchment-level population estimates themselves were based on all captured individuals (i.e. age 1+), regardless of their breeding condition. Therefore, these results should emphasize the seriousness of the threat of extinction for many redside dace populations.

New methods for estimating the population sizes of endangered freshwater species are sorely needed for the development of appropriate management actions. In this study there were several improvements in methods that may have aided the ability to capture redside dace. Although synthesis in population trajectories of redside dace is complicated owing to differences in historic sampling, it appears that much of the sampling (e.g. Gully Creek, Humber River, Don River) represents significant increases in catch per unit effort compared with historical records in these areas (COSEWIC, 2007). These increases are probably due to the methods used, and not an improved condition of redside dace populations. For example, the sampling conducted was for a much larger area than previous efforts (~ 7 km of river). It is likely that this additional sampling uncovered pools not previously sampled but with high species abundances. In addition, sampling here was continuous (e.g. downstream to upstream) and incorporated block nets. Therefore, unlike previous sampling using electrofishing that has a known fright response (Reynolds, 1996; Poos *et al*., 2007), fish movement was restricted into and out of the study pools. Also the sampling method used was considered non-selective. Seine mesh-size may limit the

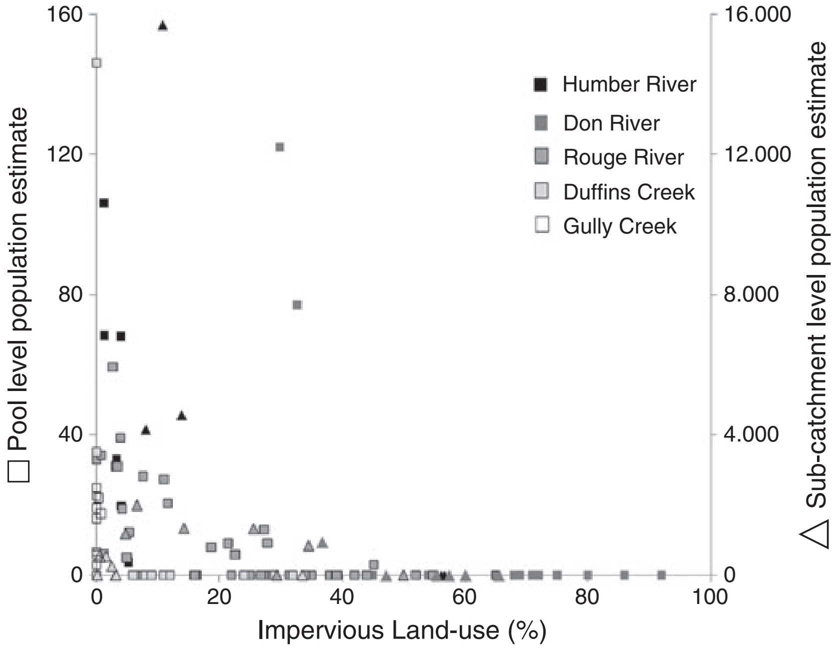


Figure 4. Population estimates for redside dace (*Clinostomus elongatus*) at the pool (□) and sub-catchment (Δ) scale in relation to adjacent impervious land-cover. Relationships between impervious land-use and population size were highly significant at both the pool ($R^2 = 0.86$, $P = 0.01$) and sub-catchment level ($R^2 = 0.86$, $P = 0.003$). Population estimates are colour-coded for each catchment. Note: Land use was quantified as percentage impervious land cover (e.g. roads, residential and industrial) using the Southern Ontario Land Resource Information System (SOLRIS) version 1.2 (OMNR, 2008) found within a 1 km buffer at individual pools (i.e. adjacent land-use), or as the amount of impervious land-cover within a given sub-catchment, and each was extracted using Geographic Information Systems (e.g. ArcView v.9.1). Sub-catchment population estimates were extrapolated using median reach density estimates considering 50% reductions at non-optimal habitats (mean scenario identified in Table 2). Model 2 (i.e. ranged major axes) regressions were fitted using the pool-level and extrapolated sub-catchment population estimates using the lmodel2 library (Legendre, 2011) in R v.2.8 programming language (R Development Team, 2009).

 

capture of younger redside dace (e.g. juveniles < 30 mm may escape through the mesh); however, in general, seining is less size-selective than other active fish sampling methods, such as electrofishing (Reynolds, 1996). In particular, given the high detection probabilities and low mortality rates, it appears that seining rather than electrofishing may be the preferred method of capturing redside dace. Overall, these methodological advancements may not have been trivial. For example, in a survey by OMNR of the Humber River in 1972, one survey team found the species at only two locations while a second team found it to be widespread throughout the catchment (Wainio and Hester, 1973). The differences in rate of redside dace occurrence were attributed to differences in sampling methods (electrofishing versus seining), sampling effort and crew experience; thereby emphasizing the intrinsic variability associated with previous sampling approaches for redside dace.

Quantifying accurate population estimates for endangered species remains an important aspect of species protection and recovery. The population estimates from this study suggest, as others have noted, that redside dace may be yet another Laurentian Great Lakes species moving toward extinction (McKee and Parker, 1982). Immediate recovery actions that will help eliminate chronic and episodic impacts of land-use alteration, and maintain population connectivity, will help ensure that redside dace remains a species at risk of – rather than facing – extinction.

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