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Silver Shiner (Notropis photogenis) Size-Class Structure, Habitat Utilization, Movement and Persistence in an Urbanized Fragment of a Great Lakes Tributary

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Abstract.—Silver Shiners (*Notropis photogenis*) were monitored with underwater videography, captured and measured, and their habitat was characterized from 38 locations in an urbanized fragment of the Grand River, Ontario, from 2006 to 2015. Cobble was the most frequently used substrate type (44.6% of observations) in heterogeneous transitional habitat near backwater pools and areas adjacent to deep runs. Population size structure and qualitative growth patterns suggested rapid growth during the first 2 y after hatching (n = 439). The largest fish captured was 143 mm total length, which is a new Canadian record and tied the world record from Tennessee. Spawning was not directly observed, but gamete evidence suggested it took place from early to mid-June when the water temperature was approximately 24 C. Underwater video monitoring revealed schools of Silver Shiners migrating upstream during late afternoon and evening in October/November presumably to overwintering areas. Silver Shiners were located near known sources of groundwater seepage in 92% of observations. This association requires further investigation to determine if groundwater represents critical habitat that facilitates persistence of Silver Shiner populations in urbanized rivers with notoriously poor water quality.

Introduction

Three decades have passed since the last targeted study of the Silver Shiner (*Notropis photogenis*) in Canada (Baldwin, 1983). Recent sampling to map the distribution of the Silver Shiner, showed small increases in their range and possible decreases in abundance according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2011). Limiting factors include poor water quality, habitat loss, and degradation; however, they continue to persist in highly urbanized areas. There is very little information available on habitat preferences and general life history information especially with regard to reproduction. Growth rates appear to be rapid during the first year (Parker and McKee, 1984) and maximum recorded length is 143 mm total length (TL) (COSEWIC, 2011). The oldest known age is 3 y; recent research suggests it could be much older (COSEWIC, 2011).

The Silver Shiner may be difficult to accurately identify, and this may partially explain the lack of data, as well as perceived declines in abundance in areas where this species historically occurred. In the United States, the Silver Shiner occurs primarily in the Ohio River Basin, excluding the Western Lowlands, and in the upper Tennessee River watershed (Gilbert, 1980; COSEWIC, 2011). It is also found in Georgia, Alabama, Kentucky, Indiana, Michigan, New York, Pennsylvania, West Virginia, Virginia, and North Carolina (Gilbert, 1980; COSEWIC, 2011). The Canadian distribution includes Lake Erie, Lake St. Clair, and Lake Ontario drainages where this species occurs in the Grand River, Conestogo River, Nith River, Sixteen Mile Creek, Bronte Creek and the Thames River. The area of occupancy (estimated river km) in Canada is 19.3 km^2 (COSEWIC, 2011). Canadian populations are

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likely distinct from United States populations due to unsuitable habitat separating them (Gruchy *et al.*, 1973; Parker and McKee, 1980).

Silver Shiners were first documented in Canada in 1971 (Gruchy *et al.*, 1973), but a re-examination of collection records identified this species from three Ontario watersheds as early as 1936 (COSEWIC, 2011). Canadian populations are at the northern extent of their range and comprise only 2% of the global distribution (COSEWIC, 2011). In April 1983 COSEWIC designated the Silver Shiner as a species of "Special Concern" (Schedule 3). This status was re-examined and confirmed in April 1987. In May 2011 the status was revised from "Special Concern" to "Threatened" due to the small area of occupancy, as well as collection records for this species from only 10 locations (COSEWIC, 2011). In 2013 the recovery potential for the Silver Shiner in Canada was assessed and several sources of uncertainty were identified, including preferred habitat, life history characteristics related to reproduction, growth, age and environmental or biological factors limiting their persistence (Department of Fisheries and Oceans Canada, 2013).

Research conducted several decades ago indicated the Silver Shiner was generally rare or absent in smaller tributaries (Parker and McKee, 1980), but occurred in medium to large streams with moderate-fast current (Gilbert, 1980; Gruchy *et al.*, 1973; Trautman, 1957). Most streams that support the Silver Shiner have alternating pool-riffle-run sequences and most are wider than 30 m. Based on previous habitat studies, suitable substrate consists of pebble and cobble, with some boulders, gravel, sand, silt, mud and clay (Parker and McKee, 1980; Baldwin, 1983). The Silver Shiner has also been found over uniform concrete aprons below dams (Parker and McKee, 1984). There appears to be no correlation between macrophytes, especially those that are rooted, and Silver Shiner presence (Baldwin, 1983). Deep (>1 m) flowing riffles or runs are suspected spawning sites (Parker and McKee, 1984) although spawning has never been observed or described. There is also the potential for Silver Shiners to occupy areas of groundwater upwelling and seepage, similar to Brook Trout (Biro, 1998; Baird and Krueger, 2003), Lake Trout (Snucins and Gunn, 1995), Rainbow Trout (Ebersole *et al.*, 2001), and Black Redhorse (Bunt *et al.*, 2013).

This study aims to fill contemporary knowledge gaps essential for improved ecological understanding and conservation of the Silver Shiner in Canada, with the following objectives: (1) develop a length (L) - weight (W) regression and examine size-class structure of this species at the northernmost extent of its range; (2) characterize and describe habitat utilization and explore potential linkages with groundwater, as described for other species of fish that occupy similar areas with notoriously poor water quality in the Grand River, Ontario (Bunt *et al.*, 2013); (3) document and describe movement and behaviour in the early summer and during habitat shifts to overwintering sites in late autumn; and (4) attempt to observe and record spawning in order to describe habitat essential for Silver Shiner reproduction. Collectively, this information will aid in the protection and recovery of the Silver Shiner, and will provide useful information to facilitate the creation of a Government Response Statement and/or Recovery Strategy for this threatened Canadian species.

METHODS

STUDY AREA

Collection of Silver Shiners, habitat surveys and underwater observations occurred from April to November in the Grand River near Kitchener, Ontario, Canada, over a distance of approximately 10.5 river km from 2006 to 2015 (Fig. 1). The study reach extended upstream of the Mannheim Weir (43°24′8"N, 80°25′2"W), which has two Denil fishways that are known

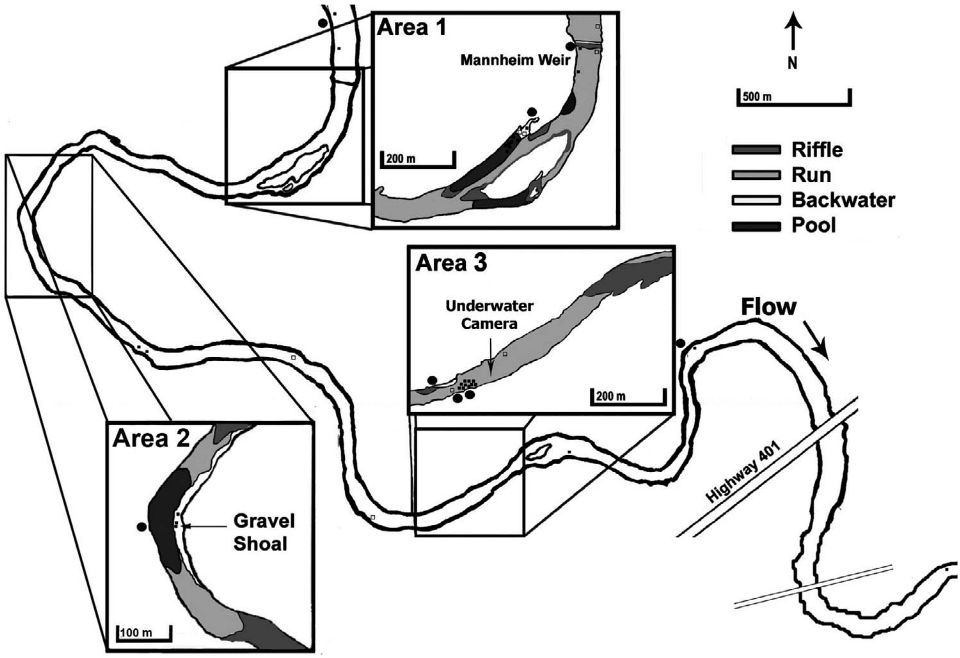

FIG. 1.—Sampling sites for the Silver Shiner in the Grand River, Kitchener, Ontario, Canada from 2013 to 2015. Capture locations are indicated with solid black circles; known locations of groundwater upwelling and seepage are indicated by large open circles; and survey locations with no Silver Shiners are shown with black diamonds

to pass cyprinids and are described in detail in Bunt *et al.* (2001), to the downstream limit of the study area (43°23′14"N, 80°22′35"W).

STUDY SPECIES

In terms of morphological characteristics, the Silver Shiner is a small and slender bright silver fish with olive to dark grey coloration dorsally. Fish in spawning condition may have red pigmentation on the head (Parker and McKee, 1984) and males develop tubercles. They have more than eight (usually nine) anal fin rays, and 36–43 lateral line scales (COSEWIC, 2011). This species is easily confused with congeneric and occasionally syntopic Emerald Shiners (*N. atherinoides*) and Rosyface Shiners (*N. rubellus*). However, both of these species do not attain the size of the adult Silver Shiner. The dorsal fin of the Silver Shiner is positioned almost directly above the pelvic fins, unlike the Rosyface Shiner and the Emerald Shiner (Scott and Crossman, 1973). Furthermore, the Silver Shiner has distinct pigmented crescents between the nares and a well-defined dark or orange dorsal stripe. It has large eyes and a large mouth and it feeds on insects and other invertebrates in the upper part of the water column, or at the surface.

Silver Shiners were collected from 2013 to 2015 using beach seines (0.5 cm mesh, 15 m long × 1.5 m high), dipnets (25 cm × 19 cm, <1 mm mesh), and framed mesh screen (used to corral Silver Shiners and then capture them by rapidly lifting the screen out of the water).

In addition Silver Shiners were caught incidentally using a Smith-Root 5.0 GPP boat electrofisher at two locations in 2014. Survey sites included areas where Silver Shiners were both present and absent.

HABITAT CHARACTERIZATION

Sampling sites (N = 38) were areas occupied by at least one Silver Shiner (*i.e.*, actively captured or visually observed) and where data for at least one habitat characteristic were recorded. Measured habitat characteristics included distance from bank-full shoreline (m), water depth (m), water velocity (m/s, recorded at the surface, 60% below the surface, and 10 cm above the river bed), water temperature (C), and discharge (m^3/s). Water velocities were measured with a Sigma PVM ultrasonic velocity meter. Discharge data were from the Environment Canada water quality monitoring station in the Grand River located mid-way along the study site. General river habitat was visually identified and categorized as run, riffle, pool, or backwater. Habitat quadrats (25 cm × 25 cm) were used to characterize substrate type, which was classified using a modified Wentworth scale (Cummins, 1962) and macrophyte abundance (percentage cover). Other recorded data included fish and macrophyte species associations and nearest available cover type. Distinct localized changes in water temperature were used to identify potential locations where there was an influx of groundwater. Further indicators of groundwater seepage in the study area are described in Bunt *et al.* (2013). Global Positioning System coordinates of each site were recorded for mapping purposes, and satellite imagery was used to identify specific areas where the Silver Shiner was collected.

Underwater videography and motion triggering algorithms were used to record Silver Shiners with a cabled underwater video monitoring system (BRAVO™ Underwater Fish Monitoring System, Biotactic Incorporated, Kitchener, Ontario, Canada). This fixed system was deployed in habitat that appeared suitable for Silver Shiners (continuously over 8 y). The camera was equipped with an infrared LED array to facilitate unobtrusive data collection of nocturnal behaviour and movement patterns. A portable GO-PRO™ camera was also temporarily used in areas where Silver Shiners were visually located. Videos of Silver Shiners were serendipitously collected and archived from 2006 to 2013 from the Biotactic BRAVO system. Observations from archived underwater video were carefully reviewed and transcribed to produce a data set that included habitat characterization (excluding water velocity), as well as relevant times/dates, fish abundance, species associations and behaviour.

Specimens that were incidentally killed during netting were retained as vouchers and preserved in 10% buffered formalin or ethanol. These fish were measured (±0.1 mm) and weighed (±0.01 g) using a digital scale (Infyniti 2P-100). Additional length and weight data were collected from live specimens in the field. To minimize stress live specimens were weighed in water. Polynomial regression analysis using a power function for length and weight data was performed in Microsoft Excel.

RESULTS

LENGTH-WEIGHT REGRESSION AND SIZE-CLASS STRUCTURE

The mean total length of Silver Shiners was 66.33 ± 1.45 mm (range 26–143 mm) and mean weight was 3.03 ± 0.21 g (range 0.14–22.70 g). A standard L-W regression was calculated as $W=1E\text{-}05 \times L^{2.9107}$ (r^2=0.97, n=390, Fig. 2). Size class-structure was based on total length of 439 fish (390 with length and weight plus 49 with only length). Modalities were not discernable (Fig. 3). There is a conspicuous gap in the L-W data from

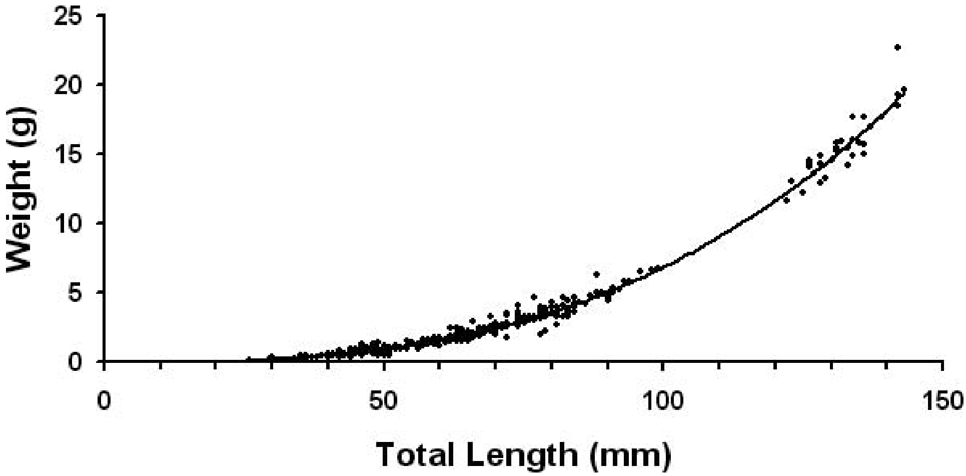

FIG. 2.—Standard length-weight regression for *Notropis photogenis* ($W = 1E\text{-}05 \times L^{2.9107}$, $r^2 = 0.97$, $n = 390$) from the Grand River, Ontario

approximately 100 mm to 120 mm TL. On September 28 and September 29, 2015, schools of large adult Silver Shiners (thousands estimated) migrated upstream to the base of the low-head weir at the upper reach of the study area. Most of the largest fish (>120 mm) in Fig. 3 were captured during this period, including numerous fish larger than 138 mm TL (previous Canadian record), and one 143 mm TL individual (tied the current world record).

HABITAT CHARACTERIZATION

Silver Shiners most commonly occupied areas near the edges of gravel shoals particularly during early July (Fig. 1, Area 2), as well as backwater pools, or areas adjacent to runs and deep runs. They were often found in transitional habitat (*i.e.*, along current breaks, or areas where habitat features such as turbidity, temperature, water velocity, and depth were heterogeneous). They were most frequently found over substrates consisting of cobble (44.6% of observations), followed by gravel (22.8%), pebble (13.2%), silt (10.9%) and sand (7.4%). Boulders were also used (1.1%); however, this number may be underestimated because the small quadrat was generally inappropriate for quantifying boulder habitat. Boulders were present within 2–3 m in 16 of the 38 locations sampled. In

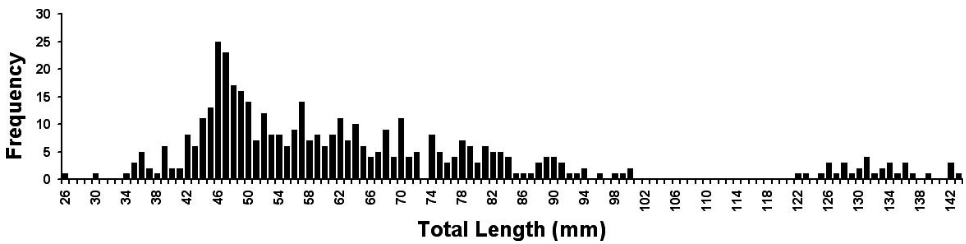

FIG. 3.—Length-frequency distribution of Silver Shiners ($n = 439$) collected from 2013 to 2015 in the Grand River

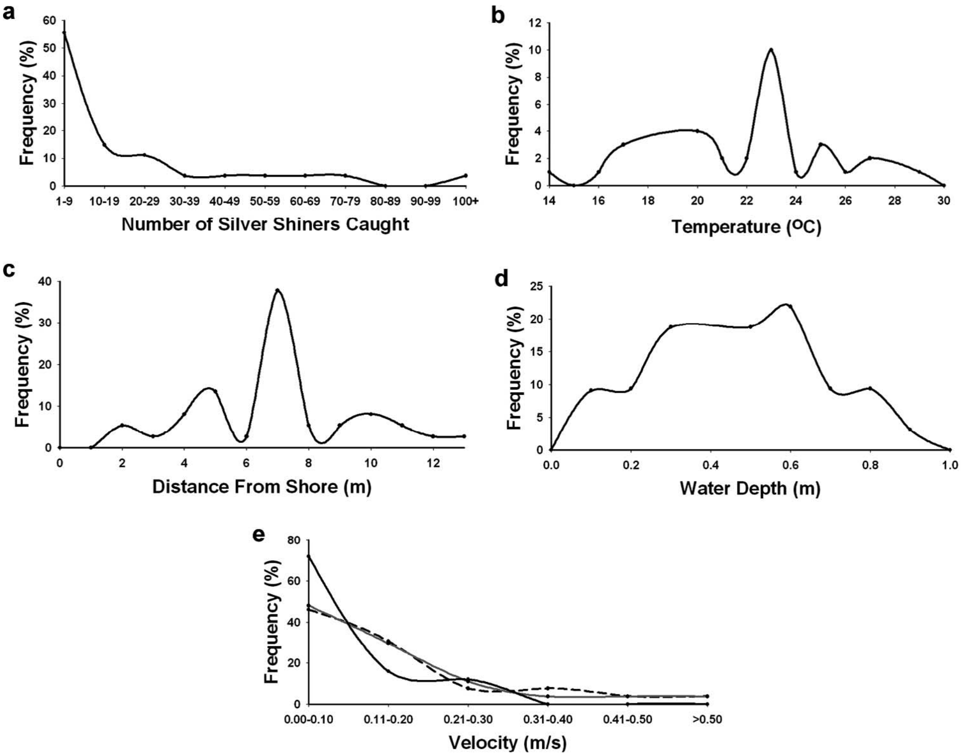

FIG. 4.—Capture frequency and habitat utilization curves for Silver Shiners from the Grand River from 2013 and 2015 showing **(A)** relative abundance at sampling sites where fish were collected, **(B)** temperature plot from sample sites, **(C)** distance from bank-full shoreline, **(D)** water depth, **(E)** water velocity with the solid black line indicating surface velocity, dashed line indicating velocity at 0.6 x depth, and the solid grey line showing velocity 10 cm above the river bed.

general boulder habitat may have been under-sampled because collecting Silver Shiners with a seine in this habitat is impractical. The Silver Shiner was not observed near any habitat containing clay substrate. Habitat characteristics in locations where various numbers of the Silver Shiner were caught (Fig. 4A) showed temperatures ranging from 14 - 29 C, with a mean of 23 C (Fig. 4B). Occupied habitat was 7.00 m ± 0.05 m (mean ± standard error, Fig. 4C) from the closest bank-full location, with a mean depth of 0.50 m ± 0.04 m (Fig. 4D), and mean water velocity of 0.12 m/s ± 0.02 m/s (Fig. 4E) midway in the water column where most fish were located, except during foraging-related excursions to the surface. Mean annual discharge was 43.7 m^3/s in 2013, 38.2 m^3/s in 2014, and 20.9 m^3/s in 2015. Known sources of groundwater seepage and/or upwelling were common throughout the study area (Fig. 1) and the Silver Shiner was closely associated with them (*i.e.*, located within 100 m) during 92% of observations. Most areas containing the Silver Shiner did not include any macrophytes, but those that did had very sparse amounts, including Sago Pondweed (*Stuckenia pectinata*),Water Milfoil (*Myriophyllum* spp.), *Cladophora* spp., and other filamentous algae.

TABLE 1.—Summary of 46 archived underwater video events of the Silver Shiner recorded within a 1 m^2 area in the Grand River from 2006 to 2013

Month	No. of events	Time range	No. individuals	Mean temperature (C)	Mean discharge (m^3/s)
April	1	16:28–16:30	18	7.0	10.3
May	–	–	–	15.2	28.6
June	6	14:59–20:51	44	19.1	15.5
July	–	–	–	23.9	17.1
August	6	12:45–19:10	22	22.9	14.4
September	6	15:58–18:51	14	14.4	11.3
October	19	10:00–17:56	24	12.0	15.3
November	18	00:34–17:55	28	6.9	13.4

BEHAVIOUR AND MOVEMENT

Video data from the fixed recording system revealed 46 separate events of archived Silver Shiner footage from 2006 to 2013 (Table 1; Fig. 5). Substrate at the camera location was approximately 85% cobble and 15% finer material (pebbles, gravel, and sand) and the mean depth was 0.6 m during low summer flow conditions (approx. 11 m^3/s). Silver Shiners actively moved and foraged in groups of five to over 200 individuals. Based on videographic observations they actively avoided predation by Smallmouth Bass (*Micropterus dolomieu*), and were associated with Rock Bass (*Ambloplites rupestris*), Pumpkinseed (*Lepomis gibbosus*), and Common Shiners (*Luxilus cornutus*). October was the most common month that Silver Shiners were recorded and during this time they migrated in groups, presumably to over-wintering habitat upstream from the fixed underwater fish monitoring system. These were the final observations each year until the following spring.

The Silver Shiner was not directly observed using the fishways at the Mannheim weir during field work from 2013 to 2015. However, they have been collected in fishway traps at the exit of the Mannheim Weir Denil fishways in previous years (Bunt, unpubl.). In October 2014 numerous specimens were collected using a dip-net near the fishway entrances and they were also sampled using electrofishing upstream from the fishways, in the impoundment created by the weir.

SPAWNING

Spawning behaviour was not observed at any time during this study. High and dangerous flow conditions precluded fulfillment of this study objective in 2013. On June 4, 2014 (water temperature = 18.9 C, discharge = 12.5 m^3/s), ripe males and gravid females that freely expressed milt and eggs were captured using a beach seine in backwater habitat in Area 1 (Fig. 1). On June 13, 2014 (water temperature = 23.8 C, discharge = 13.0 m^3/s), Silver Shiners did not freely express gametes and were no longer gravid, suggesting spawning was complete. In 2015 mobile underwater cameras recorded spawning among several Cyprinid species including Rosyface Shiners and Common Shiners, but not Silver Shiners.

DISCUSSION

Silver Shiner habitat surveys in the Grand River watershed were consistent with previous studies conducted in Canada and the United States. Results indicated this species occupies relatively clear areas with access to drifting prey items, and utilizes deeper water with nearby boulders as cover from aquatic and avian predators. Trautman (1981) also noted the Silver Shiner was abundant in deep riffles and eddies in pools downstream from riffles. Gruchy *et al.* (1973) documented the Silver Shiner in medium to fast current and deep riffles and runs. Baldwin (1983) noted adults were most common in flowing pools and along current edges and were rarely found in riffles. The current study showed 0+ Silver Shiner occupied the edges of gravel shoals with slower currents and warmer temperatures (particularly during July), and larger fish occupied transition areas with heterogeneous, patchy habitat within backwater pools, runs and deep runs with cobble substrate often near areas influenced by groundwater seepage. Consistent associations between Silver Shiner and the presence of groundwater, across a wide range of temperature suggests that behavioural thermal regulation may not fully explain the dynamics of this interaction. Groundwater seepages and upwelling in the Grand River appear to be critical habitat features for Silver Shiner populations.

Parker and McKee (1980) reported catches of 37 Silver Shiners per 100 m^2 in 1979 in watersheds of the Grand and Thames River. However, it is unclear if the data were from areas that contained suitable habitat, or if these catch rates were consistent throughout the watersheds. This latter scenario is doubtful. Silver Shiners were common in suitable habitat in the urbanized fragment of the Grand River that was the focus of this study. From July to September, they were caught in abundance at nearly every location that was sampled. Based on videographic evidence, over 200 Silver Shiners were observed in a 1 m^2 area over a 5 h period (Table 1).

There are no data on relative abundance of various age classes or sex ratios. Most Silver Shiners mature in their second summer; fish >60 mm SL are mature and most spawn at age two (Parker and McKee, 1980). Young-of-the-year (0+) can be distinguished by length from adults in July and most of August, but near the end of August distinctions are less obvious (young-of-year 16–30 mm SL, adults 51–78 mm SL, Baldwin (1983)). Most schools contain fish of all length classes (Parker and McKee, 1980), but Baldwin (1983) also found some differences in habitat usage between young-of-the-year and adults. Data from the Grand River indicates size segregation, especially in late September, when large adults migrated to the base of a low-head weir at the upper reach of the study area.

Silver Shiner total lengths ranged from 26 to 143 mm with a conspicuous gap comprising 18% of the total distribution of data between 101 mm and 121 mm. All individuals in the dataset >122 mm TL were the large adults that migrated upstream to the weir in late September. Reasons for the gap are unknown but may be related to rapid growth towards the end of the summer, habitat partitioning among size classes, or size/age differences in behavior that affect capture. If the Silver Shiner, like other cyprinids, spawns over a period of several weeks, age-0 fish may have several size modes and histogram analysis may not a reliable method for estimating ages. However, there is no evidence that Silver Shiners spawn over a protracted period. Furthermore, sample sizes may not have been sufficient to accurately detect age-class modalities. Age validation (length at age, by chemically marking otolith annuli) is required to verify this.

Although spawning was not observed in the Grand River, previous studies have inferred, based on capture of gravid, and subsequently spent individuals, that reproduction occurs in mid-June when mean water temperature is 17 C (Parker and McKee, 1980). COSEWIC (2011) suggested that spawning probably occurs between 18 and 24 C. Spawning in the Grand River likely occurred during the first two weeks of June 2014 when the water temperature was approximately 24 C. Baldwin (1983) found Silver Shiner with ripe/nearly ripe gonads throughout the month of May over 2 y in the Grand River, with surface water temperatures between 10 and 19 C. However, gonad ripening may occur in 0+ individuals (Baldwin, 1983) and may begin the year prior to spawning (August –November). Baldwin's (1983) data also suggested the Silver Shiner may move upstream to spawn, but movements are limited and specific sites may not be required (*i.e.*, they may still spawn if blocked by dams). Furthermore, spawning may occur during or after high discharge events, during periods with elevated turbidity, or at night, and in association with other shiners or chubs (COSEWIC, 2011).

Silver Shiner occupied areas immediately upstream and downstream from the low-head weir and also occupied impounded areas immediately upstream. As confirmed in the current study, the Silver Shiner was actively preyed upon by piscivores such as Smallmouth Bass [as suggested but not proven by Parker and McKee (1980)]. The most significant threats to Silver Shiner populations in Canada, however; are contaminants and toxins, increased nutrient and sediment loads, and reductions in flow or river discharge (DFO, 2013). Indeed, 76% of land surrounding the Grand River is agricultural (Cooke, 2006), and soil erosion rates are usually high in both the Grand River and Thames River (Taylor *et al.*, 2004). Long periods with elevated turbidity may impair foraging by visually oriented insectivores such as the Silver Shiner but it may also impair predator avoidance. Water quality, particularly in the section of the Grand River where the current study was conducted, is notoriously poor, particularly during warm summer months (Cooke, 2006). Turbidity and water clarity (based on underwater camera records) varied considerably and it was rare for the river to remain turbid for more than a week after significant rain or run-off.

Groundwater seepages in sections of the Grand River might facilitate persistence of populations of the Black Redhorse (*Moxostoma duquesnei*)—a species that is sensitive to poor water quality (Bunt *et al.*, 2013). On several occasions, the Silver Shiner was captured in association with juvenile and adult Black Redhorse in areas where there are known groundwater seepages. By increasing oxygen solubility or diluting run-off and pollution [*e.g.*, ammonia, personal care products, pharmaceuticals, artificial sweeteners (Spoelstra *et al.*, 2013), and/or other contaminants from wastewater treatment effluent (Gillis *et al.*, 2013)], groundwater seepage provides refuge that sensitive species may utilize during periods of excessively poor water quality. The Silver Shiner was frequently associated with known sources of groundwater in the Grand River. However, this association may simply be the result of their propensity to occupy transitional habitat with heterogeneous features including but not limited to temperature. Alternatively, Silver Shiners may be much more tolerant of poor water quality from both rural and urban run-off than previously thought. However, it is likely groundwater influx may also be providing refuge for pollution intolerant species. This is supported by data from some of the largest specimens of Silver Shiners ever recorded as well as their record of persistence, especially in highly urbanized sections of the Grand River (as well as Thames River and Bronte Creek).

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