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Habitat utilization, movement and use of groundwater seepages by larval and juvenile Black Redhorse, *Moxostoma duquesnei*

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Abstract Black Redhorse (*Moxostoma duquesnei*) larval and juvenile habitat was characterized in the Grand River, Ontario from June to September 2007–2012. Similar to adult Black Redhorse and their congeners, larval Black Redhorse were most likely to be located in clean, clear, stable runs with low to moderate flow, over pebble, gravel and cobble substrate, mixed with sand. Areas (n=22) where 0+ Black Redhorse were observed and collected were 1.4±0.2 m from shore, with a mean water temperature of 22.0±0.5 °C, mean depth of 0.20±0.02 m and mean water velocity of 0.12±0.05 m/s. Larval and juvenile Black Redhorse occupied riffles, runs, pools and backwater areas; however, there was a strong preference for runs. Juvenile Black Redhorse moved upstream in the early evening and at night to overwintering areas in the Grand River in November when water temperature approached 5 °C. The persistence of Black Redhorse populations in the Grand River may be related to the presence of groundwater, which provides refuge from extreme temperature and poor water quality during the summer.

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Introduction

Black Redhorse (*Moxostoma duquesnei*) constitute one of seven congeneric species within the Catostomidae in Canada. They are medium-bodied, long-lived, potamodromous and iteroparous freshwater fish, that can be distinguished as adults from other members of this family by differences in tail colour, lip morphology, dorsal fin shape and lateral line scale count. Distribution of Black Redhorse is wide, but fragmented throughout Eastern North America particularly in parts of the Great Lakes region, the Mississippi River as well as some surrounding drainages and tributaries. Very little is known about population trends, early life history and seasonal habitat preferences due to a lack of commercial interest and difficulty associated with accurate identification throughout different life stages due to morphological similarities with more common congeneric species such as Golden Redhorse (*M. erythrurum*) without substantial training and experience. Ironically, lack of exploitation has partially contributed to the imperiled status of Black Redhorse, and ignorance and misconceptions have resulted in limited protection efforts (Cooke et al. 2005).

In 2005, the Committee on the Status of Endangered Wildlife in Canada listed Black Redhorse as a threatened species due to restricted spawning habitat preferences

(Kwak and Skelly 1992) and small, fragmented distribution in parts of seven highly urbanized watersheds in Southwestern Ontario (Reid 2006). In Ontario, Black Redhorse are located at the northernmost extent of the species' geographic range, and is only known to be widespread in the Grand River and Thames River. Small Black Redhorse populations have also been found in the Maitland River, Ausauble River, Bayfield Creek and Spencer Creek; they have been extirpated from Catfish Creek (COSEWIC 2005).

Earlier studies suggested that poor habitat conditions are considered the primary threat to Black Redhorse (Vélez-Espino and Koops 2009). Adult Black Redhorse do not tolerate habitat degradation, river fragmentation, pollution, turbidity or siltation well (Bowman 1970; Cooke et al. 2005; Reid 2006, 2009; Reid et al. 2008). Contrary to this theory, Black Redhorse populations are widespread in a fragmented section of the Grand River which is susceptible to sources of anthropogenic pollution such as phosphorus and nitrogen from agricultural activity, urban runoff, private waste disposal and sodium chloride from transportation corridors (Ostry 2007). Dissolved oxygen concentrations, salinity, pH levels and temperatures in the Grand River are known to approach lethal levels for other *Moxostoma* species. Therefore, the persistence of Black Redhorse in the Grand River may be facilitated by a source of refuge from poor water quality and temperature conditions, such as groundwater upwelling in pools and along the banks of the river.

Extensive literature exists related to the use of groundwater influxes as thermal refugia for salmonids in summer conditions (Snucins and Gunn 1995; Biro 1998; Ebersole et al. 2001; Baird and Krueger 2003). Labbe and Fausch (2000) suggested that more work must be conducted on the use of groundwater as thermal refuge for temperate and warmwater non-salmonid species. This study was designed to characterize the types of habitats used by Black Redhorse prior to overwintering movements following the first 2 years of life after hatching.

Study area

Field work was conducted in a highly urbanized section of the Grand River in Kitchener, Ontario, located between Freeport (547319E 4806803N), and Highway 401 (550738E 4805233N, Fig. 1) to characterize habitat utilization and availability.

During the summer months the river is approximately 20–40 m wide and <1 m deep in most places, with many riffle, pool and run sequences. The river is relatively stable, with generally low to moderate flow. Summer low flow is approximately 11 m^3/s throughout the study area; high water flow events usually coincide with heavy precipitation. Riparian vegetation on both sides of the river reduces erosion and there is very little benthic submerged vegetation beyond some *Cladophora spp.*, *Myriophyllum spicatum* and *Potomogeton pectinatus*. Benthic substrate consists of a heterogenous composition of pebble, gravel and cobble, mixed with varying amounts of sand and silt in backwater habitats and closer to the banks of the river.

Materials and methods

Habitat characterization

A combination of standard field measurements, sample collection, visual observations, and underwater videography were used to characterize the habitat and movement of 0+ Black Redhorse after hatching from spawning riffles. Between 2007 and 2012, site locations were characterized and backpack electrofishing (Smith-Root Model LR-20), D-shaped kicknets (30 cm×30 cm, 3 mm mesh size), dip nets (25×19 cm, < 1 mm mesh size) and beach seines (0.5 cm mesh, 15 m long) were used to collect fish in summer and early fall. Voucher specimens were preserved in a 10 % solution of buffered formalin. Black Redhorse were visually identified in the field and later verified using meristic and morphometric characters (Kay et al. 1994; Bunt et al. 2013) to ensure that habitat characterizations were conducted in areas occupied by Black Redhorse.

In areas where specimens were observed and collected, the shortest distance to shore (m), water depth (cm), water temperature (°C) and water velocity (m/s) was recorded. Mean and standard error for these measurements was calculated for every site where at least one Black Redhorse was found. Distance from shore and depth was measured using a pole gauge accurate to 0.5 cm and flow was measured using an ultrasonic velocity meter accurate to 0.1 m/s. Habitat quadrats (0.25 m×0.25 m) were characterized by visual inspection, and substrate type was classified according to a modified Wentworth scale (Cummins 1962). Areas of groundwater upwelling detected with a thermometer,

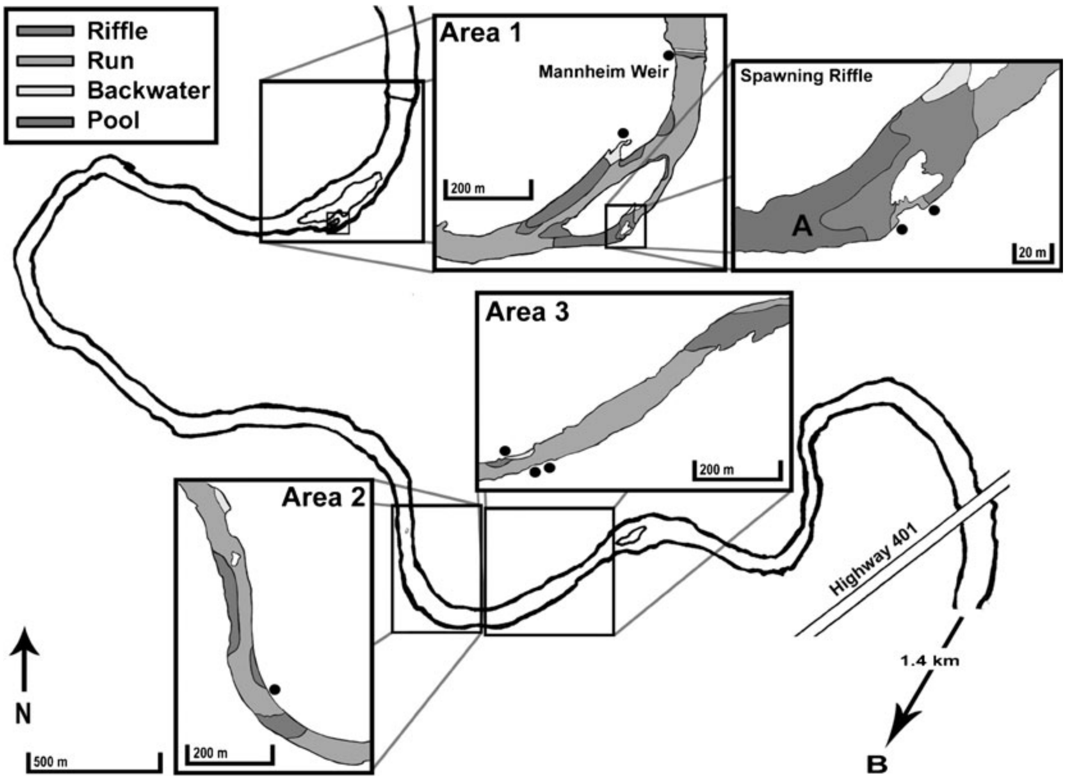

Fig. 1 Sampling sites for larval and juvenile Black Redhorse in the Grand River. Known locations of groundwater upwelling or groundwater inflow are indicated with *black dots*. Locations of adult over-wintering habitat and the GRCA water monitoring station in Blair are indicated by the letters A and B, respectively

were recorded and substrate use was calculated as a percentage of the frequency of total observations. Seasonal patterns related to conductivity, pH and water temperature were obtained from the Grand River Conservation Authority (GRCA) water quality monitoring station at Blair, located 1.4 km downstream of HWY 401 (Fig. 1).

Satellite images of the study areas from 2005, with a resolution of 3 m per pixel were obtained and river sections were categorized as riffle, run, pool and backwater habitat. These habitat designations were verified during data collection in the field. Areas of each habitat category were calculated using the computer program GE Path v 1.4.6. Differences between habitat utilization and habitat availability were examined using a log-likelihood ratio test (Zar 1984). Habitat utilization (%) was divided by habitat availability in areas where Black Redhorse were observed to determine habitat preferences. These values were standardized by dividing by the highest habitat preference value to create a habitat selection curve.

Juvenile Back Redhorse movement was recorded using motion-triggered underwater videography. A stationary underwater fish monitoring system (BRAVO Underwater Fish Monitoring System, Biotactic Incorporated, Kitchener, Ontario, Canada) was deployed near areas where Black Redhorse were located each summer. Algorithms were used to filter lack of fish activity prior to manual screening that was used to identify and summarize juvenile Black Redhorse movement data.

Results

Habitat characterization

Areas where larval Black Redhorse were collected were similar in habitat composition with flowing water, but usually at low velocities near the river banks, in riffles, runs and small pools (Fig. 1). Substrate was occasionally covered with periphytic algae, with other vegetation on the river banks and overhanging shade from trees, which stabilized the banks and provided cover.

From 22 sample sites where at least one larval Black Redhorse was found between June and September, the most common substrate was sand with some quantity present in 35.7 % of observations. The next most common substrates were cobble and gravel, which were found in 26.2 % and 21.4 % of observations, respectively, followed by 9.5 % in silt, 4.8 % in pebble and 2.4 % in clay. Some areas with boulders were present in the river, but no larval Redhorse were found near this substrate type. Areas occupied by Black Redhorse were 1.4 ±0.2 m from shore, with a mean water temperature of 22.0±0.5 °C, mean depth of 0.2±0.02 m and a mean water velocity of 0.1±0.05 m/s.

River runs were the most common general habitat type available in all sampling areas, making up 72.4 % of the total river surface area, followed by riffle and pool habitat, which comprised 18.8 % and 6.8 % of the total surface area, respectively (Table 1). Locations of the spawning area, area 1, area 2, and area 3 are shown in Fig. 1. Backwater habitat was the least common general habitat type comprising 2.0 % of the total river surface area. By comparison, larval Black Redhorse occupied runs in 40.9 % of observations. They occupied both riffles and pools in 22.7 % of observations and backwater areas in 13.6 % of observations (Table 1, Fig. 2). Habitat utilization was not used in proportion to availability ($G=15.23$, $0.001<p<0.005$).

On November 8, 2007 a school of at least seven juvenile Black Redhorse was recorded with underwater video moving upstream presumably to overwintering areas. These movements occurred during darkness in the early evening (17:00–18:00) mid river when the water temperature was 5 °C. Stream bank areas (within 2 m of the river bank) were typically occupied earlier in the year. This video is available online at http://www.biotactic.com/bravo/archive/Nov082007redhorse.wmv. During underwater video monitoring and field observations, juvenile Black Redhorse were observed to freely associate with other fishes such as White Sucker (*Catostomus commersoni*), Smallmouth Bass (*Micropterus dolomieu*), Greenside Darter (*Etheostoma blennioides*), Greater Redhorse (*M. valenciennesi*), Northern Hog Sucker (*Hypentelium nigricans*), Blacknose Dace (*Rhinichthys atratulus*) and Common Shiner (*Notropis cornutus*). Beach seining in the backwater habitat identified in area 1 (Fig. 1) between August and September 2012 produced 26 juvenile Black Redhorse (size range 62–112 mm TL) near the river bank with mean depth approximately 0.5 m, sediment substrate and in association with the species listed above plus Black Crappie (*Pomoxis nigromaculatus*), Common Carp (*Cyprinus carpio*) and Silver Shiner (*Notropis photogenis*).

Groundwater upwelling and/or seepage was observed along the river banks at several locations within the general study area (Fig. 1). On August 20 2009, groundwater was detected flowing into the river near the site most commonly and consistently occupied by juvenile Black Redhorse (Fig. 1). Groundwater temperature was approximately 11 °C and the river temperature was 21 °C. Hundreds of juvenile Black Redhorse were observed approximately 30 m downstream from the area where groundwater flows were located during the day (Fig. 1, Area 3, north shore). Juvenile (0+) Smallmouth Bass occupied locations approximately 10 m downstream from the groundwater inflow during the day. At night, juvenile Black Redhorse occupied areas with very little flow and were easy to illuminate with flashlights and capture

Table 1 Area of each general habitat type throughout the study area

Water type	Spawning area		Area 1		Area 2		Area 3		Total availability		Total use (%)	n
	Proportion (%)	Area (m^2)	Proportion (%)	Area (m^2)	Proportion (%)	Area (m^2)	Proportion (%)	Area (m^2)	Proportion (%)	Area (m^2)		
All water	100.0 %	5171	100.0 %	85598	100.0 %	43712	100.0 %	50803	100.0 %	180113	100.0 %	22
Riffle	39.8 %	2059	12.1 %	10355	22.0 %	9811	27.0 %	13717	18.8 %	33883	22.7 %	5
Run	17.8 %	920	71.7 %	61343	75.0 %	32876	71.2 %	36186	72.4 %	130405	40.9 %	9
Pool	38.2 %	1975	14.3 %	12203	0.0 %	0	0.0 %	0	6.8 %	12203	22.7 %	5
Backwater	4.2 %	217	2.0 %	1967	2.0 %	1025	1.8 %	900	2.0 %	3622	13.6 %	3

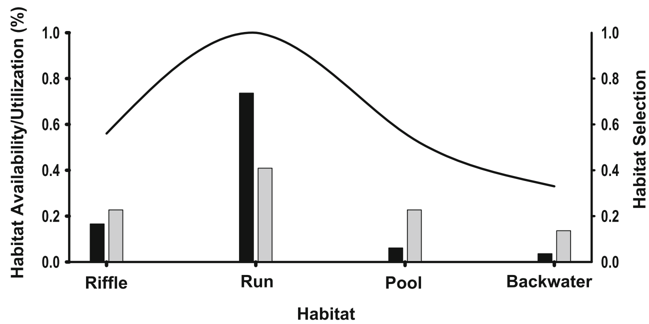

Fig. 2 General lotic habitat availability (*black bars*), larval/juvenile Black Redhorse habitat utilization (*grey bars*) and the calculated habitat selection curve

with dipnets. On August 25 2009 at approximately 23:00, 0+ and perhaps 1+ Black Redhorse (fish were not aged) were located approximately 10 m downstream from the area where groundwater flowed into the Grand River (Fig. 1, Area 3, north shore). No juvenile Smallmouth Bass were observed in this location at night. This area is relatively ice-free in winter months and also attracts waterfowl that indicate the presence of groundwater year-round. However, Black Redhorse occupy this area only during the summer months prior to overwintering movements presumably to pool-type habitat.

Discussion

Persistence of Black Redhorse in the Grand River would first appear to contradict earlier studies that suggest this species is negatively affected by degradation of habitat due to urbanization, agriculture, migration barriers, siltation and pollution compared to other catostomids (Bowman 1970; Reid 2006, 2009; Reid et al. 2008). Juvenile Black Redhorse generally occupy vegetated littoral zones 0.8–2.0 m in depth, with shallow slopes and slow currents with clean, pebble, gravel and cobble substrate of heterogenous composition, with some mixture of sand or silt, similar to both 0+ Copper Redhorse and River Redhorse (COSEWIC 2004, 2005, 2006). Both species are considered at risk for habitat loss and degradation from factors such as extreme sedimentation and loss of benthic vertebrate prey due to poor water quality. However, hydrogeological conditions within the study area (Fig. 1) result in groundwater upwelling and may create beneficial microhabitats that provide refuge from unsuitable thermal conditions (Hayashi and Rosenberry 2002) or poor water quality not only for Black Redhorse but for other species as well.

The use of groundwater seepages as coldwater refuge from high temperature conditions has been well documented, predominantly for salmonids (Snucins and Gunn 1995; Biro 1998; Ebersole et al. 2001; Baird and Krueger 2003). The upper lethal incipient temperature for adult Shorthead Redhorse (*M. macrolepidotum*) and Golden Redhorse (*M. erythrurum*) is 33.3 °C and their critical thermal maximum is 35.1 °C (Reash et al. 2000). Black Redhorse are also likely to be stressed by low dissolved oxygen levels in the Grand River (as low as 1.1 mg/L in 2005, see Table 2). Cooler groundwater when mixed with and aerated by warmer Grand River would have a higher DO saturation point and would therefore contain more oxygen than surrounding areas. Persistence of YOY Black Redhorse at groundwater seepages discovered in this habitat characterization

Table 2 Mean, minimum and maximum values for dissolved oxygen, conductivity, pH and temperature recorded downstream from Black Redhorse sampling sites from 2005 to 2009 (GRCA data)

Year	Dissolved oxygen (mg/L)			Conductivity (uS/cm)			pH			Temperature (°C)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2005	1.1	9.7	17.9	333.0	773.0	3049.0	7.5	8.2	9.3	−0.1	11.7	29.4
2006	1.4	10.1	17.9	348.0	719.0	1557.0	7.0	8.0	8.7	−0.1	11.0	30.4
2007	1.5	10.0	16.8	474.0	785.0	1622.0	7.1	8.0	9.6	0.1	12.7	29.1
2008	3.5	10.3	16.2	215.0	691.0	2068.0	7.3	8.1	8.7	0.1	11.1	28.1
2009	2.0	9.9	18.2	294.0	702.0	1465.0	7.6	8.2	8.9	0.0	10.5	27.2

study, indicate that catastomids in the study area exhibit groundwater preferences. This indicates that groundwater may offer refuge not only from temperature but more importantly from poor water quality. Therefore, groundwater may be an important modifier for river water quality which allows sensitive species, such as Black Redhorse, to inhabit degraded areas. Groundwater manipulation for the improvement of water quality has been well documented to serve as a remediation technique in highly polluted areas (Neal et al. 1997a, b, 2000). However, there is a paucity of scientific information related to the use of groundwater as a dilution factor for the remediation of poor water quality to improve fish habitat for sensitive species.

As the Grand River represents the northernmost extent of the Black Redhorse range, and populations in this area are both highly fragmented and considered threatened (COSEWIC 2005), it is critical to better understand the role that groundwater plays in the habitat preferences of this species. Furthermore, current models for allowable harm indicate that the protection of 0+ Redhorse habitat is critical for the conservation or enhancement of Black Redhorse populations (Vélez-Espino and Koops 2009). Future work with larger sample sizes, a focus on specific water quality parameters (e.g., elevated levels of ammonia) and an analysis of seasonal temperature effects would enhance our understanding of the relationship between Black Redhorse and groundwater upwelling.

In conclusion, there have been numerous studies designed to demonstrate the importance of groundwater for maintenance of riverine fishes (Biro 1998; Snucins and Gunn 1995; Ebersole et al. 2001). Most of these studies showed that fish responded to thermal tempering aspects of groundwater upwelling during warm summer months (Biro 1998; Snucins and Gunn 1995; Ebersole et al. 2001) as well as during the winter (Brown 1999). This is perhaps one of the only recent studies that suggests the importance of groundwater upwelling for species site selection for reasons other than temperature. Evidence suggests that Black Redhorse and perhaps other species utilize habitats with groundwater upwelling and springs as refuge from poor water quality due to the dilution effect of groundwater in highly urbanized riverine environments. Practical application of this research includes, but is not limited to increasing attraction and hence fish passage rates at fishways by supplementing fishway inflows with groundwater. Migratory Black Redhorse are known to use the Denil fishways at the Mannheim weir (Fig. 1, Habitat 1) to a limited extent in May and June (Bunt, unpublished). The use of groundwater may be a useful and extremely cost-effective strategy to enhance fish passage at fishways in riverine systems with poor water quality. More research is necessary to empirically test this hypothesis.

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