

## Summer microhabitat use and overlap by the invasive Round Goby (*Neogobius melanostomus*) and native darters in the Trent River (Ontario, Canada)

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**Abstract** – Understanding the impacts of the invasive Round Goby (*Neogobius melanostomus*) is important for North American native fish conservation. One proposed mechanism for native species declines is competition for habitat. In this study, summer habitat use by Round Goby and Channel Darter (*Percina copelandi*) and Logperch (*P. caprodes*) was studied in the Trent River (Canada). Spot-electrofishing and systematic habitat sampling were used to measure habitat availability and use. Suitability for all species varied across the range of habitat conditions. At Glen Ross, habitat suitability for Channel Darter and Round Goby was highest at intermediate water depths (0.2–0.6 m), lowest at high water velocities ( $> 1.0 \text{ ms}^{-1}$ ) and increased with greater amounts of gravel and cobble. There were no significant habitat differences between capture locations of the two species. At Meyer's Reach, Logperch and Round Goby habitat suitability was highest at intermediate water depths (0.4–0.6 m) and where gravel and cobble were abundant. The relationship between suitability and water velocity differed between species, with moderate velocities less suitable for Round Goby. The amount of boulder and bedrock at capture locations of each species differed. Results indicate that competition for habitat with Round Goby will vary among darter species.

**Keywords:** habitat / invasive species / competition / fishes / river

**Résumé – Utilisation et chevauchement des microhabitats d'été par le gobie à taches noires (*Neogobius melanostomus*) et les darters indigènes dans la rivière Trent (Ontario, Canada).** Comprendre les impacts du gobie à taches noires (*Neogobius melanostomus*) est important pour la conservation des poissons indigènes d'Amérique du Nord. L'un des mécanismes proposés pour le déclin des espèces indigènes est la concurrence pour l'habitat. Dans cette étude, l'utilisation de l'habitat d'été par le gobie à taches noires et deux darters indigènes, le fouille-roche gris (*Percina copelandi*) et la perche noire (*P. caprodes*) a été étudiée dans la rivière Trent (Canada). La pêche ponctuelle à l'électricité et l'échantillonnage systématique de l'habitat ont été utilisés pour mesurer la disponibilité et l'utilisation de l'habitat. La pertinence pour toutes les espèces variait selon les conditions de l'habitat. A Glen Ross, la qualité de l'habitat du fouille-roche gris et du gobie à taches noires était la plus élevée aux profondeurs intermédiaires (0,2–0,6 m), la plus faible aux vitesses élevées ( $> 1,0 \text{ ms}^{-1}$ ) et augmentait avec des quantités supérieures de gravier et de galets. Il n'y avait pas de différences importantes entre les habitats des deux espèces entre les lieux de capture. À Meyer's Reach, la qualité de l'habitat de la perche noire et du gobie à taches noires était la plus élevée aux profondeurs d'eau intermédiaires (0,4–0,6 m) et là où le gravier et les galets étaient abondants. La relation entre l'adéquation et la vitesse de l'eau différait d'une espèce à l'autre, les vitesses modérées étant moins adaptées au gobie à taches noires. La quantité de blocs rocheux et de substratum rocheux aux lieux de capture de chaque espèce différait. Les résultats indiquent que la concurrence pour l'habitat du gobie à taches noires variera selon les espèces de darter.

**Mots clés :** habitat / espèces envahissantes / compétition / poissons / rivière

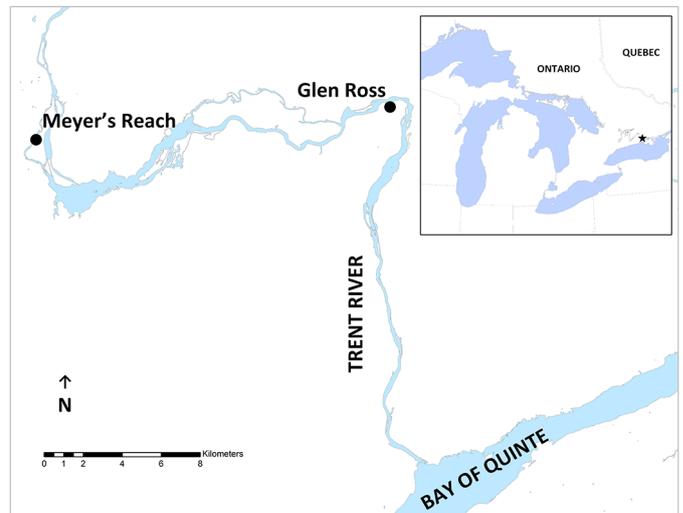
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## 1 Introduction

The Round Goby (*Neogobius melanostomus* Pallas, 1814) is a small-bodied, benthivorous fish of Eurasian origin. The species was first detected in North America in 1990 from the St. Clair River (Jude *et al.*, 1992); which connects Lake Huron to Lake St. Clair. Round Goby was likely introduced to North America from ballast water discharged from transatlantic ships originating from Eastern Europe. Within five years, the species had spread to all five of the Laurentian Great Lakes (Charlebois *et al.*, 2001). Round Goby is an aggressive, rapidly colonizing, invasive fish that disrupts spawning of other benthic fishes and may eat the eggs and fry of native fishes (Kornis *et al.*, 2012). In parts of the Great Lakes, the species has been implicated in the decline of small, native benthic fishes such as the Channel Darter (*Percina copelandi* Jordan, 1877), Johnny Darter (*Etheostoma nigrum* Rafinesque, 1820), Logperch (*P. caprodes* Rafinesque, 1818), and Mottled Sculpin (*Cottus bairdii* Girard, 1850) (Janssen and Jude, 2001; Thomas and Haas, 2001; Reid and Mandrak, 2008). While present in the Great Lakes for more than 25 years, the secondary invasion upstream of Round Goby into Ontario streams and rivers has been a more recent occurrence (Poos *et al.*, 2010; Raby *et al.*, 2010; Raab *et al.*, 2018). Subsequent research in Great Lakes tributaries has identified that habitat and dietary competition between Round Goby and native darters is likely occurring (Abbett *et al.*, 2013) and, in some watercourses, the distribution and abundance of small native fishes are negatively associated with Round Goby presence and abundance (Krakowiak and Pennuto, 2008; Abbett *et al.*, 2013; Kornis *et al.*, 2013; Raab *et al.*, 2018).

In 2003, Round Goby was first collected from the Trent River downstream of the Lock 18 dam in the town of Hastings, Ontario (Canada) (Gutowsky and Fox, 2011). The Trent River forms part of the 386 km long Trent-Severn Waterway (National Historic Site of Canada) that connects Georgian Bay (Lake Huron) to Lake Ontario. The introduction is believed to be the result of anglers using baitfish collected from goby-infested waters in Lake Ontario. At the time of the discovery, Round Goby was also abundant in the Bay of Quinte (Lake Ontario), where the Trent River flows into (Taraborelli *et al.*, 2009). An abundance of suitable Round Goby habitat (areas with cobble and boulder-sized bed material) is present along the Trent River, and the species' downstream and upstream expansion throughout the river was rapid (Raby *et al.*, 2010) and complete by 2010 (Reid, unpublished data). Beyond Lock 18, Round Goby has spread more than 60 km upstream along the Otonabee River to the City of Peterborough (EDDMapS, 2019).

Seven native, small-bodied, benthic fishes are present along the Trent River: Central Stoneroller (*Campostoma anomalum* Rafinesque, 1820), Channel Darter, Fantail Darter (*E. flabellare* Rafinesque, 1819), Johnny Darter, Logperch, Longnose Dace (*Rhinichthys cataractae* Valenciennes, 1842), and Stonecat Madtom (*Noturus flavus* Rafinesque, 1818). Of these species, the Channel Darter is listed as Endangered under the Federal *Species at Risk Act* (SARA). Invasive species are considered a significant threat affecting Canadian freshwater fishes at risk (Dextrase and Mandrak, 2006). For imperiled darters, the risk of adverse population impacts due to Round



**Fig. 1.** Location of the two study sites along the Trent River, and the study area within the Laurentian Great Lakes basin (inset map).

Goby invasions has been assessed as high (DFO, 2011; COSEWIC, 2016). However, these assessments were largely based on expert opinion and, therefore require validation through field research and monitoring. One of the proposed mechanisms associated with negative Round Goby impacts is competition for habitat and shelter (Balshine *et al.*, 2005; Abbett *et al.*, 2013). In this study, summer microhabitat use by Round Goby and two darter species (Channel Darter and Logperch) was characterized at wadeable Trent River sites, and the magnitude of habitat overlap assessed.

## 2 Materials and methods

### 2.1 Data collection

Over the period of September 5th and 21st, 2017, daytime (9:00 am to 17:00 pm) microhabitat use was studied at two Trent River sites: Channel Darter and Round Goby habitat use at Glen Ross (44°15'47"N; 77°35'49"W) and, Logperch and Round Goby habitat use at Meyer's Reach (44°15'18"N; 77°48'43"W) (Fig. 1). Both sites are located downstream of Lock 18. Sites were selected based on suitability of habitats for sampling (*i.e.* electrofishing could be safely undertaken by foot) and the abundance of native darters. Channel Darter and Logperch have been collected at other Trent River sites, but the numbers of each species were considered too low for a robust study of habitat use (Reid, 2004, 2006). Wetted channel widths were between 37 and 100 m at the Meyer's Reach site, and between 145 and 179 m at the Glen Ross site. The mean river flow rate was 64.9 m<sup>3</sup>/s. Water temperatures during sampling ranged from 15.1 to 22.8 °C. Sampling occurred over seven days at Glen Ross and six days at Meyer's Reach.

A spot-sample electrofishing technique was used to collect darters and Round Goby and characterize habitat use (Johnson, 2008; Abbett *et al.*, 2013). Electrofishing was limited to those wadeable habitats that could be safely and effectively sampled (water depths < 1 m). The area of habitat sampled was approximately 13 000 m<sup>2</sup> at Glen Ross (within 40 m of the riverbank), and 20 000 m<sup>2</sup> at Meyer's Reach (across the entire

channel width). Fishes were collected by a 2-person crew using a Smith-Root 12B backpack electrofishing unit (settings: 400 v). Darter and goby collection points were individually marked with coloured, flat metal rings (*i.e.* a washer). Markers were placed by hand at locations where individual fishes were visually observed to be first stunned by the electrical field. Captured fishes were measured for total length (TL) on a measuring board after sampling was complete. All fishes were released after measurement.

A systematic transect sampling approach was used to describe habitat availability (Simonson, 1993). At each site, habitat characteristics were measured at points systematically distributed across the area of habitat electro-fished. Multiple transects were placed parallel to the shoreline and evenly distributed across the river. Transects (and sampling points) were demarcated with an anchored 68 m length of rope with white floats every four metres. Habitat availability was characterized at a total of 800 points in the area sampled at Glen Ross, and at a total of 500 points in the area sampled at Meyer's Reach. With this study design, individual resource use is characterized but availability is measured at a population level (Manly *et al.*, 2002).

Physical habitat measurements taken at each point included water depth (m), mid-water column velocity ( $\text{ms}^{-1}$ ) and bed material composition (visual assessment of percent bedrock, boulder, cobble and gravel). Habitat characteristics common to other riverine fish-habitat studies (*e.g.* woody debris, aquatic vegetation, and fine sediment) were rare or absent, and therefore not measured. Water depth and water velocity were measured with a top-setting wading rod and a Swiffer<sup>TM</sup> water velocity meter. Water velocity was measured at 0.6 of the water depth (Bain and Stevenson, 1999). Visual-based (*i.e.*, snorkelling) studies of stream fish microhabitat selection often include estimates of focal point elevation (vertical distance of the fish from the bottom) and focal point water velocity (velocity at the fish's snout) (Leidy, 1992). For benthic fishes, focal point water velocities can be expected to be less than mean water column velocity (as measured at 0.6 of depth) (Stauffer *et al.*, 1996; Welsh and Perry, 1998). Darter and Round Goby focal point elevations could not be estimated using electrofishing-based collections. For this study, mean water column velocity is assumed to be an index of focal point velocity. Percent composition of bed material was visual assessed using the following modified Wentworth particle size categories: bedrock, boulder (> 256 mm diameter), cobble (65–256 mm), and gravel (2–64 mm).

## 2.2 Data analysis

For each species, habitat suitability curves were developed individually for (i) water depth, (ii) water velocity, and (iii) combined percentage of gravel and cobble bed material. Curves were generated following the approach described by Hightower *et al.* (2012). The probability of using habitat category  $i$  was modeled as:

$$P_i = \frac{w_i a_i}{\sum_{j=1}^n (w_j a_j)},$$

where  $a_i$  is the proportion of habitat available in category  $i$ , and  $w_i$  is the unscaled relative probability of using habitat  $i$  based on the frequency of each species in habitat  $i$  if all habitats were equally available. Estimates of  $w_i$  would be similar in magnitude if all habitats were used in proportion to their availability. As per Hightower *et al.* (2012),  $w_i$  values were rescaled to a maximum of 1 for all habitat variables.

Principal component analysis (PCA) was used to visualize, in multivariate space, the similarity of habitat use by native darters and Round Goby, with reference to available habitat. As variables were measured with different units, variables were standardized by subtracting the mean and dividing by the standard deviation (Legendre and Legendre, 1998). Principal components (PC) with eigenvalues greater than 1 and loadings greater than |0.6| were retained. PC scores were subsequently used as dependent variables in Multivariate Analysis of Variance (MANOVA) to test for habitat differences between darters and Round Goby, and between collection points and available habitat. Hotelling's  $T^2$  was used to test for pairwise differences, and  $p$ -values were adjusted using a sequential Bonferroni correction. Statistical analysis was completed using PAST version 1.94 (Hammer *et al.*, 2001).

## 3 Results

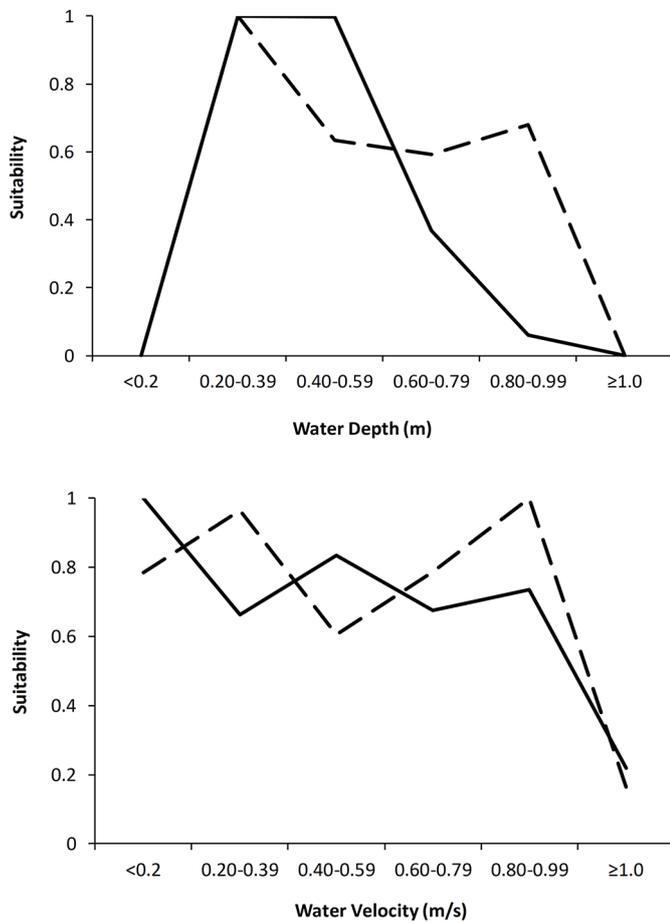
One hundred-nineteen Channel Darter, 421 Logperch and 360 Round Goby were captured during electrofishing. The median (range, standard deviation) total length of Channel Darter was 61.5 (52–70, 3.6) mm, of Logperch was 106 (61–140, 12.8) mm, and of Round Goby was 83 (29–168) mm. Round Goby collected from Glen Ross (median: 81 mm; range: 29–168; standard deviation: 21.3) and Meyer's Reach (median: 86 mm; range: 40–134; standard deviation: 24.9) were of similar size. Other species commonly encountered during electrofishing include Longnose Dace, Pumpkinseed (*Lepomis gibbosus* Linnaeus, 1758), Rock Bass (*Ambloplites rupestris* Rafinesque, 1817), and Smallmouth Bass (*Micropterus dolomieu* Lacépède, 1802). Glen Ross flow conditions were characterized by moderate water depths (0.4–0.8 m) and water velocities typically below  $0.6 \text{ ms}^{-1}$ . Along Meyer's Reach, water depths were generally shallow (< 0.4 m) with water velocities less than  $0.3 \text{ ms}^{-1}$ . The Glen Ross riverbed was a relatively even mix of gravel, cobble, boulder and bedrock. Riverbed material along Meyer's Reach was dominated by cobble, boulder and bedrock; with only a small amount of gravel present (Tab. 1).

### 3.1 Glen Ross

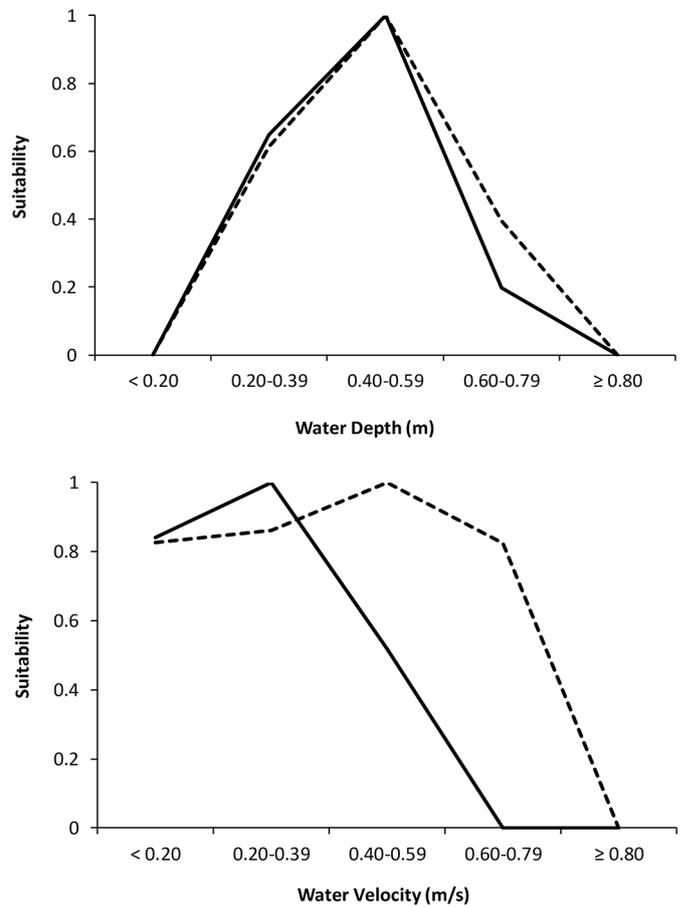
Channel Darter and Round Goby captures were generally associated with moderate water depths (0.4–0.8 m) and slow to moderate water velocities ( $0.1$ – $0.5 \text{ ms}^{-1}$ ), and with gravel and cobble substrates (Tab. 1; Figs. 2 and 3; Figs. S1 and S2). Channel Darter habitat suitability was greatest at water depths between 0.2 and 0.4 m, and water velocities between 0.2 and  $0.4 \text{ ms}^{-1}$ , and 0.8 and  $1.0 \text{ ms}^{-1}$ . Suitability declined substantially at depths greater than 0.6 m and velocities >  $0.8 \text{ ms}^{-1}$  (Figs. 2 and 3). Round Goby habitat suitability was greatest at water depths between 0.2 and 0.6 m and water velocities less

**Table 1.** Comparison of mean (standard deviation) habitat measurements at Channel Darter, Logperch and Round Goby collection spots. Available and used microhabitat data were measured at two Trent River locations (September, 2017).

	Water depth (m)	Water velocity ( $\text{ms}^{-1}$ )	Bedrock (%)	Boulder (%)	Cobble (%)	Gravel (%)
<b>Glen Ross</b>						
Available ( $n = 800$ )	0.45 (0.18)	0.35 (0.26)	22.4 (40.0)	21.6 (25.0)	34.1 (25.5)	22.0 (19.4)
Channel Darter ( $n = 119$ )	0.42 (0.18)	0.32 (0.22)	2.6 (12.9)	22.4 (20.9)	47.1 (18.0)	27.8 (15.3)
Round Goby ( $n = 165$ )	0.38 (0.14)	0.31 (0.23)	7.7 (22.0)	21.1 (20.5)	44.2 (22.3)	27.0 (17.8)
<b>Meyers Reach</b>						
Available ( $n = 500$ )	0.27 (0.13)	0.18 (0.13)	38.6 (45.0)	27.1 (25.4)	25.6 (25.4)	8.8 (10.6)
Logperch ( $n = 421$ )	0.31 (0.09)	0.19 (0.13)	11.1 (22.5)	38.5 (20.5)	36.4 (21.3)	14.0 (9.7)
Round Goby ( $n = 195$ )	0.31 (0.08)	0.16 (0.10)	23.0 (30.6)	21.0 (17.7)	39.7 (27.2)	16.3 (11.6)



**Fig. 2.** Estimated Channel Darter (— —) and Round Goby (solid line) habitat suitability for water depth (upper panel) and water velocity (lower panel) at Glen Ross, based on a resource selection function fitted to habitat use and availability data (Figs. S1 and S2). Suitability is scaled from 0 (unsuitable habitat) to 1 (highly suitable).

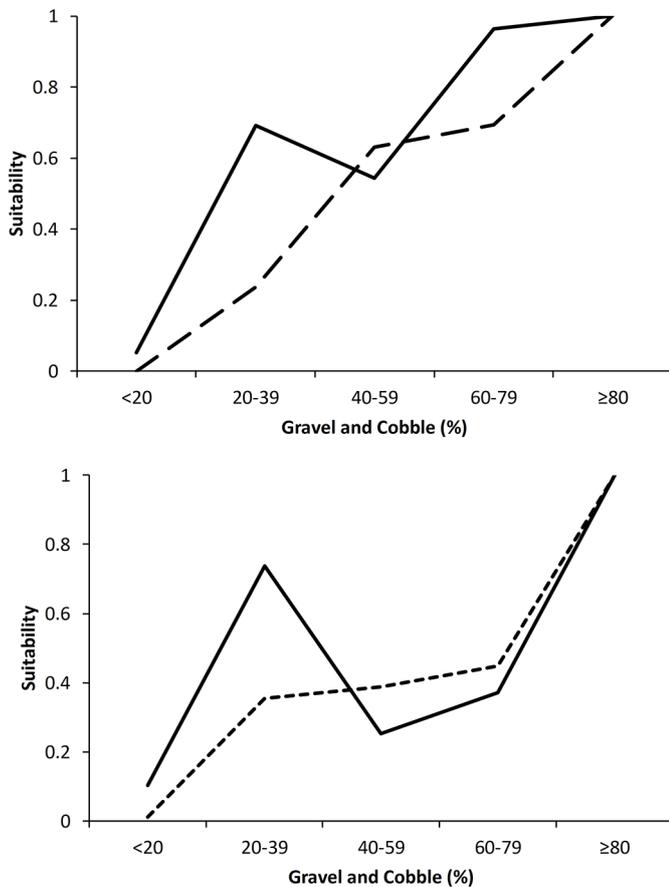


**Fig. 3.** Estimated Logperch (—) and Round Goby (solid line) habitat suitability for water velocity and water depth at Meyer's Reach, based on a resource selection function fitted to habitat use and availability data (Figs. S1 and S2). Suitability is scaled from 0 (unsuitable habitat) to 1 (highly suitable).

than  $0.2 \text{ ms}^{-1}$ . Suitability declined substantially at depths greater than 0.6 m and velocities  $> 0.8 \text{ ms}^{-1}$ . For both species, habitat suitability improved as the amount of gravel and cobble increased (Fig. 4).

The first three principal components explained 75.0% of the total variance among habitat use and availability measure-

ments at Glen Ross. The first axis (PC1) reflected differences in the amount of gravel, cobble and bedrock at measurement points. Differences in the amount of boulder (PC2), and differences in water velocity and depth measurements (PC3) were represented by the other two axes (Fig. 5). There were significant differences among PC scores associated with

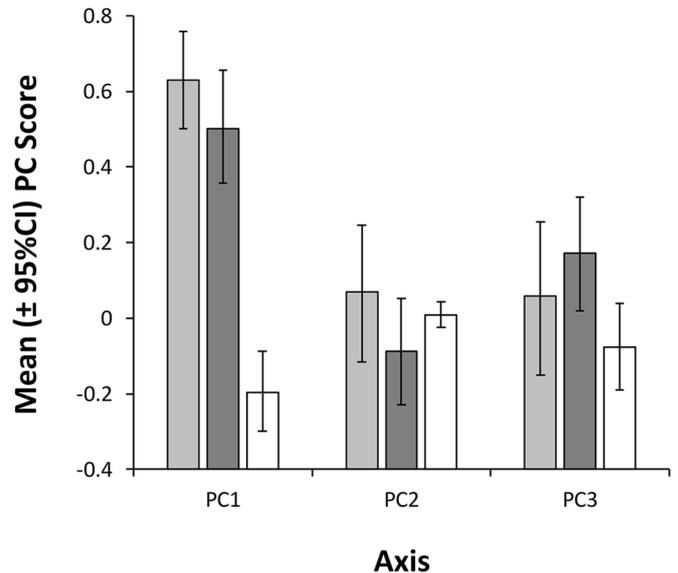


**Fig. 4.** Estimated Channel Darter (— · —), Logperch (---) and Round Goby (solid line) habitat suitability for gravel and cobble bed material at Glen Ross (upper panel) and Meyer's Reach (lower panel), based on a resource selection function fitted to habitat use and availability data. Suitability is scaled from 0 (unsuitable habitat) to 1 (highly suitable).

available habitat, Channel Darter habitat use, and Round Goby habitat use (MANOVA, Wilk's Lambda: 0.94,  $p < 0.0001$ ). However, there was no significant difference between Channel Darter and Round Goby PC scores (pairwise comparison Hotelling's  $T^2$ :  $p > 0.45$ ). For both species, habitat use PCA scores were significantly different than available habitat (Hotelling's  $T^2$ :  $p < 0.0001$ ). Differences among PC 1 scores indicate Channel Darter and Round Goby were both collected from locations with more gravel and cobble, and less bedrock than available across the Glen Ross site (Tab. 1; Fig. 5).

### 3.2 Meyer's Reach

Logperch and Round Goby captures were generally associated with shallow to moderate water depths (0.2–0.4 m), and slow to moderate water velocities (0.1–0.3  $\text{ms}^{-1}$ ). At Logperch capture points, there was less bedrock and more boulder than where Round Goby were captured (Tab. 1; Figs. 3 and 4; Figs. S1 and S2). For both Logperch and Round Goby, habitat suitability at Meyer's Reach is predicted to be greatest at water depths between 0.2 and 0.4 m and at locations dominated



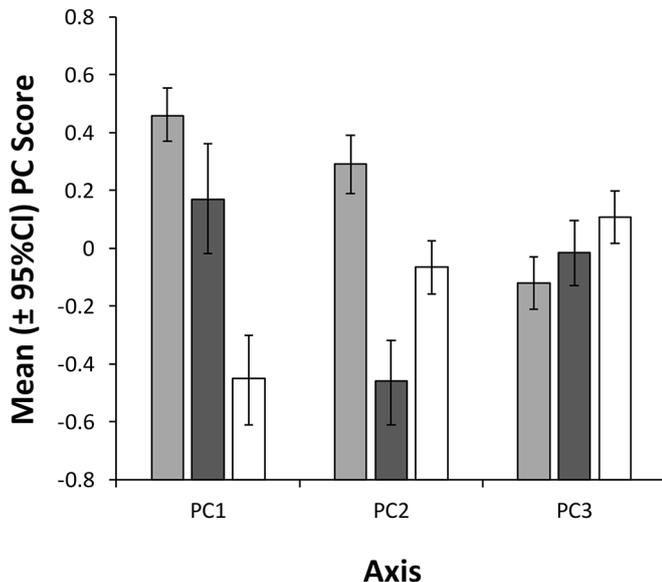
**Fig. 5.** Comparison of mean (95% confidence interval) PC scores associated with Channel Darter habitat use (■), Round Goby habitat use (■) and available habitat (□) at Glen Ross, Trent River. The amount of variation explained by PC1, PC2 and PC3 was 34.4, 21.9 and 18.7%. Dominant PC 1 loadings: bedrock (−0.62), gravel (0.50) and cobble (0.54); dominant PC2 loading: boulder (0.84); and dominant PC3 loadings: water depth (−0.59) and water velocity (0.70).

by gravel and cobble bed material (Figs. 3 and 4). Suitability declined substantially for Round Goby when water velocity was greater than  $0.4 \text{ ms}^{-1}$ , and for Logperch when water velocity was greater than  $0.8 \text{ ms}^{-1}$  (Figs. 3 and 4).

The first three principal components explained 75.1% of the total variance among habitat use and availability measurements along Meyer's Reach. The first axis (PC1) reflected differences in the amount of gravel, cobble and bedrock. Differences in the amount of boulder (PC2) and water velocity (PC3) were represented by the other 2 axes (Fig. 6). There were significant differences among PC scores associated with available habitat and habitat used by Logperch, and habitat used by Round Goby (MANOVA, Wilk's Lambda: 0.87,  $p < 0.0001$ ). There was a significant difference between Logperch and Round Goby habitat use PC scores (Hotelling's  $T^2$ :  $p < 0.0001$ ). Differences between PC scores from the first 2 axes indicate that Logperch and Round Goby were collected from locations with differing amounts of boulder and bedrock (Tab. 1; Fig. 6). For both species, habitat use PCA scores were significantly different than available habitat (pairwise comparison Hotelling's  $T^2$ :  $p < 0.0001$ ). Compared to available habitat, both species were collected from spots with less bedrock, and more gravel and cobble.

## 4 Discussion

Past observational and experimental studies have shown that Round Goby affects local habitat use by native small-bodied benthic fishes such as Mottled Sculpin (Dubs and Corkum, 1996; Janssen and Jude, 2001) and Logperch (Balshine *et al.*, 2005; Leino and Mensinger, 2017).



**Fig. 6.** Comparison of mean (95% confidence interval) PC scores associated with Logperch habitat use (■), Round Goby habitat use (■) and available habitat (□) at Meyer's Reach, Trent River. The amount of variation explained by PC1, PC2 and PC3 was 39.5, 19.8 and 15.9%. Dominant PC 1 loadings: bedrock (−0.63), gravel (0.48) and cobble (0.43); dominant PC2 loading: boulder (0.73); and dominant PC3 loadings: water velocity (0.88).

Accordingly, competition for space and shelter (such as interstitial spaces between rocks) has been identified as a causal mechanism for native species declines after Round Goby invasions (Burkett and Jude, 2015). At the microhabitat scale, darters are known to segregate spatially based on water depth, water velocity and bed material size (Stauffer *et al.*, 1996; Welsh and Perry, 1998), and non-native darter species have been observed to shift habitat use by native darters (van Snik *et al.*, 2009). Differences in microhabitat use have also been reported between Round Goby and darters (Fantail Darter: Abbett *et al.*, 2013; Logperch: Leino and Mensinger, 2017). In this study, the degree of similarity with Round Goby summer microhabitat differed between the two native darter species studied and, was based on different habitat characteristics.

Habitat differences between Channel Darter and Round Goby were small; largely limited to Channel Darter occupying deeper habitats. In contrast to these results, Abbett *et al.* (2013) reported Fantail Darter to occupy shallower habitats than Round Goby in a St. Lawrence River tributary (Mullet Creek). The lack of agreement between studies may reflect Trent River habitats being deeper than Mullet Creek, or that Channel Darter typically occupies deeper habitats than Fantail Darter (Stauffer *et al.*, 1996; Reid *et al.*, 2005). Based on past descriptions of Channel Darter habitat use (Reid, 2004; Reid *et al.*, 2005) and practical sampling limitations, habitat use by native darters and the invasive Round Goby was only studied at Trent River habitats of shallow to moderate water depth. Along the Trent River, such wadeable habitats are uncommon as reaches are dominated by deep run habitat and impounded areas. While Channel Darter are known to preferentially use shallow riffle and shoal habitats for most of the year (Etnier

and Starnes, 1993; Reid, 2004), Round Goby are easily angled in the summer from deeper habitats along the Trent River (Gutowsky *et al.*, 2011). Therefore, the breadth of microhabitats utilized by Round Goby is expected to be much greater than measured.

There were significant differences between Logperch and Round Goby habitat use; reflective of water velocities and riverbed material selected. As observed in nearby rivers (Reid *et al.*, 2005), Logperch occupied habitats dominated by cobbles and boulders. In experimental studies, Round Goby has been shown to outcompete Logperch for shelter (Balshine *et al.*, 2005) and food resources in rocky habitats (Leino and Mensinger, 2017). While Round Goby has been observed to be more aggressive than native, small-bodied benthic fishes (Dubs and Corkum, 1996), the outcomes of competitions for space and shelter are also size-dependent (Balshine *et al.*, 2005; Groen *et al.*, 2012). Trent River Logperch were on average 20 mm longer than Round Goby, and therefore, habitat use may be unaffected by the presence of Round Goby.

Habitats occupied by Channel Darter and Logperch differed; along with the degree of habitat overlap with Round Goby. Past studies have found differences between the habitats occupied by the two darter species (Stauffer *et al.*, 1996; Reid *et al.*, 2005). While both species appear to select particular microhabitats, differences among studies are not consistent. In the Trent River, the greater association of Channel Darter with faster and deeper habitats, and more gravels and cobbles, may simply reflect site-level differences in available habitat.

Past research undertaken along the Trent-Severn Waterway on the invasive Round Goby has provided insight into detection and monitoring methods (Gutowsky *et al.*, 2011), rates of expansion (Brownscombe *et al.*, 2012), diet composition (Raby *et al.*, 2010), and variation in behavioural and demographic characteristics along the invasion front (Gutowsky and Fox, 2011; Groen *et al.*, 2012). The length distributions of Round Gobies collected during this study were similar to that measured during the expansion phase of the Trent River invasion, nine years earlier (Gutowsky and Fox 2011). Also, the strong affinity for gravel, cobble and boulder material by Round Goby at Glen Ross and Meyer's Reach was consistent with observations by Brownscombe and Fox (2012) at other Trent-Severn Waterway sites. Round Goby diet in the Trent River includes a variety of invertebrates (zooplankton, amphipods and benthic macroinvertebrates) (Raby *et al.*, 2010; Paton *et al.*, 2019) that are also important prey for Channel Darter and Logperch. Therefore, competition between Round Goby and native darters is potentially occurring for both physical habitat and food resources along the Trent River. While the stomach contents of Logperch and Round Goby collected from the Trent-Severn Waterway have been compared (Paton *et al.*, 2019), diet overlap with Channel Darter has not been studied. Future research on Channel Darter diet and trophic overlap with Round Goby is necessary to provide stronger evidence of resource competition.

Globally, most Round Goby impact studies have been undertaken within a short-time frame (< 5 years) after detection (Hirsch *et al.*, 2016). Observations from this study provide a longer-term (> 10 years later) perspective on the potential for resource competition with native, small-bodied benthic fishes along the Trent River. In other aquatic habitats, evidence of resource competition has been reported along with

declines in native fish distribution and abundance (Burkett and Jude, 2015). Documentation of population-level impacts to species such as the Channel Darter that utilize the same microhabitats as Round Goby will, however, require additional field study along the Trent River (e.g. Raab et al., 2018).

## Supplementary Material

Fig. S1. Frequency distributions (percentage of all measurements) for water depth measurements at two Trent River study sites (upper panel: Glen Ross; lower panel: Meyer's Reach), September 2017. Legend abbreviations: Avail – available habitat; CH – Channel Darter; LG – Logperch; RG – Round Goby.

Fig. S2. Frequency distributions (percentage of all measurements) for water velocity measurements at two Trent River study sites (upper panel: Glen Ross; lower panel: Meyer's Reach), September 2017. Legend abbreviations: Avail – available habitat; CH – Channel Darter; LG – Logperch; RG – Round Goby.

The Supplementary Material is available at <https://www.kmae-journal.org/10.1051/kmae/2019021/olm>.

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