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PRIMARY RESEARCH PAPER

Experimental displacement of longnose dace, *Rhinichthys cataractae* (Actinopterygii, Cyprinidae), reveals rapid fish avoidance of a stormwater drain in an urban watershed

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Abstract Land-use change associated with human development can alter aquatic habitat and imperil aquatic species. Fish are challenged when urban streams are altered, for example for stormwater conveyance, but little is known about how such activities influence the space use of individual fish. Electronic tagging and experimental displacement of fish can be used to explore site fidelity and homing behaviour of fish and can therefore be useful for testing hypotheses about space use and habitat selection. In this study, we used experimental displacement to determine how longnose dace (LND, *Rhinichthys cataractae*) utilize reaches within a watershed that have varying degrees of degradation. LND were tagged using passive integrated transponders (PIT tags), transported upstream, and released either into the natural stream reach, impaired stormwater drain reach, or at their confluence. Fixed PIT antennas were used to monitor movement of the PIT-tagged fish among the three reaches for a period of 3 weeks. LND exhibited dramatic and rapid selection against the stormwater drain. No LND moved into the drain and 97% of fish transported to the drain left within 24 h. LND were actively avoiding the stormwater drain, emphasizing the need for enhancement work to improve the biological connectivity of the system.

Keywords Passive integrated transponders · Site fidelity · Stream · Habitat impairment · Experimental displacement

Introduction

Landscape alterations, such as urbanization and the development of agricultural land, are essential to suit the needs of a growing population (Vitousek et al., 1997; Paul & Meyer, 2001). However, landscape disturbances can be particularly damaging to aquatic systems, such as streams, given manifold changes to hydrology, water quality, and habitat configuration associated with alterations to terrestrial environments (DeFries & Eshleman, 2004; Strayer & Dudgeon, 2010). Indeed, habitat loss, resource depletion, nutrient runoff, and changes to stream flow velocity can all occur as a result of land-use alterations (Schlosser, 1991; Allan, 2004). Changes to physical and chemical characteristics of the environment can alter biotic elements including population abundance and community structure in aquatic systems (Paul & Meyer, 2001; Allan, 2004; Dudgeon et al., 2006). This is particularly evident in urban watersheds where impervious surfaces lead to dramatic changes to water

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runoff and in some cases result in natural streams being altered for stormwater conveyance (i.e. being designated as stormwater drains). Watershed degradation can affect species diversity, abundance, and life history (Schlosser, 1991; Paul & Meyer, 2001; Dudgeon et al., 2006), and is likely to influence movements and distribution of individual fish (Strayer & Dudgeon, 2010).

Studies of the space use of fish are useful for understanding how fish interact with their environment, as well as their sensitivity to environmental change (Lucas & Baras, 2000). Indeed, behavioural avoidance and selection of different habitats represent fundamental aspects of high-level ecological processes (e.g. trophic interactions, population and community biology; Gorman & Karr, 1978; Railsback et al., 1999) as well as individual fitness (Huey, 1991). Stream fish vary in the way that they utilize habitats based largely on individual habitat requirements, environmental tolerances, and biotic interactions (i.e. predator–prey dynamics) often resulting in species-specific ranges within a system (Kinzie, 1988; Schlosser, 1991). At one time, stream fish were regarded as sedentary (Funk, 1957), but now it is widely known that even small-bodied stream fish can be highly mobile (Rodríguez, 2002), with the aforementioned abiotic and biotic drivers influencing movement (Railsback et al., 1999). When habitat quality (physical or chemical) suffers, individual fish may disperse to find favourable conditions and abundant resources (Schlosser, 1991).

Animals use habitat that provides necessary physical and chemical resources. As mobile organisms, fish actively select habitat where they can access these resources (Railsback et al., 1999). Although there are many ways to study fish habitat selection (Rosenfeld, 2003), monitoring the space use of individual fish with electronic tags is an effective way of determining the relationship between habitat and its residents (Lucas & Baras, 2000). This approach can yield information regarding the degree of site selection as well as determining if a site is unfavourable for a specific species. Although the most common approach using electronic tags is to simply track individually tagged fish and assess habitat use or selection after releasing them at the site of capture, displacement studies (i.e. where a fish is moved from one location to another) also have the potential to further elucidate fish-habitat relationships in an experimental context. Such an approach has been used to study the homing behaviour of migratory fish (e.g. Hansen & Jonsson, 1994; Bélangerz & Rodríguez, 2005). This method can further be applied for the study of macro-habitat use in an interconnected system with different types of human development. Advances in passive integrated transponder (PIT) technology (see Roussel et al., 2000; Gibbons & Andrews, 2004) provide a tool for the study of the space use of small-bodied stream fish. PIT tags are generally small, not limited by battery life, and individually coded, which allows for evaluations of growth, behaviour, and fate through an individual's life (Gibbons & Andrews, 2004). PIT-tagged animals can be monitored in real time using fixed antennas that generally have reasonable detection efficiency in small streams (Aymes & Rives, 2009; Cooke et al., 2012), making them ideal for studying the movement of stream fishes.

To evaluate movement and reach-scale habitat selection of stream fishes, a site-fidelity and displacement study was carried out in an Ottawa River tributary, Watts Creek, located in Kanata, Ontario, Canada. Research efforts focused on longnose dace (*Rhinichthys cataractae*, Valenciennes 1842; LND), a common small-bodied cyprinid that lives in fluvial systems and occupies fast-flowing riffle environments (Scott & Crossman, 1998) resulting from habitat complexity within fluvial systems. LND provide an interesting model species for studying the effects of stream degradation because channelization and other human alterations often remove cobble and boulders that contribute to habitat complexity needed to support this species (Lau et al., 2006). Our first goal was to evaluate whether LND residency is influenced by reach-scale habitat qualities. Our second goal was to determine whether LND exhibit homing behaviour following displacement. Finally, we attempted to determine whether there were temporal differences in LND reach selection. Based on previous research in Watts Creek where community assemblage varied between a stormwater drain and a more natural reach (Bliss et al., 2015), it was anticipated that there would be selection against the reach with the greatest amount of human disturbance (i.e. stormwater drain). Additionally, we anticipated that fish would exhibit homing behaviour, returning to the reach where they were captured. That is, fish would leave both the stormwater drain and the upstream reach of the natural system and move downstream past the confluence to where they were captured. Finally, we anticipated that reach selection would vary seasonally, with fish tagged in mid-autumn more likely to move into the larger confluence reach than earlier tagged fish, in favour of overwintering habitat.

Methods

Study species

LND is a common cyprinid species found in cool water streams and rivers within North America (Scott & Crossman, 1998). A comprehensive fish distribution study carried out in Watts Creek found that LND rarely inhabits Kizell, but are abundant in Watts and Main (Bliss et al., 2015; Table 1). LND favour riffle habitats, a characteristic of sinuous rivers and streams, containing gravel substrates and fast-flowing waters, where they feed on benthic invertebrates (Gibsons & Gee, 1972; Richards, 1978; Mullen & Burton, 1995; Scott & Crossman, 1998).

Study site

This study was conducted in August, September, and October 2013 in the Watts Creek watershed (45°20′42″N, 75°52′19″W), Kanata, Ontario, Canada (Fig. 1). This system is divided into three reaches, herein referred to as Watts, Main, and Kizell. The watershed has its headwaters located in the Katimavik-Hazeldean neighbourhood of the city and flows downstream for approximately 3.2 km until its confluence with Kizell Drain. Kizell Drain is an earthen stormwater drain maintained by the City of Ottawa, with its headwaters located at Beaver Pond. The reach of the Watts Creek watershed downstream of the confluence with Kizell, herein Main, is characterized by an abundance of riffle habitats and instream vegetation (Bliss et al., 2015; Table 1). Main flows for approximately 5.4 km before entering the Ottawa River at Shirley's Bay. Although all parts of the Watts Creek watershed have been altered to some extent by urban development, Kizell has an elevated degree of

Table 1 Descriptive statistics describing the biotic and abiotic environmental conditions in the Watts Creek watershed

Metric	Kizell	Main (confluence)	Watts
Velocity (m/s)	0.12 ± 0.1	0.15 ± 0.1	0.17 ± 0.1
Riffle (%)	1 ± 2	35 ± 18	23 ± 20
Pool (%)	2 ± 2	8 ± 5	9 ± 7
Glide (%)	97 ± 1	57 ± 22	67 ± 15
Substrate composition	Silt/clay (80%), sand (15%), cobble (5%)	Silt/clay (49%), sand (31%), cobble (20%)	Silt/clay (63%), sand (30%), cobble (6%)
Stream depth (cm)	23 ± 13	34 ± 12	22 ± 10
Stream width (cm)	308 ± 160	385 ± 53	316 ± 52
Instream vegetation cover (%)	1 ± 2	9 ± 11	3 ± 4
Temperature	19.8 ± 4.0	20.2 ± 4.0	19.0 ± 4.2
Temp range	8.0–26.4	8.4–26.4	7.4–26.4
LND abundance	8	147	40
Shannon–Wiener diversity	1.02	1.31	1.78
Dominant fish species	Banded killifish (*Fundulus diaphanous*)	Banded killifish (*Fundulus diaphanous*)	Creek chub (*Semotilus atromaculatus*)

Abiotic environmental data include the percentage of riffle, pool, and glide habitat in each reach and dominant substrates. Temperature ranges were recorded using iButtons from May 7th, 2012 until August 31st, 2012 because temperature data collected in 2013 were not complete. Fish species data are from Maarschalk-Bliss (2014) and for the confluence are taken from measures in Main (i.e. not directly within the confluence but from the reach of the stream downstream). Values are means from transect measurements in September and May delineated by Maarschalk-Bliss (2014) and are presented as ±SD

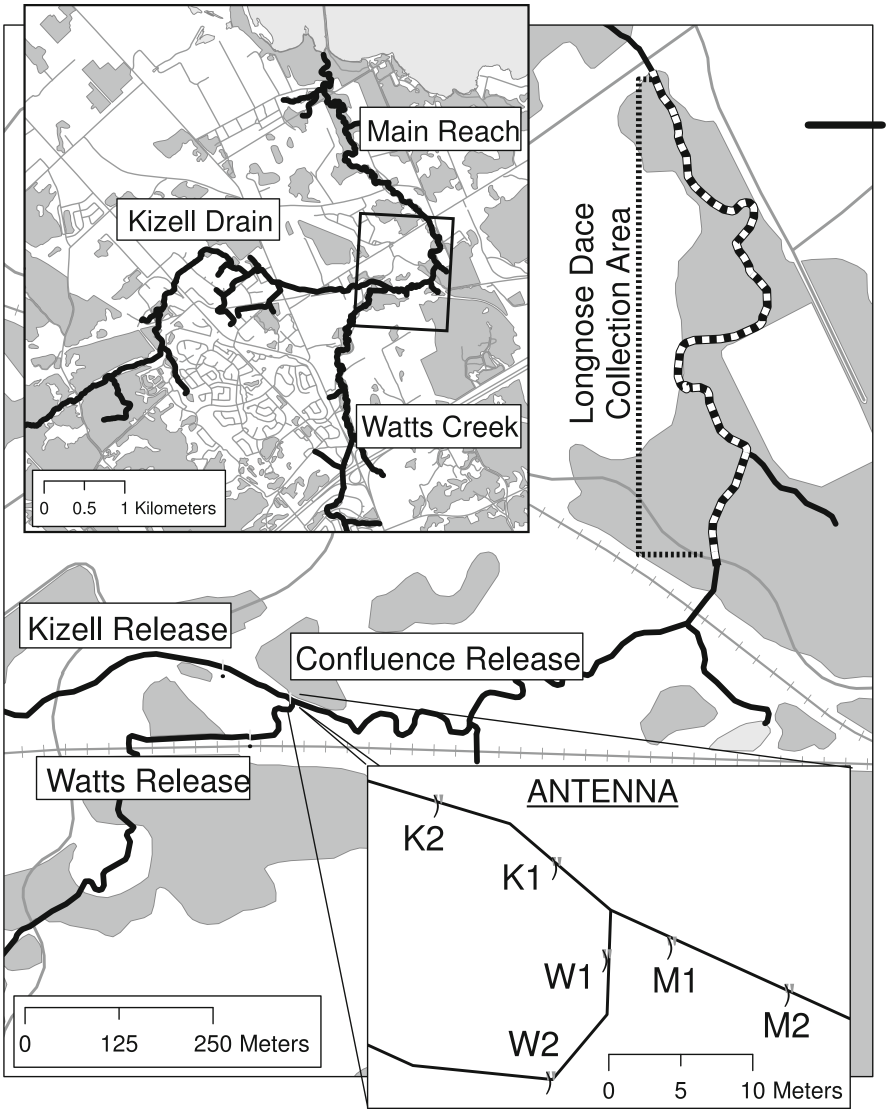

Fig. 1 Top inset shows a map of Watts Creek with the Watts Creek-Kizell Stormwater Drain confluence and its downstream reach, Main. The main map shows the portion of the Main reach where longnose dace were captured (*black* and *white* checkers) as well as the three release locations (*grey circles*). Finally, the bottom inset shows a zoomed in view of the confluence with the locations of the six passive integrated transponder antennas. Note that water from the Main reach is flowing northward into the Ottawa River

modification (i.e. channelization) corresponding to a lower fish diversity (Maarschalk-Bliss, 2014).

Watts had the fastest stream velocity and Kizell had the slowest (Table 1). Watts and Main contained more medium to coarse sediments, including large rocks and boulders, compared to Kizell, which was predominantly composed of fine sediments (Table 1). As a result, Main, followed by Watts, contained the most riffle habitats and in-stream structures. Main and Watts also had similar degrees of stream sinuosity in contrast to Kizell, which is a linear system. Finally, Kizell is warmer than Watts and Main corresponding to the slower flow of water, shallower profile, less riparian shade, and urban runoff at the headwaters (Table 1). Although this stormwater drain was channelized several decades ago, it has not been maintained for about 10 years such that riparian and in-stream vegetation have become established. The watershed supports a diverse fish assemblage dominated by banded killifish, bluntnose minnow, central mudminnow, creek chub, and white sucker and had 22 species recorded in the system (Maarschalk-Bliss, 2014).

Fish capture, tagging, and tracking

To avoid disrupting reproduction (May to mid-July; Scott & Crossman, 1998), fish displacements for this study were conducted from August to October. On each of three sampling dates (15 August, 24 September, 17 October), LND were captured using an electrofishing backpack unit (Model 12, Smith-Root, Vancouver, WA, USA). All fish used for this study were captured in Main (Fig. 1) due to its high probability of yielding adequate numbers of LND, as well as its distance (0.8 km downstream) from the Watts/Kizell confluence.

All LND measuring less than 70 mm in length were released immediately given that they were too small for tagging (Bliss et al., 2015). For LND longer than 70 mm, small (12 mm) passive integrated transponder (PIT) tags were inserted into the body cavity through a small incision anterior to the pelvic fins; this incision was made using the edge of a 14-gauge needle (see Bliss et al., 2015). The fish were divided into three similarly sized groups for release in Watts, Kizell, or at the confluence of the two. The Watts and Kizell groups were released 100 m upstream of the confluence in their respective reaches, and the Confluence group was released directly into a pool area formed by the confluence of Watts and Kizell, which drains into Main (Fig. 1). Each release site was standardized at 100 m from the confluence and therefore did not necessarily correspond to suitable habitat; rather, we expected to observe movement of LND from the release locations.

To monitor movement of the tagged LND among the reaches of the watershed, six fixed PIT array antennas, three located at the entrance of each reach from the confluence and three others located approximately 10 m into each reach from the first antennas, were installed. The antennas were downstream of the release sites in Watts and Kizzel so we only expected to detect fish that exited the reaches. Antennas surrounded fish displaced into the confluence and therefore we expected to detect any LND that moved into Watts, Main, or Kizell. The paired configuration of the antennas enabled us to determine the direction of fish movements, while also ensuring that detections were independent from those of the other antennas. The antennas were surrounded by fencing material and fixed to the bottom of the stream using heavy rocks (Burnett et al., 2013). Following each release, fish movements were tracked for a period of 3 weeks using remote tuner boxes, which were connected to a MultiAntenna HDX Reader (Oregon RFID).

Data analyses

A two-way ANOVA was used to determine if there were significant differences in mean fish size among release locations and release dates. Fish movement data were assessed to determine the total reach residency time (in days) and ultimate destination of each individual during the three-week interval after release. To test the null hypothesis of no reach selection by the LND, Chi-square tests were performed for each of the three displacements with two degrees of freedom (i.e. one minus the number of potential reaches available to the fish) with expected values equivalent to 1/3 of the released LND per reach (i.e. no reach preference, random movement among reaches). Subsequent post hoc exact tests were performed on each reach to test which reaches differed significantly from expected values (McDonald, 2009). The exact tests used two values for each test (e.g. proportion of total release in Kizell [expected = 0.33) compared to proportion of total release not in Kizell [expected = 0.66]). P values were Bonferroni corrected for the post hoc tests and therefore tested at $\alpha = 0.0167$ (i.e. 0.05/3).

Overall site selection was determined based on the ultimate destination of each fish per release group. The in situ detection efficiency of each fixed antenna array was calculated based on the known starting and finishing locations of tagged LND. Efficiency therefore measures the number of fish detected at an antenna divided by the number of fish that were known to have successfully passed that antenna (detected at a location upstream or downstream of that antenna). All analysis was completed in JMP 9.0 (SAS Institute, Cary, NC, USA).

Results

In total, 209 LND were tagged for this study. However, only data received from 205 of the tagged fish were included in the analysis due to the lack of detections at the fixed array antennas of three fish released within the confluence (two from August and one from September). Without detections, the movements and reach selections of the individuals could not be determined, therefore they were omitted (Table 2). Similarly, a fish from the Watts release in October died during release, resulting in its omission from the data analyses. LND ranged in size from 77 to 106 mm during the first release, 73 to 110 mm during the second release and 70 to 120 mm for the third release (Table 2). No differences in fish size existed among the release locations or release dates (Two-way ANOVA, $F_{(199,8)} = 1.899$, $P > 0.05$).

Based on fish movement data yielded from the PIT array antennas, there was selection against Kizell, with as few as 3.4% of all fish selecting Kizell during all releases (see Fig. 2 for ultimate destinations of LND following displacement). In all three displacements there was therefore significant deviation in the distribution of LND from the expected distribution under the null hypothesis of no reach selection (August: $\chi^2 = 26.98$, $P < 0.01$; September: $\chi^2 = 64.00$, $P < 0.01$; October: $\chi^2 = 41.15$, $P < 0.01$). These results were driven by selection against Kizell Drain (Table 2); for each of the three displacements, LND released into Kizell tended to select Watts as their habitat, and those released into Watts tended to remain in that reach. However, LND released into the confluence in August equally selected Watts and Main as their habitats (Fig. 2). Regardless of initial release location, Watts was selected by approximately 70% of all LND during the August and September releases. In October, selection shifted towards Main, as fish released into the confluence mostly moved downstream (Fig. 2; Table 2). The overall selection towards Main in October was approximately 60% (Fig. 2).

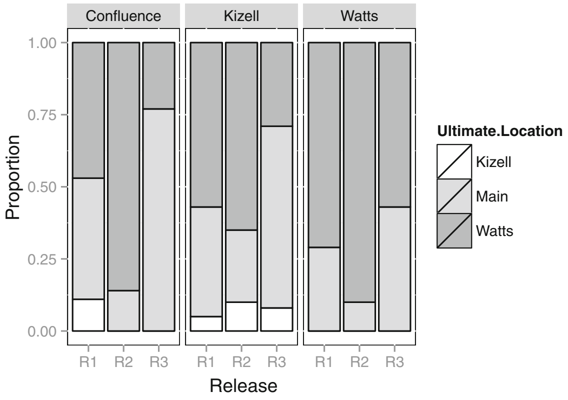

Fig. 2 Proportion of LND that were released into the Confluence, Kizell Drain, and Watts Creek that ultimately selected Kizell Drain, Watts Creek, or the Main Reach (downstream of the confluence of the Drain and Creek). Proportional selection is broken up based on the release times including: August (R1), September (R2) and October (R3)

Fish consistently spent the least amount of time in Kizell, which yielded the shortest mean residency times, generally being shorter than 24 h. LND released into Watts had the longest residency times with the exception of the October release, when the longest residency times were observed in Main (Table 3). These residency times are consistent with the overall reach selection observed for LND.

Five LND were recaptured on 17 October while capturing fish for the final release. Recaptures

Table 2 Summary of post hoc Chi-squared results testing the evenness of ultimate LND distributions following displacements in August, September, and October at 3 weeks post release

Release	Location	Mean length (mm) ± SD	Number released	Ultimate number	Chi-squared value	DF	*P* value
August	Confluence	89 ± 7	19*	22	0.21	1	0.6510
	Kizell	86 ± 4	21	3	22.16	1	**<0.0001**
	Watts	89 ± 7	21	36	18.11	1	**<0.0001**
September	Confluence	88 ± 7	22*	10	8.25	1	**0.0041**
	Kizell	93 ± 8	20	2	25.29	1	**<0.0010**
	Watts	89 ± 9	20	50	62.45	1	**<0.0001**
October	Confluence	85 ± 9	26	49	25.76	1	**<0.0001**
	Kizell	89 ± 10	27	2	33.22	1	**<0.0001**
	Watts	89 ± 9	29*	31	0.74	1	0.3900

Summary of total fish released per reach and mean lengths are included. *P* values are from the post hoc exact Chi-square test; significant differences (bold) were determined at the Bonferroni-corrected α-level of 0.0167. In terms of location, the analysis for LND released into the confluence was related to their selection of the Main or downstream portion of the stream. Asterisks indicate releases for which fish were omitted from the analysis

Table 3 Summary of the mean total residency time (in days) spent in each reach for all three releases, each for a span of 3 weeks

Release	Watts (days) ± SD	Main (days) ± SD	Kizell (days) ± SD
August	12.0 ± 4.3	6.0 ± 3.5	0.8 ± 0.1
September	15.0 ± 4.6	3.4 ± 2.0	0.6 ± 1.0
October	4.8 ± 2.7	12.0 ± 3.8	0.4 ± 2.1

occurred in the initial fish sampling area approximately 0.8 km downstream of Main. Recaptures came from one fish released into each of Watts and the confluence during the August release, and one fish released into each of Watts, Kizell, and the confluence during the September release. Recaptured LND were not reused for subsequent displacements but indicated a 4% rate of return (i.e. five returns from 123 fish tagged during the first two displacements).

The mean detection efficiency of each PIT array antenna was calculated for 3 weeks following each release (Table 4). The Watts entrance and Main downstream arrays proved to be the most efficient (~85% efficient) followed by the Main and Kizell entrance arrays (~65% efficient). The array upstream of Watts yielded a mean detection efficiency of 46%. Finally, the array upstream of Kizell was on average only 7% efficient.

Discussion

The most compelling result of the displacement experiments was that the majority (97%) of LND displaced into the stormwater drain departed rapidly. Although we anticipated that the stormwater drain would not be selected by fish, we did not anticipate the magnitude of the avoidance and the speed with which fish made the decision to leave. It is well known from community assemblage surveys and tagging/tracking studies that not all fish species are equally distributed within a watershed as a result of variation in physical and chemical characteristics (Paul & Meyer, 2001; Allan, 2004); species-specific environmental tolerances, habitat requirements, and connectivity among habitats influence how and why fish use different reaches within watersheds (Schlosser, 1991; Fausch et al., 2002). Ultimately, selected habitat is a function of food availability, competition, and predation. Experimentally displacing LND within the Watts Creek watershed demonstrated how individual fish respond to different habitats, especially to an altered earthen stormwater drain. The fact that fish exited the drain so rapidly suggests that the conditions in the drain were such that it was desirable or necessary for fish to move to other locations.

Table 4 Summary of the average detection efficiencies (%) for each fixed antenna PIT technology array for each release

Release	Mean detection efficiency (%) ± SD
W1	85.8 ± 4.8
W2	46.7 ± 15.1
M1	66.3 ± 13.1
M2	86.0 ± 3.6
K1	65.1 ± 11.3
K2	7.2 ± 4.7

W1 watts entrance, *W2* watts creek (10 m upstream), *M1* main entrance, *M2* main channel (10 m downstream), *K1* Kizell entrance, *K2* Kizell (10 m upstream)

LND inhabit fast-flowing, shallow systems that contain medium to coarse sediments (Richards, 1978; Mullen & Burton, 1995). Riffles provide a number of services including shelter, oxygen, food conveyance, and spawning habitat (Edwards et al., 1983; Brookes, 1987; Hondzo, 1998). The Kizell stormwater drain is low gradient and lacks the riffle-run-pool sequences that are present in Watts and Main. Moreover, given that Kizell is channelized, it lacks sinuosity. Therefore, Kizell provides limited habitat normally associated with LND residency. Nonetheless, Bliss et al. (2015) found LND in the drain during electroshocking surveys and although it was likely that some LND would exit Kizell, it was expected that LND would take time to explore the drain and that some fish would identify suitable habitats and reside in the system more permanently. The rapid exodus from Kizell was particularly surprising given that LND movement is predominantly nocturnal (Bliss et al., 2015), meaning that the LND were able to gather information about their new habitat, appraise its quality, and decide where to move (i.e. upstream or downstream) in a short time frame. Nonetheless, some LND do reside in

Kizell (according to community surveys) indicating that there are locations within the reach that provide suitable habitat. Indeed, there is some vegetation and riffle habitat in Kizell (Bliss et al., 2015) where LND could persist.

Examining the behaviour of fish released at the confluence of Watts and Kizell provided interesting information about habitat selection by LND. By transporting LND and releasing them at the confluence of three distinct reaches of the stream, we were able to evaluate the behaviour of LND in terms of reach selection. LND released into the confluence moved both upstream into Watts and downstream into Main, but never upstream into Kizell. Whereas LND typically moved into Watts from the confluence in August and September, we observed greater selection of Main during October. This variation suggests that LND could be seeking suitable overwintering habitats. Cunjak (1996) determined that LND, among other small stream fishes, seek overwintering habitats that provide security from harmful physiochemical conditions, such as low oxygen and persistent ice cover, while also providing shelter from predators. Correspondingly, Cunjak & Power (1986) observed blacknose dace (*Rhinichthys atratulus,* Hermann 1804) inhabiting deep water with an abundance of coarse substrates during the winter. The Main reach was generally the deepest within the system and contained the greatest proportion of coarse substrates (Maarschalk-Bliss, 2014). Therefore, it is possible that during autumn, LND began seeking overwintering habitat in Main rather than moving upstream into Watts as they usually did in September and October. However, this implies a mechanism for understanding habitat characteristics in the two reaches and the ability to decide which of the two reaches contained more suitable habitat after exiting Kizell and encountering the confluence of Watts and Main. Although it is possible that the LND moved downstream in October in search of more suitable overwintering habitat, Bliss et al. (2015) did not observe any LND moving from Watts into Main during fall or winter. Moreover, Bliss et al. (2015) observed that the majority of movement of LND (in all seasons) was upstream rather than downstream, making it unclear why October-released LND more frequently moved downstream into Main.

Among the 123 LND transported during the first two displacements (i.e. August, September), five were confirmed to have returned to the initial capture site during subsequent electroshocking surveys. It is not surprising that some of the fish should return to the initial site given that it was selected as the capture site because it had high abundance of LND. However, it is unclear whether the LND returned by chance or due to site fidelity. Many cyprinids are migratory (e.g. common dace *Leuciscus leuciscus*, Linnaeus 1758; Clough & Laddle, 2005) and exhibit homing behaviour that may depend on olfactory imprinting (e.g. white sucker *Catostomus commersonii,* Lacépède 1803; Werner, 1979). In the Watts Creek watershed, it is unlikely that the LND that returned to the capture location could have used olfactory cues to orient given that the fish were transported upstream and chemical cues are transported downstream from upstream sources. Because a small number of the LND actually returned, it is more likely that the fish returned by chance and not systematically via homing. Had LND been transported downstream of the capture site, it would have been better suited to test homing capabilities.

The use of PIT tags and fixed array antennas enabled us to observe LND movements among reaches within the watershed. Although the detection efficiencies of the W1, M1, M2, and K1 arrays were satisfactory, the efficiencies of the remaining arrays were lower. It is possible that water depths above the arrays may have been deep enough that fish could pass undetected above the arrays, because detection efficiency of 12 mm PIT tags generally declines beyond 18 cm (Zydlewski et al., 2001). Lower efficiencies have been observed in instances when large numbers of tags are within the detection range (Castro-Santos et al., 1996), which perhaps could be indicative of synchronous movements. Although movements are predominantly nocturnal (i.e. somewhat synchronized; Bliss et al., 2015), there is no evidence that LND are a schooling fish and therefore low detection rates were not likely to have arisen from synchronous movements of tags over the arrays. The low efficiency of the array located upstream of Kizell may have biased our ability to detect fish entering Kizell. However, a large percentage of the released LND clearly selected Watts and Main and we are therefore confident with the observations. In addition, the paired nature of the telemetry array allowed for redundancies in detections such that even though individuals may have been missed at the upstream Kizell antenna, they could still be detected at the downstream antenna as well as one of the two antennas in their ultimate reach destination.

Experimental displacement of tagged fish within watersheds was a useful tool for testing the reach selection of LND and provided information about the suitability of a stormwater drain for fish residency. We made use of the confluence area where Watts and Kizell join to form Main by translocating some fish into the confluence to determine which direction these fish traveled. The confluence is a small area and we were confident that fish would leave the area in favour of one of the three available reaches, and experimental displacement allowed us to observe the choices made by these fish. In addition, translocation of LND from the Main reach of the watershed into either Watts or Kizell provided information about the habitat suitability in each reach. Ultimately, displacement allowed us to identify activity, dispersal, and homing capacities of the fish, which may not be evident from traditional tagging studies in which fish are released at the capture location. When fish are released into habitats known to be familiar and likely to be suitable, they are unlikely to disperse to the same extent as fish that are released into novel areas with habitat of uncertain quality. Hill & Grossman (1987) indicated that LND will maintain small home ranges and exhibit limited movement; however, using translocation in this study allowed us to demonstrate that LND can be highly mobile when searching for suitable habitat. Using displacement studies with greater coverage of a stream or river (i.e. with active transmitters rather than passive transponders) would provide more information about the mobility of translocated fish.

Conclusions

With a combination of passive telemetry and active displacement, this study demonstrates that LND, a common stream fish, appears to avoid an earthen stormwater drain in favour of natural reaches with different habitat services (e.g. riffles). Because the reaches differ significantly in their composition such that depth, flow, temperature, and substrate type all differ consistently among reaches (i.e. Kizell is shallower, slower, and warmer with finer substrate whereas Watts is the deepest, fastest, and coolest with coarser substrate), it is difficult to identify which feature of the stormwater drain is driving the response of LND to displacement. Nonetheless, it is suggested that the suite of environmental characteristics in Kizell that repelled LND were all attributable to the urbanized aspects of the drain. Remediating or naturalizing urban stormwater drains such that they have higher substrate complexity, hydrological features (i.e. pool and riffle availability), and riparian shading may be necessary to encourage the establishment of LND and other specialist species in stormwater drains (e.g. Jungwirth et al., 1995).

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