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# Denil fishway utilization patterns and passage of several warmwater species relative to seasonal, thermal and hydraulic dynamics

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Abstract – Two different Denil fishways on the Grand River, Ontario, were used as check-points to evaluate the upstream movement of fishes past a low-head weir and to examine the proportions and inferred swimming performance of non-salmonid warmwater fishes that used each fishway type. Traps installed at fishway exits were used to collect fish during 24-hour sampling periods, over 40–51 days each year, from 1995 to 1997. Passage rates, size selectivity, water temperature, water velocity and turbidity for the periods of maximum passage for each year were examined. General species composition from trap samples shifted from catostomids to cyprinids to ictalurids to percids and centrarchids, with some overlap, as water temperatures increased from 8 °C to 25 °C in the spring and early summer. Water depths, and therefore water velocities in each fishway, were independent of river discharge due to variable accumulations of debris on upstream trash-racks. Relationships between the water velocity and the swimming and position-holding abilities of several species emerged. Turbidity was directly related to river discharge and precipitation events, and many species demonstrated maximum fishway use during periods of increased turbidity. This study 1) provided evidence of strongly directional upstream movements among several species that were previously considered non-migratory and 2) describes physical and hydraulic conditions during fishway use for 29 non-salmonid fish species.

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Key words: fishways; fish passage; warmwater species; utilization patterns; Grand River; Ontario

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**Un resumen en español se incluye detrás del texto principal de este artículo.**

## Introduction

Only within the last 15 years have researchers focused on the swimming abilities of non-salmonid warmwater fish and their utilization of fish by-pass structures (Schwalme et al. 1985; Bunt et al. 1999). The pertinent literature contains numerous reports of rheotactic behavior and upstream migration of several non-salmonid or non-clupeid species such as common carp *Cyprinus carpio* (L.) (Rodriguez-Ruiz & Granado-Lorencio 1992), northern pike *Esox lucius* (L.) (Schwalme et al. 1985), white suckers *Catostomus commersoni (*Lacépède) (Schwalme et al. 1985; Bunt et al. 1999) and walleye *Stizostedion vitreum* (Mitchill) (Rawson 1957). These studies indicate that water temperature and discharge are the primary factors that trigger upstream movement. Several researchers have shown that fishway use by freshwater fish is related to reproduction. For example, fish that used a fishway on the Parana River, Brazil (Borghetti et al. 1994) and several fishways in Alberta, Canada (Schwalme et al. 1985) had gonads in advanced stages of development. This is also true among darters (Etheostomidae) and members of several other families in the Grand River, Ontario in the spring and summer (Bunt et al. 1998). To maintain healthy populations of migratory fish, access to spawning and feeding areas must not be restricted. In cases where fish by-pass facilities have been constructed at river obstructions, it is not only vital for fish to ascend or descend successfully, but they must also remain in good physical condition so that their reproductive success is not compromised.

Migration exists in both temporal and spatial dimensions. For any species, fish may occupy several life-stage specific habitats. These include spawning areas, post-spawn (foraging) areas, nursery areas, overwintering areas, refugia during drought or spates and corridors between these areas. For the purpose of this article, fishway use was equated with a strong urge for directional movement into different, separate habitats (Northcote 1978), and this was considered to be evidence of migratory tendencies.

Monitoring fishway use provides data that may illuminate how attraction and passage rates may be increased where necessary. By trapping fish within fishways, it is possible to identify species with migratory tendencies and the environmental variables that affect fishway use. This article describes the movement patterns of 29 warmwater fish species in the Grand River, Ontario, based on data collected from two Denil fishways that were used as checkpoints for upstream movement. Fishway use was examined relative to date, water temperature, turbidity and water velocities within the fishways.

## Study area

The study was conducted at the Mannheim Weir (43°25′N, 80°25′W) on the Grand River, near Kitchener, Ontario, Canada. The Grand River is a mid-order stream that flows 297 km from its source in Dundalk, Ontario to the eastern basin of Lake Erie near Port Maitland. The Mannheim Weir is located approximately mid-way along the river and creates an impoundment for abstraction of regional drinking-water. In the spring and summer, mean depth downstream from the weir is approximately 0.5 m, mean annual discharge is approximately 33 $m^3/s$ and primary substrates consist of cobble and broken rock (Bunt et al. 1998).

## Material and methods

To allow upstream fish passage, the Mannheim Weir was constructed with a Denil fishway at each bank. The construction of the 2.2-m-high weir and fishways was completed in 1990. Prior to 1990, fish movement was not restricted at this site.

Characteristic of Denil fishways, those at the Mannheim Weir use baffles to direct the flow of water back on itself to reduce the velocity of a primary flow through which fish must swim. Water velocities in Denil fishways are low towards the bottom of each fishway channel and increase upward to the water surface, where a layer of fast, turbulent water exists. This implies that fish using these fishways may face varying water velocities depending on swimming depth.

A 27-m Denil fishway that doubled back on itself twice was constructed from reinforced concrete along the west bank of the river. Each of three parallel channels (slope 10%) was fitted with metal baffles spaced approximately 25 cm apart. Two resting pools were provided between the channels. On the east bank of the river, a much simpler and less expensive Denil fishway was constructed. It consisted of a single 11-m reinforced concrete channel with baffles, along a 20% slope. All channels were 0.6 m wide, 2.15 m deep and covered with removable steel plates. Further details of the fishways are reported in the study by Bunt (2001).

Fish activity at the fishways was monitored from 30 March to 17 July 1995, 15 April to 12 July 1996 and 24 April to 17 July 1997. Water temperature and turbidity were monitored and recorded constantly as part of normal operating procedures at the Mannheim Weir pumping station. The Grand River is well mixed, and there are no major differences in temperature within the region immediately upstream or downstream from the weir. Headwater and tailwater elevations were recorded daily, as were water depths at 10 stations within the west fishway and 5 stations within the east fishway. Data collected in the field consisted of measurements of the vertical distance from a series of fixed points along the fishway to the water surface using a calibrated rod to the nearest cm. Water depths were calculated by subtracting the field measurement values from the previously measured vertical distance to the baffle crests for the various measurement locations.

Water velocities, water depths, discharge and water surface profiles in Denil fishways are interdependent, and relationships among them have been described through hydraulic studies of scale and prototype models (Katopodis & Rajaratnam 1983; Rajaratnam & Katopodis 1984; Katopodis et al. 1997). We therefore used equations derived from these scale-model studies to convert depth data into water velocities. Concordance between estimated velocities and actual velocities at the Mannheim Weir was verified with direct measurements of water velocity within the fishways using a Sigma PVM ultrasonic Doppler-shift velocity meter. Maximum water velocities were present within the upper layer (0.8×water depth) of the primary flow, approximately 3 m downstream from each fishway trap. Water velocities immediately prior to trap inspection are reported. The minimum velocities yielded by the velocity rating curves were 0.24 m/s and 0.33 m/s for the west and east fishway, respectively. Water depths and water velocities in each fishway were linked to river levels and debris accumulation on upstream trash-racks and blocking screens. We attempted to keep the fishway traps and blocking screens clear of debris for the duration of the study to reduce fluctuations in water velocities within the fishways. This was accomplished with limited success; and reductions in depth that occurred in response to debris accumulation provided a range of water velocities that fluctuated over several hours. Upstream passage was related to distinct ranges of water velocities for each species that used the fishways.

Both fishways allowed fish to pass freely until they entered the top pool, where fish larger than approximately 60 mm TL were prevented from escaping upstream by a wire mesh blocking screen (mesh size approximately 1.5 cm). It was assumed that no fish caught in the fishway traps were of upstream origin. Escape downstream from the upper pool was averted with a wire mesh funnel-trap. The screens and the funnel-trap were usually cleared of debris two or three times daily. Fishway traps were checked daily or twice daily between 09:00 and 12:00 and from 17:00 to 20:00 from April to mid-July for each of the study years. During sampling episodes, a small-diameter blocking mesh (mesh size 0.5 cm) was used to minimize the loss of trapped fish (particularly small cyprinids). Fish were removed from the fishway traps with dipnets and placed in aerated coolers for examination and enumeration before being released into the river, upstream from the weir and fishways.

## Results and discussion

Variability in the weather in southern Ontario during the three study years affected conditions at the Mannheim Weir. River levels remained constant during the investigation except for two peaks during storms at the end of April and beginning of June 1995, during several occasions from May to July 1996, early May 1997 and the first week of June 1997. When river levels were high, turbidity was concomitantly elevated. Within the fishways, water depths fluctuated depending on the amount of debris on the blocking screens. Debris accumulation varied and was affected by not only the amount of macrophyte material and algae present in the water column, but also by the direction of the prevailing winds. When the wind was from the west, the east fishway blocking screens clogged more rapidly than those at the west fishway. Therefore, the fishways were occasionally under-supplied with water because of limitations with the blocking screens (there was a trade-off between the ability to trap small fish and clogging time), and time constraints associated with twice-daily manual trap inspections. In this study, it was not possible to develop statistically valid measures of efficiency and selectivity between the two fishways. In fact, hydraulic conditions in the fishways may have facilitated passage of some individuals and species that may not be able to use the fishways under normal operating conditions.

White suckers, northern hog suckers *Hypentelium nigricans* (Rafinesque), large common shiners *Luxilus cornutus* (Mitchill) and large striped shiners *L. chrysocephalus* (Rafinesque) began using the west fishway when the water temperatures were consistently above 8 °C. Spawning among white suckers and northern hog suckers usually begins when water temperature is about 10 °C (Barton 1980; Curry & Spacie 1984; Matheney & Rabeni 1995). Although data are not shown, observations from the Grand River suggest that males migrate first, as also reported by Barton (1980). Timing of migrations at the Mannheim fishways corresponded with literature reports indicating that white suckers spawn first, followed shortly thereafter by northern hog suckers (Curry & Spacie 1984).

Fish were observed to use the east fishway 2–3 days after they began to use the west fishway. Smallmouth bass *Micropterus dolomieu* (Lacépède) and all other species began using the fishways when water temperatures were consistently above 10 °C. The maximum temperature of the Grand River in July of each of the study years was approximately 25 °C. The mean turbidity for each year combined was $7.3 \pm 0.6$ NTU (median 4.4 NTU, $n=259$). The range of recorded turbidity was 0.4–95.7 NTU.

Under the observed physical and hydraulic conditions, 29 species of fish used the Mannheim fishways. Over 11,800 fish were sampled from both fishway traps. The diversity of fish species that used the fishways increased annually since 1994, possibly reflecting changes in the Grand River fish community. In 1995, greenside darters *Etheostoma blennioides* (Rafinesque) and green sunfish *Lepomis cyanellus* (Rafinesque) were observed to use the Mannheim fishways for the first time. Species first captured in the fishway traps in 1996 included black crappie *Pomoxis nigromaculatus* (Lesueur), bluegill *Lepomis macrochirus* (Rafinesque), largemouth bass *Micropterus salmoides* (Lacépède), bluntnose minnow *Pimephales notatus* (Rafinesque) and golden shiner *Notemigonus crysoleucas* (Mitchill). Each of these species is often considered to be more lacustrine and better adapted to lentic habitats in impounded waterways than typical riverine species (Martinez et al. 1994).

### West fishway

The west fishway accommodated approximately 67% (7961) of total fish passage at the Mannheim

Weir. There were two patterns of use by the species that were represented in the trap samples. Some species demonstrated constant or protracted use (e.g., striped shiner, common shiner). Other species used the west fishway in a more punctuated fashion (e.g., greater redhorse *Moxostoma valenciennesi* (Jordan), largemouth bass and green sunfish). Twenty-five species used the west fishway, and 22 of these were common to both fishways. Three species (stonecats *Noturus flavus* (Rafinesque), greenside darters and black crappie) used the west fishway exclusively. Fig. 1 summarizes data for each species that used the west fishway, including date of peak usage, temperature during peak usage and water velocity associated with peak usage over the 3-year study period. For example, both largemouth bass and green sunfish used the west fishway most intensively during the first and second week of June in each of the study years. During this period, water temperatures ranged between 16 and 18 °C and water velocities in the fishway varied between 0.24 and 0.4 m/s. Smallmouth bass used the west fishway most intensively between the last week of May and the first week of June. Water temperature was 15–16 °C, and water velocities in the fishway varied between 0.24 and 0.65 m/s. In Wisconsin rivers, smallmouth bass adults also migrate upstream in May when temperatures near

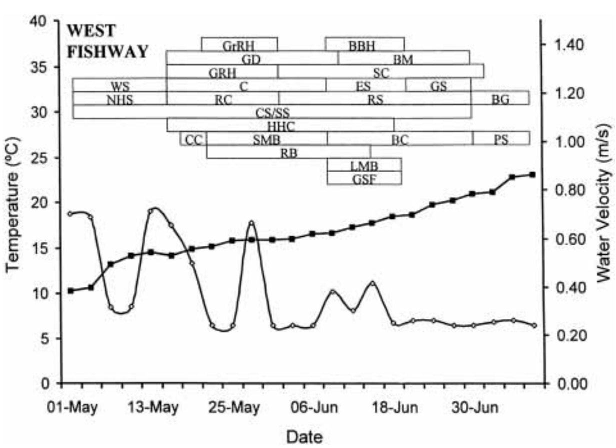


*Fig. 1.* Thermal and hydraulic conditions during use of the west fishway by various fish species in the spring and summer from 1995 to 1997. Horizontal bars indicate periods of maximum passage by each species. Black squares represent water temperature and open diamonds represent water velocities within the fishway. Species abbreviations are as follows: BBH = brown bullhead, GrRH = greater redhorse, SC = stonecat, GD = greenside darter, BM = bluntnose minnow, CC = creek chub, GRH = golden redhorse, CS/SS = common shiners, striped shiners and hybrids, WS = white sucker, C = carp, ES = emerald shiner, GS = golden shiner, NHS = northern hog sucker, RC = river chub, RS = rosyface shiner, BG = bluegill, HHC = hornyhead chub, SMB = smallmouth bass, BC = black crappie, PS = pumpkinseed, RB = rockbass, LMB = largemouth bass and GSF = green sunfish.

15 °C (Langhurst & Schoenike 1990). In July, modest numbers of juvenile smallmouth bass (<100 mm TL) also used the fishways.

Turbidity was strongly correlated with precipitation events at the study site and upstream. Table 1A summarizes the relationships between use of the west fishway and river turbidity. Several species demonstrated maximum use of the west fishway during periods of increased turbidity (i.e., turbidity values greater than the mean turbidity for each year combined). These species included brown bullhead *Ameiurus nebulosus* (Lesueur), black crappie, green sunfish, greenside darter, largemouth bass, pumpkinseed sunfish *Lepomis gibbosus* (L.), rock bass *Ambloplites rupestris* (Rafinesque), and striped shiners. Turbidity during use by brown bullhead, black crappie, greenside darters, rock bass and striped shiners was highly variable. In contrast, several other species used the west fishway most when turbidity was low. These species included bluegill, common carp, common shiners and common shiner/striped shiner hybrids, emerald shiners *Notropis atherinoides* (Rafinesque), hornyhead chub *Nocomis biguttatus* (Kirtland), golden redhorse *M. erythrurum* (Rafinesque), northern hog suckers, river chub *Nocomis micropogon* (Cope), rosyface shiners *Notropis rubellus* (Agassiz), smallmouth bass, stonecats and white suckers. The turbidity of the river during use by common shiners, common shiner hybrids, smallmouth bass and stonecats was highly variable. Too few bluntnose minnows, creek chub *Semotilus atromaculatus* (Mitchill), golden shiners and greater redhorse suckers used the west fishway for any generalizations to be made.

There is some controversy regarding the relative importance of temperature and stream discharge on the initiation of fish migration and spawning. Some authors indicate that sucker migrations begin after a sudden increase in stream discharge with water temperatures near 10 °C (Barton 1980). Conversely, Curry & Spacie (1984) observed that initiation of spawning coincided with an increase in water temperature followed by a decrease in stream discharge. Geen et al. (1966) reported no correlation between temperature and discharge, while other authors suggest that discharge is most important (Walton 1979). From this study, it appears that both parameters are important, as also indicated in a review of factors that affect fish migration by Jonsson (1991).

### East fishway

Approximately 33% (3849) of total fish passage at the Mannheim Weir occurred at the east fishway. Twenty-six species were represented in the fishway

## Fishway utilization patterns

Table 1. A. Total numbers and sizes (mm TL) of species that used the west fishway and corresponding mean and range of turbidity values (NTU) for dates of maximum passage between 1995 and 1997. B. Total numbers and sizes of species that used the east fishway and corresponding mean and range of turbidity. Data for common shiners includes common and striped shiner hybrids

| Species | A) West fishway Total passed | A) West fishway Mean total length±SD | A) West fishway Turbidity | B) East fishway Total passed | B) East fishway Mean total length±SD | B) East fishway Turbidity |
|---|---|---|---|---|---|---|
| *Pomoxis nigromaculatus* | 153 | 130.1±11.3 | 10.8 (1.7–20.0) | 0 | – | – |
| *Lepomis macrochirus* | 91 | 98.2±14.4 | 2.7 (1.7–3.7) | 47 | 98.3±23.7 | 5.3 |
| *Pimephales notatus* | 1 | 79.0 | 10 | 22 | 61.6±5.9 | 1.7 |
| *Ameiurus nebulosus* | 30 | 181.8±44.1 | 10.2 (3.3–20.0) | 10 | 211.0±36.1 | 9.2 (2.0–20.0) |
| *Cyprinus carpio* | 9 | 461.8±223.9 | 3.9 (1.9–7.0) | 5 | 647.4±56.9 | 16.9 (13.8–20.0) |
| *Luxilus cornutus* | 2514 | 136.7±34.7 | 3.6 (1.0–7.8) | 1737 | 114.6±31.3 | 5.3 (0.8–10.0) |
| *L. cornutus/Notropis atherinoides* | 0 | – | – | 1 | 96 | 4.2 |
| *Semotilus atromaculatus* | 2 | 141.0±26.9 | 5.0 (2.1–7.9) | 33 | 87.4±21.9 | 4.7 (2.0–7.4) |
| *Notropis atherinoides* | 516 | 69.5±6.1 | 3.9 (2.9–4.9) | 18 | 69.4±8.6 | 34.8 |
| *Notemigonus crysoleucas* | 1 | 146.0 | 15.3 | 1 | 72.0 | 1.7 |
| *Etheostoma blennioides* | 323 | 68.1±7.6 | 8.1 (2.7–13.5) | 0 | – | – |
| *Lepomis cyanellus* | 38 | 104.0±20.3 | 4.1 (91.0–8.4) | 23 | 98.0±14.6 | 3.3 (1.3–5.3) |
| *Nocomis biguttatus* | 81 | 120.8±14.8 | 3.1 (0.8–6.4) | 94 | 88.8±13.9 | 6.9 (3.3–10.0) |
| *Etheostoma exile* | 0 | – | – | 24 | 45.7±4.0 | 1.2 |
| *Micropterus salmoides* | 25 | 172.5±30.7 | 7.1 (6.8–7.4) | 13 | 185.9±48.5 | 5.2 (0.4–10.0) |
| *Rhinichthys cataractae* | 0 | – | – | 5 | 77.8±13.2 | 10.7 |
| *Moxostoma erythrurum* | 168 | 380.7±50.5 | 3.3 (1.9–5.8) | 365 | 386.7±40.6 | 5.2 (1.7–7.8) |
| *Moxostoma valenciennesi* | 1 | 483.0 | 4.3 | 4 | 406.5±19.6 | 4.0 (1.7–6.2) |
| *Hypentelium nigricans* | 512 | 306.8±43.8 | 3.7 (2.9–5.0) | 51 | 246.6±41.3 | 8.9 (1.2–20.0) |
| *Lepomis gibbosus* | 408 | 102.0±19.1 | 5.6 (1.7–7.8) | 426 | 98.3±18.2 | 6.1 (5.3–7.4) |
| *Etheostoma caeruleum* | 0 | – | – | 1 | 39.0 | 5.7 |
| *Nocomis micropogon* | 4 | 154.5±30.1 | 2.0 (1.8–2.1) | 3 | 99.0±4.6 | 3.2 (2.7–3.7) |
| *Ambloplites rupestris* | 1411 | 125.6±20.4 | 12.8 (7.8–20.0) | 315 | 128.3±22.4 | 4.9 (1.5–10.0) |
| *Notropis rubellus* | 247 | 72.9±6.2 | 4.0 (2.7–5.3) | 5 | 79.8±6.9 | 4.6 |
| *Micropterus dolomieu* | 49 | 305.9±66.3 | 5.3 (1.5–7.8) | 81 | 342.0±82.9 | 3.6 (1.9–6.7) |
| *Noturus flavus* | 221 | 141.6±23.7 | 6.4 (0.8–15.8) | 0 | – | – |
| *Luxilus chrysocephalus* | 44 | 134.5±35.2 | 10.6 (4.8–16.3) | 90 | 113.1±39.4 | 4.9 (2.0–10.0) |
| *Catostomus commersoni* | 1112 | 322.1±65.1 | 3.7 (2.9–5.0) | 475 | 294.3±73.7 | 24.0 (6.4–34.8) |

trap samples, and four species used the east fishway exclusively. These species included rainbow darters *Etheostoma caeruleum* (Storer), longnose dace *Rhinichthys cataractae* (Valenciennes), common/emerald shiner hybrids and Iowa darters *Etheostoma exile* (Girard), but each species except the latter was represented by very few individuals (Table 1B). There were two patterns of use at the east fishway, similar to the observations at the west fishway. Some species demonstrated prolonged or protracted use, such as common and striped shiners and river chub. Punctuated or more temporary use occurred among longnose dace, largemouth bass, bluntnose minnow, rosyface shiner and golden shiner. Fig. 2 summarizes the most intensive periods of use by each species, water temperature and water velocity during use. For example, peak use by largemouth bass at the east fishway occurred during the second week of June at water temperatures between 19°C and 20°C. During use by largemouth bass, water velocities ranged between 0.32 and 0.4 m/s. Green sunfish used the east fishway most intensively during the second week of June and the first week of July.

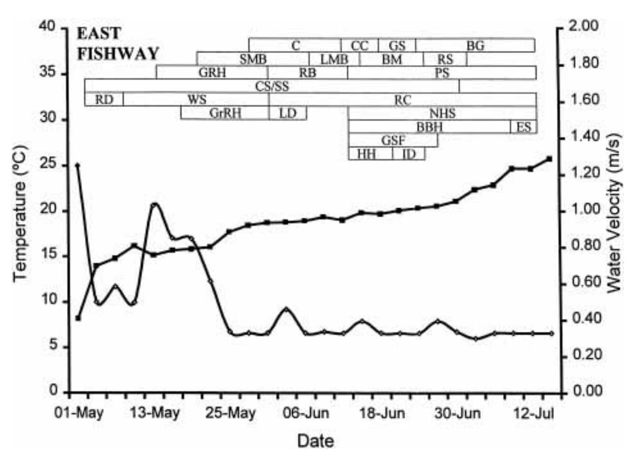


*Fig. 2.* Thermal and hydraulic conditions during use of the east fishway by various species in the spring and summer from 1995 to 1997. Horizontal bars indicate periods of maximum passage by each species. Black squares represent water temperature and open diamonds represent water velocities within the fishway. Species abbreviations are as in Fig. 1 with the following additions: RD=rainbow darter, LD=longnose dace, and ID=Iowa darter.

Water temperatures varied between 19 °C and 21 °C and water velocities were 0.3–0.4 m/s. Smallmouth bass used the east fishway during the same period as the west fishway (i.e., last week of May to the first week of June). During use by smallmouth bass, water temperatures ranged between 16 °C and 17 °C and water velocities were 0.33–0.80 m/s.

The relationships between maximum use of the east fishway and turbidity are summarized in Table 1B. Common carp, emerald shiners, hornyhead chub, golden redhorse, northern hog suckers and white suckers used the east fishway during turbidity conditions that did not match turbidity conditions during maximum use of the west fishway. The species that demonstrated maximum use of the east fishway during periods with elevated turbidity included brown bullhead, common carp, creek chub, emerald shiners, longnose dace, largemouth bass, golden redhorse, northern hog suckers, rock bass and white suckers. Turbidity during use by common shiners and common shiner/striped shiner hybrids, hornyhead chub, northern hog suckers, pumpkinseeds, striped shiners and white suckers was highly variable. Bluegill, bluntnose minnows, green sunfish, Iowa darters, greater redhorse, river chub, rosyface shiners and smallmouth bass used the east fishway most when turbidity was low. It was not possible to generalize relationships between turbidity and use of the east fishway for common shiner/emerald shiner hybrids, golden shiners, and rainbow darters due to insufficient sample sizes.

### Species and size selectivity

There were seasonal species shifts with some overlap, from catostomids to cyprinids, to ictalurids, percids and then centrarchids as water temperatures increased from 8 °C to 25 °C in the Grand River. Maximum fishway use by several species occurred during periods of decreased water clarity (during or after major precipitation events). Species diversity in the fishway traps was affected by the water velocity in the fishways and the swimming and position-holding abilities of the species that entered the fishways (Bunt, unpublished videographic data). Benthic species utilize low velocities in the boundary layers along the fishway walls and floor. Small individuals fit in the spaces between baffles and used burst swimming to progress upstream from refuge to refuge (Bunt, unpublished videographic data). In addition, interspecific interactions (exclusion and predation) likely occurred in and near the fishways, and the importance of this needs to be elucidated in further studies. There was evidence of size selectivity by the Mannheim fishways, as reported for white suckers and smallmouth bass by Bunt et al. (1999). The white suckers that used the west fishway tended to be larger than those that use the east fishway (Table 1). This pattern also occurred among northern hog suckers, hornyhead chub and common shiners. In contrast, there appears to be selection for larger smallmouth bass, common carp and brown bullhead at the east fishway (Table 1). As described by Bunt et al. (1999), size selectivity by Denil fishways is related to species-specific critical swimming speeds and the ability of fish to maintain positions in high-velocity, turbulent flows.

Of the 29 species that used the Mannheim fishways, the only ones that have been reported to have migratory tendencies and use fishways include common carp (Monk et al. 1989), smallmouth bass (Bunt et al. 1999), pumpkinseed (Bunt 2001), greenside darters (Bunt et al. 1998) and white suckers (Schwalme et al. 1985; Katopodis et al. 1991; Bunt et al. 1999). Blackside darters *Percina maculata* (Girard), fantail darters *Etheostoma flabellare* (Rafinesque), northern pike, silver shiners *Notropis photogenis* (Cope), black redhorse *M. duquesnei* (Lesueur), yellow perch *Perca flavescens* (Mitchill), least darters *Etheostoma microperca* (Jordan & Gilbert), Johnny darters *Etheostoma nigrum* (Rafinesque) and brook stickleback *Culaea inconstans* (Kirtland) were present downstream from the Mannheim Weir (C. Bunt, unpublished data) but did not use the fishways. Northern pike and yellow perch have been reported to use other Denil fishways in Canada (Schwalme et al. 1985). Lack of fishway use by these species in this study may have been related to physical and behavioral limitations related to attraction and/or passage efficiency, low abundance downstream from the weir or lack of detection in the fishways. Northern pike, for example, may have used the fishways in March or April, before monitoring began.

It may be argued that just because a fish enters a fishway, this is not necessarily evidence of migratory tendencies. For cases where only a few individuals were counted in the fishways (e.g., bluntnose minnow, golden shiner, greater redhorse, Table 1), the results suggest that these species are either poorly represented downstream from the Mannheim weir, are not attracted or passed effectively by the fishways or were not as mobile during the monitoring period as other species. However, studies on greater redhorse, for example, downstream from the Mannheim Weir indicate that this species occurs in abundance, and that large numbers migrate upstream to spawning riffles near the weir in May and June (Cooke & Bunt 1999) and then migrate several kilometers back downstream after spawning is complete (Bunt & Cooke 2000). On several occasions, greater redhorse were observed in the stilling basin at the Mannheim Weir. The fact that very few greater redhorse were counted in the fishways adds credence to the possibility that the fishways are inefficient for attracting and passing some species, despite occasional under-supply of water.

In summary, there was evidence of strong tendencies for directional movement among several species that were not previously considered migratory. The results of this study may help management agencies ensure that fishways are operational during periods when upstream movement of warmwater fishes can be expected. There are limited data on fishway use by warmwater species, and this is important for the development of design criteria and fishway maintenance programs for non-salmonid migrants. Fishway use and the facilitation of upstream passage over lowhead barrier dams may be enhanced by ensuring that fishways are available (i.e., clear of debris) and easy to locate during periods when fish migration is likely (Bunt 2001). Although steeper fishways may have economic advantages, they may exclude many species or many individuals of a particular species and may reduce or shift the optimum window for passage. Steeper Denil fishways limit use to individuals that are 1) able to swim against very strong flows and/or 2) individuals that exploit velocity refugia within the fishways.

## Resumen

1. En el río Grand (Ontario, Canada) utilizamos dos trampas de peces para evaluar movimientos arriba sobre un azud y para examinar las proporciones e inferir la realización natatoria de especies de peces no salmónidos de aguas templadas que utilizan este tipo de pasos. En las trampas instaladas a la salida de los pasos colectamos peces durante períodos de muestreo de 24 horas sobre 40–51 dias desde 1995 hasta 1997. Examinamos tambien las tasas de pasaje, la selectividad de tamaños, así como la temperatura, la velocidad y la turbidez del agua durante los periodos de paso maximo de cada año.
2. Al aumentar la temperatura de 8 a 25 grados durante la primavera y el inicio del verano, la composición de las especies en los muestreos de las trampas cambió desde catostómidos a ciprínidos, e ictalúridos y pércidos, hasta centrárquidos con algún solapamiento entre ellos. Las profundidades del agua y por ello las velocidades del agua en cada paso de peces fueron independientes del caudal del rio debido a una acumulación variable de "debris" aguas arriba. Emergieron relaciones entre la velocidad del agua y la habilidad de varias especies para mantener posiciones y para nadar. La turbidez estuvo directamente relacionada con el caudal y con la precipitación y muchas especies mostraron un uso maximo de los pasos durante los periodos de turbidez.
3. Este estudio aporta evidencia de movimientos direccionales aguas arriba entre varias especies que eran previamente consideradas no-migratorias. Además, describe las condiciones fisicas e hydraulicas durante el uso de los pasos para 29 especies de peces.

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