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Fishway entrance modifications enhance fish attraction

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Abstract Two Denil fishways on the Grand River, Ontario, were monitored annually since 1994 for activity by several dozen fish species. Fishway entrances were enlarged and repositioned approximately 2 m closer to the weir face, in areas where fish were attracted by weir discharge. These simple modifications resulted in increased attraction efficiency for pumpkinseed, *Lepomis gibbosus* (L.). After modifications, annual relative rate of recapture was 39% (95% confidence interval [CI] = 32–46%), representing a 2.6–3-fold increase in fishway use relative to pre-modification conditions. Median daily recapture rates also increased significantly from 0% at both fishways to approximately 2%. These results suggest that fishway entrances should be located as close to a dam or weir face as possible, but velocity barriers from spillway or tailrace discharge must not compromise access.

KEYWORDS: attraction, efficiency, enhancement, fishways, modifications, warmwater species.

Introduction

To be effective, fishways must attract fish to the entrances, enable fish to swim upstream through the downward flow of water, and do so with minimal energy expenditure. Most research has focused on hydraulics, and whether water velocities within fishways are within species-specific ranges of swimming abilities (Beach 1984). This is of importance as non-leaping species (percids, centrarchids, catostomids, esocids, ictalurids and cyprinids) must swim at least 30% faster than opposing flows to progress upstream (Beach 1984). A good fishway will be easy for fish to find under most flow conditions, and will allow fish to pass upstream without compromising fitness. Access to a fishway may be blocked or restricted by turbulence that disorients fish, supercritical velocity barriers caused by high discharge, or distracting flows in areas away from fishway entrances (Bunt, Katopodis & McKinley 1999). The unique features of each fishway site must be considered to ensure that fishway entrances are well positioned (Beach 1984).

Two Denil fishways at Mannheim weir on the Grand River, Ontario, have been monitored for activity by several dozen fish species annually since 1994. Fishway use was related to water temperature, water velocity, season and the ease with which the entrances

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were located (Bunt 1999). These criteria differed for each species observed. In 1995, an intensive radio telemetry study using a submerged array of seven antennas (Bunt *et al.* 1999), indicated smallmouth bass, *Micropterus dolomieu* Lacépède, and white suckers, *Catostomus commersoni* Lacépède, were attracted by a high discharge area located upstream from the right bank fishway (Fig. 1). In anticipation of an opportunity to modify the fishway entrances, a mark-recapture experiment was initiated. The objective was to illustrate the effects of changes to the fishway entrances using a null hypothesis of no change in attraction for pre- and post-modification conditions, and no difference in attraction at either fishway entrance.

Materials and methods

Study area

This study was conducted at the Mannheim weir on the Grand River, near Kitchener, Ontario during the spring and early summer of 1995 to 1997. The weir, completed in 1990,

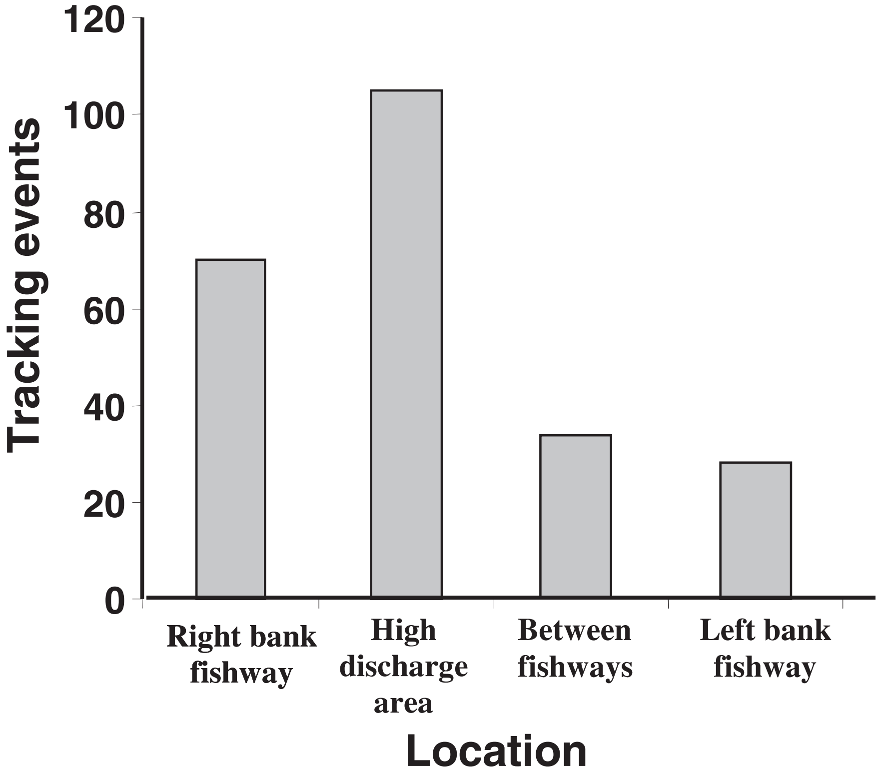

Figure 1. Summary of radio-tracking events downstream of the Mannheim weir from 17 to 31 May 1995. An event was defined as two or more consecutively logged records by up to 53 radiotagged smallmouth bass *Micropterus dolomieu* (Lacépède) or selected catostomids (white sucker *Catostomus commersoni* (Lacépède), northern hog sucker *Hypentelium nigricans* (Lesueur) and golden redhorse *Moxostoma erythrurum* (Rafinesque)) from within 3–4 m of each location.

is 90 m wide and 2 m high, and has a Denil fishway on each bank. Prior to 1990, fish movements were not restricted at this site. 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. The Mannheim weir is located approximately mid-way along the river and creates an impoundment for the abstraction of regional drinking water. Mean depth downstream from the weir is approximately 0.5 m, mean annual discharge is approximately 33 $m^3 s^{-1}$ and the substratum consists primarily of cobble and broken rock (Bunt, Cooke & McKinley 1998).

On the right bank facing downstream, a 27-m long Denil fishway which doubles back on itself twice was constructed (Fig. 2a). Two resting pools were provided between three inclined concrete channels. Each of the three channels was fitted with metal baffles spaced approximately 25 cm apart. The baffles dissipate energy and reduce the velocity in a primary flow of water that fish must swim through to pass upstream. The slope of each channel was 10% and the width of all channels was 0.6 m. On the left bank of the river, a much simpler and inexpensive Denil fishway was constructed (Fig. 3a). It was comprised of one 12-m sloped channel with baffles on a 20% incline. Each fishway entrance was 0.6 m wide and was located approximately 10 m downstream from the weir crest, adjacent to a raised sill on the end of the apron of the weir. The sill was submerged so fish could pass over it.

Fishway entrance modifications

Telemetric and visual data from previous studies at the site indicated that the fishway entrances might be easily re-located closer to the weir in areas where fish were observed to congregate (Bunt *et al.* 1999). Fish were also observed visually and videographically (C.M Bunt, unpublished data) in the vortex of a whirlpool upstream from the left bank fishway entrance. Fish located in these areas bypassed the fishway entrances during upstream migration. They seemed reluctant to swim back downstream and were consequently not attracted to the fishways.

In October 1996, a 2 × 2 m block of concrete was removed from the downstream end of the wing wall near the entrance of each fishway (Figs 2b, 3b). The new entrance began where the most downstream fishway baffles were inserted onto the fishway floor. These modifications: (1) enlarged the fishway entrances, (2) changed their shape and (3) re-positioned them 2 m further upstream in the deeper water of the stilling basin. There appeared to be no significant changes in fishway flow or attraction flow characteristics before or after modifications.

Biological data

River levels remained constant during the investigation except for two peaks during storms at the end of April and beginning of June 1995, during numerous occasions in May and June 1996 and during the first week of June 1997. Pumpkinseed *Lepomis gibbosus* (L.) were chosen for the study because they were relatively unaffected by variable weather conditions over the 3 yr period, because migrations began in early summer. In addition, pumpkinseeds are easy to mark, show few signs of stress when handled, and most

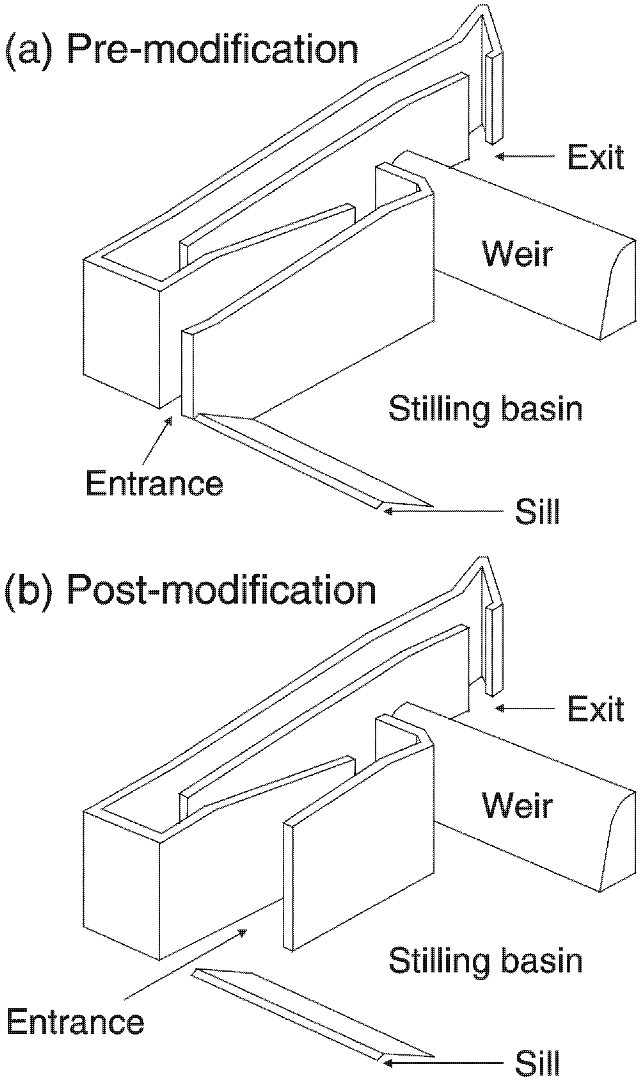

Figure 2. (a) The right bank fishway at the Mannheim weir prior to entrance modifications. (b) The right bank fishway after the entrance had been enlarged and re-located.

importantly, are caught in abundance in fishway traps on the Grand River. In earlier studies, pumpkinseeds used the fishways most frequently from mid-June to mid-July (Bunt 1999), and showed no demonstrable preference for either fishway design.

Fish activity, marking and recapture patterns were monitored for 2 yrs (1995 and 1996) prior to modification of the fishway entrances, to establish a basis for comparison. The effects of the modifications were assessed in 1997. It was assumed that changes in recapture ratios among pumpkinseeds, reflected changes in perceived difficulty associated with locating the fishway entrances. If more fish located the fishway entrances, the overall number of fish that used the fishways should also increase. It is difficult to control for

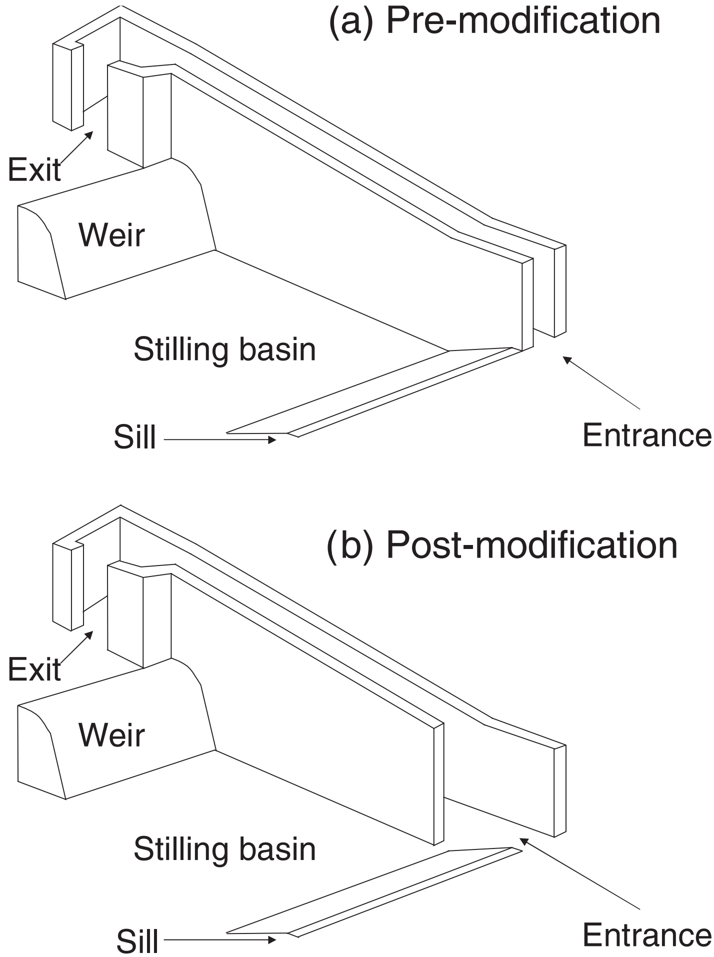

Figure 3. (a) The left bank fishway at the Mannheim weir prior to modification of the entrance. (b) Post-modification configuration and positioning of the entrance.

annual variation in the number of potential fishway users. This variation may result from changes in year-class strength, or environmental conditions that encourage or favour fishway use (Bunt 1999). Recapture ratios were therefore deemed to be more accurate indicators of ability to locate the fishway rather than overall passage rates. It was inherently assumed that association and spatial learning were not factors that affected attraction/avoidance. Furthermore, limited stress caused by handling, marking and release did not positively reinforce the experience of being in a fishway trap.

Both fishways allowed fish to pass freely until they entered the top pool, where escape upstream into the impoundment was prevented by a wire mesh blocking screen (mesh size approximately 1.5 cm square mesh). Escape downstream from the exit pool was prevented with a wire mesh funnel-trap. Both the screens and the funnel-trap were cleared of debris two or three times daily. During sampling, a small diameter blocking mesh (mesh size 0.5 cm) was used to ensure that no trapped fish escaped through the funnel. All fish were removed from the fishway traps with dip-nets and were placed in aerated coolers for examination, measuring (total length to nearest mm) and marking, daily or twice daily between 09:00 and 12:00 hrs and from 17:00 to 20:00 hrs from mid-April to mid-July 1995, 1996 and 1997. Pumpkinseeds from the right bank fishway trap received upper caudal clips and those from the left bank fishway received lower caudal clips. Fish were then released randomly at the left or right bank, approximately 150 m downstream of the weir. Equal numbers of fish from each fishway were released at both river banks.

Recapture (or return) patterns from the fishway traps were analysed for year to year variation with the first 2 yrs (pre-modification) treated as a separate factor. Overall recapture rates and relative recapture rates (RRR) at both fishways were examined. The RRR reflected the percentage of recaptured fish as a function of the number that were available to be recaptured (i.e. running total of marked fish – number previously recaptured). The following formulae were used to generate RRR from samples from each fishway trap:

$$\text{Daily RRR } (\%) = a/(\Sigma b - \Sigma a) \times 100$$

$$\text{Annual RRR } (\%) = \Sigma a/\Sigma b \times 100$$

where a = number recaptured on day i, b = number marked up to day $(i - 1)$, and $\Sigma b > \Sigma a$. The RRR were annually independent because fin clips were superficial and evidence of marking lasted for only one season. Changes in attraction efficiency were estimated using median daily RRR. Medians were analysed for significant differences using the median test ($\alpha = 0.05$, Zar 1984). Estimates of daily RRR are similar to Schnabel population estimates whereby values fluctuate to a large degree until Σa and Σb increase. Fish that returned to either fishway trap more than one time were released upstream from the weir. There was no evidence that fish released upstream subsequently dropped back over the weir and, in the analyses, it was assumed that this did not occur.

Results

In 1995, 214 pumpkinseeds used the fishways and 38% of them used the right bank fishway. A total of 74 pumpkinseeds were marked. Of these, five were recaptured in the right bank fishway and six were recaptured in the left bank fishway. The annual RRR was, therefore, 15% (95% confidence interval [CI] = 7–23%). In 1996, fishway use by pumpkinseed increased by 66%. A total of 355 fish used the fishways (54% used the right bank fishway) and 283 were marked. Of these marked fish, 25 were recaptured in the right bank fishway and 21 were recaptured in the left bank fishway. As such, the annual RRR in 1996 was 16% (95% CI = 12–21%).

There appeared to be a spike in daily RRR at the beginning of each pre-modification season up to 14%. Thereafter, values generally fluctuated between 0 and 3% until mid-July (Fig. 4). Pre-modification RRR at the left and right bank fishways did not differ statistically for either year (t-test on arcsine transformed data, $P > 0.05$). The median

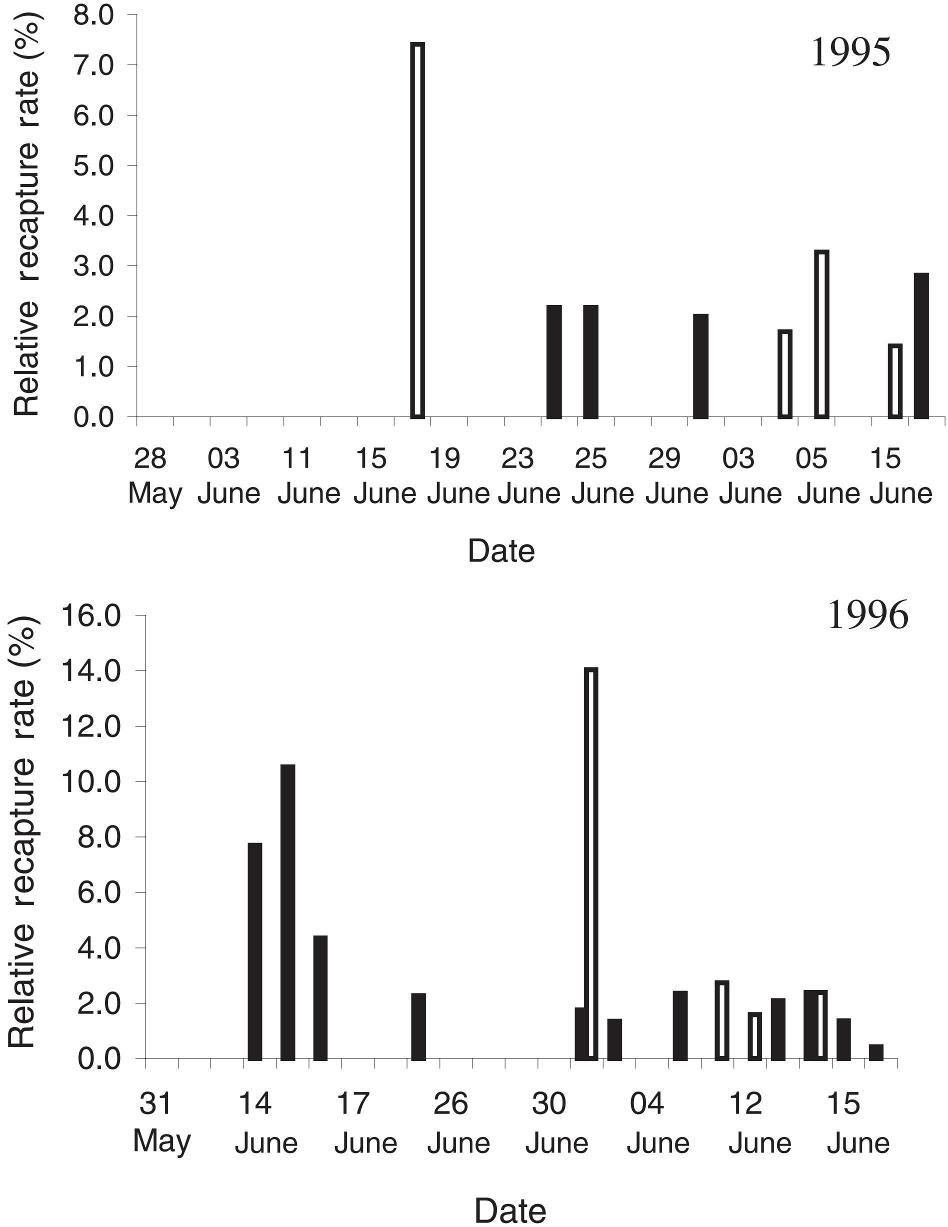

Figure 4. Pre-modification daily RRR of pumpkinseed at the right bank fishway (black bars) and left bank fishway (white bars) for the years 1995 and 1996.

daily RRR at both fishways for both years was 0%. Maximum daily RRR at the right bank fishway was 2.8 and 10.5% in 1995 and 1996, respectively. Maximum daily RRR at the left bank fishway was 13.8% in 1995 and 14.0% in 1996.

In total, 265 pumpkinseeds used the fishways after the modifications in 1997 and 51% of them used the right bank fishway. A total of 181 pumpkinseed were marked, and 31 and

39 fish were subsequently recaptured in the right and left bank fishways, respectively. The post-modification annual RRR was, therefore, 39% (95% CI = 32–46%), representing a 2.6–3-fold increase in recaptures relative to pre-modification conditions. In concordance with pre-modification years, there was a spike in daily RRR at the beginning of the season, but in 1997, values for both fishways reached 50% (Fig. 5). Daily RRR fluctuated at higher levels in 1997 relative to 1995 or 1996. Unlike previous years, marked pumpkinseeds were recaptured in either of the fishway traps every day except one. Median daily RRR, which increased from 0 to 1.9 and 2.1%, at the right and left bank fishways, respectively, were significantly greater in 1997 than either 1995 or 1996 (median test, $0.05 > P > 0.025$ for both fishways).

Discussion

Simple modifications to the entrances of two Denil fishways on the Grand River, Ontario, produced significant increases in recapture rates of pumpkinseeds. Assuming that probability of recapture increased proportionally with ability to locate fishway entrances, increased recapture rates represent concomitant increases in attraction efficiency. Although other species were not investigated in this study, they would probably experience less difficulty in locating the fishways as a direct result of entrance

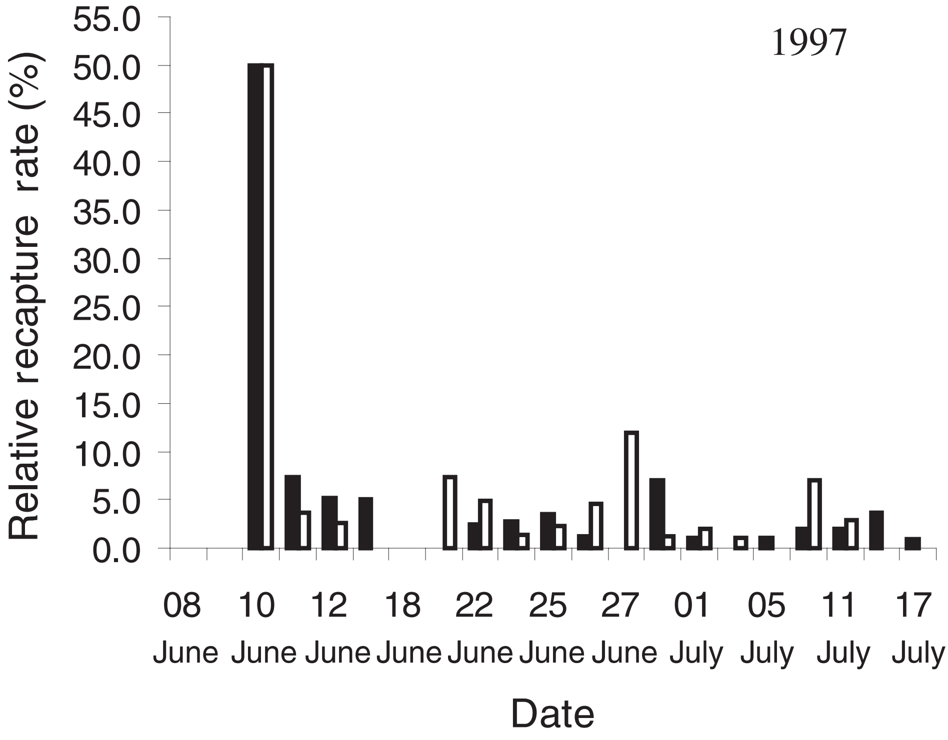

Figure 5. Post-modification daily RRR of pumpkinseed at the right bank fishway (black bars) and left bank fishway (white bars) in 1997.

modifications. Hydraulic conditions downstream of every fishway are unique. However, similarly simple modifications may help increase passage rates of fish at other fishways that have been identified as ineffective.

Deficiencies in fishway efficacy for passing fish may be caused by severe hydraulic conditions (i.e. supercritical water velocities and extreme turbulence) or poorly positioned or improperly designed entrances. One assessment of migration failure by migratory cyprinids revealed that entrance attraction was the major factor that allowed barbel *Barbus barbus* (L.) to successfully use a Denil fishway in Belgium (Baras, Lambert & Philippart 1994). Other researchers have noted that turbulence and high water velocity alter the behaviour of migrating fish and reduce success at locating and using fishways (Barry & Kynard 1986). At the Mannheim weir, migration failure was probably caused by improper location of the fishway entrances, coupled with weir discharge that attracted fish to areas several metres upstream from where the entrances were originally located. Modification improved passage by relocating entrances nearer to areas where fish were observed to congregate. In addition, modification also repositioned the first baffles nearer to the entrances, which may have improved attraction, although no differences in flow at the entrances were apparent.

In a comparative study of vertical slot and Denil fishways, Schwalme, MacKay & Lindner (1985) noted that fish bypassed the fishways and swam through a spillway that was located several metres upstream from the fishway entrances. To prevent this, access to the spillway was blocked thereby encouraging modest numbers of fish to begin re-using the fishways. A study of radiotagged Atlantic salmon, *Salmo salar* (L.), at the Pitlochry Dam on the River Tummel, in Scotland, indicated that fish sometimes failed to locate the entrance to a pool and orifice fish ladder, and appeared to be attracted by tailrace and turbine flows (Gowans, Armstrong & Priede 1999). This situation was rectified by screening off the dam tailrace, thereby preventing access to attraction flows from turbine discharge (Gowans *et al.* 1999).

During upstream migrations, fish are positively rheotactic but avoid the highest velocity flows. In cases where a waterfall or other migratory obstruction is angled across a stream, fish tend to gravitate towards the apex of water below the barrier (Power 1989). This is the ideal location for the entrance to a fishway designed to mitigate the blocking effects of such a barrier. If an obstruction is located squarely across a stream, fishway entrances should be placed as close to the face of the obstruction as possible while avoiding velocity or turbulence barriers that may develop during high flow conditions. If possible, entrances should be positioned to maximize utilization of turbine tailrace, or spillway discharge so that fish are led towards the fishway entrances. At the Mannheim weir, a combination of discharge from the weir itself and from the modified fishways is used to attract fish to the entrances.

Extensive delays have been reported among fish trying to negotiate dams, regardless of the presence of fishways (Fernet 1984; Webb 1990; Harris & Mallen-Cooper 1994; Lucas & Frear 1997; Bunt *et al.* 1999). Reproductive fitness may be affected by the availability of suitable spawning habitat downstream if passage is not possible (Bunt *et al.* 1998), delays that may prevent fish from spawning because of gamete resorbtion (Shikhshabekov 1971), and depletion of energy, injury and direct mortality that may occur as fish repeatedly attempt to swim through or leap past a dam face (C.M. Bunt, unpublished data). Spawning habitat for pumpkinseed exists downstream from the Mannheim weir, but fish that were delayed while attempting to pass upstream may have ultimately been relegated to marginal spawning areas downstream, because ideal areas may have been defended as nesting sites and as such unavailable. Delays and crowding downstream from dams may also result in increased exposure to communicable diseases such as lymphocystis and lymphosarcoma, and may also leave fish vulnerable to angling (Nelson 1983; Fernet 1984). Conservation regulations that prohibit angling immediately downstream of dams are meant to offset this problem to some extent, and help protect migratory fish during certain periods of the year. More importantly, providing effective fishways or improving the efficiency of existing fishways is an ideal way of solving the problem.

Acknowledgments

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References

Baras E., Lambert H. & Philippart J. (1994) A comprehensive assessment of the failure of *Barbus barbus* spawning migrations through a fish pass in the canalized River Meuse (Belgium). *Aquatic Living Resources* **7,** 181–189.

Barry T. & Kynard B. (1986) Attraction of adult American shad to fish lifts at Holyoke Dam, Connecticut River. *North American Journal of Fisheries Management* **6,** 233–241.

Beach M.A. (1984) Fish Pass Design. *Fisheries Research Technical Report* No. 78, Lowestoft, England: Ministry of Agriculture, Fisheries and Food, 46 pp.

Bunt C.M. (1999) Fishways for warmwater species: Utilization patterns, attraction efficiency, passage efficiency, and relative physical output. PhD Thesis, University of Waterloo, Waterloo, Ontario, 163 pp.

Bunt C.M., Cooke S.J. & McKinley R.S. (1998) Creation and maintenance of habitat downstream from a weir for the greenside darter (*Etheostoma blennioides*) – a rare fish in Canada. *Environmental Biology of Fishes* **51,** 297–308.

Bunt C.M., Katopodis C. & McKinley R.S. (1999) Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. *North American Journal of Fisheries Management* **19,** 793–803.

Fernet D.A. (1984) An evaluation of the performance of the Denil 2 fishway at Fawcett Lake during the spring of 1983. Environmental Management Associates, Calgary, Alberta, 51 pp.

Gowans A.R.D., Armstrong J.D. & Priede I.G. (1999) Movements of adult Atlantic salmon in relation to a hydroelectric dam and fish ladder. *Journal of Fish Biology* **54,** 713–726.

Harris J.H. & Mallen-Cooper M. (1994) Fish-passage development in the rehabilitation of fisheries in mainland south-eastern Australia. In: I.G. Cowx (ed.) *Rehabilitation of Freshwater Fisheries*. Oxford: Blackwell Scientific Publications, pp. 185–193.

Lucas M.C. & Frear P.A. (1997) Effects of a flow-gauging weir on the migratory behaviour of adult barbel, a riverine cyprinid. *Journal of Fish Biology* **50,** 382–396.

Nelson R.L. (1983) Northern pike (*Esox lucius*) and white sucker (*Catostomus commersoni*) swimming performance and passage through a step and pool fishladder. Masters Thesis, University of Alberta, Edmonton, Alberta, 242 pp.

Power G. (1989) One rung at a time. *Atlantic Salmon Journal* **38,** 30–32.

Schwalme K., Mackay W.C. & Lindner D. (1985) Suitability of vertical slot and Denil fishways for passing north-temperate, nonsalmonid fish. *Canadian Journal of Fisheries and Aquatic Sciences* **42,** 1815–1822.

Shikhshabekov M.M. (1971) Resorbtion of the gonads in some semi-diadromous fishes of the Arakum Lakes (Dagestan USSR) as a result of regulation of discharge. *Journal of Ichthyology* **11,** 427–431.

Webb P.W. (1990) The behaviour of adult Atlantic salmon ascending the Rivers Tay and Tummel to Pitlochry dam. *Scottish Fisheries Research Report* No. 48. 27 pp.

Zar J.H. (1984) *Biostatistical analysis*. 2nd edn. Englewood Ciffs, New Jersey: Prentice-Hall.