Reinforcement and Validation of the Analyses and Conclusions Related to Fishway Evaluation Data from *Bunt et al.*: "Performance of Fish Passage Structures at Upstream Barriers to Migration"

Bunt CM[1*], Castro-Santos T[2], Haro A[2]

[1]*Biotactic Fisheries Research and Monitoring (Biotactic Inc.), 691 Hidden Valley Road, Kitchener, Ontario, Canada N2C2S4*
[22]*USGS - Leetown Science Center, SO Conte Anadromous Fish Research Center, One Migratory Way, Turners Falls, MA*
** Corresponding Author - cbunt@biotactic.com, www.biotactic.com*

Citation: Bunt CM, Castro-Santos T, Haro A. 2016. Reinforcement and Validation of the Analyses and Conclusions Related to Fishway Evaluation Data from *Bunt et al.*: "Performance of Fish Passage Structures at Upstream Barriers to Migration". River Research and Applications. *In press*

Abstract- Detailed re-examination of the datasets that were used for a meta-analysis of fishway attraction and passage revealed a number of errors that we addressed and corrected. We subsequently re-analysed the revised dataset and results showed no significant changes in the primary conclusions of the original study: for most species, effective performance cannot be assured for any fishway type.

Introduction

"Performance of Fish Passage Structures at Upstream Barriers to Migration" by Bunt *et al.* (2012), was an objective meta-analytical evaluation of multi-species upstream fish passage data across a range of different fishway types and changes in elevation. The purpose of the original paper was to assess whether and to what extent information on performance of existing fishways could guide future fish passage designs, particularly for non-salmonid species. Due to diverse motives and questions underpinning published literature, as well as the complexity that inevitably arises from fieldwork, we elected to publish the raw data along with the paper as an Appendix, with the objective being that any errors we might have committed could be identified and corrected. Williams and Katopodis (2016, this issue) accepted this challenge, and have correctly identified several errors in the original dataset. After reviewing their comments, we have found further errors that have prompted us to re-compile the Appendix and re-run the analysis. This response serves to correct these errors, and also to respond to those comments by Williams and Katopodis with which we disagree. Most importantly, none of the errors in the original manuscript caused significant changes in the primary conclusions of the paper.

Williams and Katopodis' complaints consist of the following four primary allegations: 1) that reporting of data by Bunt *et al.* (2012) in Appendix 1, included significant errors; 2) that designation of passage performance metrics was inappropriate; 3) that Bunt *et al.*'s (2012) use of statistics on insufficient sample sizes was inappropriate; and 4) that the conclusions were not supported by the data. The primary purpose of this response is to address the valid errors that were identified but also to identify and correct errors made by Williams and Katopodis in their own critique.

Recognized Errors in Bunt *et al.* 2012

The following is a detailed list of errors that have been discovered in the original dataset. It includes all of the errors correctly identified by Williams and Katopodis, as well as several that we discovered during our subsequent review of the original datasets.

- Big Carp River and Cobourg Creek data, including fishway slopes, were inadvertently transposed and duplicated (data from O'Connor *et al.* 2003 and Pratt *et al.* 2006 were from the same set of studies). Slopes for fishways described by Sullivan (2004), Franklin (2009) and Franklin *et al.* (2012) have also been corrected, as have entry rates from Sullivan (2004) as indicated in the revised Appendix.
- In some instances, data required for the analysis were not explicit in the published papers that we included in our study. In several cases, we contacted authors directly, and included data from personal communications in the original Appendix (especially related to factors that are generally not reported, such as fishway slope, elevation change from fishway entrance to fishway exit, study site details, and others). We used the most appropriate paper citation so other researchers could follow-up and contact authors directly as we did. In our revised Appendix, we now indicate those papers where personal communications were used in addition to the published data. Also, in some cases, the content of these personal communications have subsequently been published. In those cases we replaced the personal communications with published data in this corrigendum.
- From Naughton *et al.* (2005), we failed to account for attrition in the numbers of fish passing successive dams. Due to limited data, we had to assume that all loss occurred in the reaches between the dams (supported by pers. comm. with G. Naughton, 2015). Under our rubric, these observations were originally included as failed entry, regardless of whether fate of these fish was known. This was necessary to maintain consistency across studies. We now acknowledge that this assumption was invalid: failure by Naughton *et al.* (2005) to report entry into the various fishways and alternate passage routes, means that actual entry and

passage rates are unknown for most of these sites, and we have therefore reluctantly removed data from all of the evaluations that did not clearly separate approach/entry from passage. By contrast, evaluations of the Snake River dams by Naughton *et al.* (2007) documented attraction, and passage was inferred from a statement in the body of the text. Also, we had interpreted Naughton *et al.*'s (2007) data as representing 3 different studies, when in fact they were within-year treatments on a single fishway. Using our criteria, and for consistency with respect to other studies it was more appropriate to include these as single studies. We have adjusted our data accordingly, and this had the effect of boosting within-fishway sample size, but also reducing the number of fishway studies. Taken together, these changes have reduced the number of individual studies in our analysis from 101 to 81.

In addition to the above errors, we have identified the following 2 errors: In Table 1: White Sucker (*Catostomus commersoni*) was designated as anadromous instead of its proper description as potamodromous. This error occurred during the proof stage and had no effect on the analyses. An additional typographical error was discovered in Table 3 of the original paper (Bunt *et al.* 2012). Here, under PC2 for Passage, the soft/spiny attribute had an eigenvector value of -0.479. This value should have been -0.0479. This did not affect our conclusions, but is helpful for comparison with the revised table.

Appropriate Designation of Passage Metrics

The rubric for our paper was founded on the principle that the behavioral and physiological processes associated with passage through a fishway are fundamentally different from those required to find and enter a fishway. This is consistent with long-established design principles, as we and other authors have developed and discussed at length in several other papers (Bunt 2001; Bunt 2001; Bunt *et al.* 1999; Castro-Santos *et al.* 1996; Castro-Santos 2004; Castro-Santos and Haro 2006; Castro-Santos *et al.* 2009; Castro-Santos 2012; Castro-Santos and Haro 2010; Lucas *et al.* 1999). In contrast, Williams and Katopodis claim that the only appropriate method for evaluating fishways is to combine entry and passage into a single unit (i.e., evaluating whether a fish that arrives at a dam ultimately passes it). While we agree that this produces the outcome of interest (passage) it does not provide the detail necessary for understanding the behavioural and biomechanical components that limit passage. Curiously, they go on to suggest that there is an intrinsic characteristic of fishways whereby entrance pool passage is different from passage further upstream. Here again we disagree, and for several reasons. First, the entrance pool designs described by Williams and Katopodis only exist in large fishways, and are not broadly representative of fishways in general. Further, these constitute variable and site-specific structures that are inappropriate for the type of meta-analysis we performed. Each fishway has its own unique characteristics, and while it is important to study these, it is incorrect to insist that this feature is a necessary component of all fishway evaluations.

In our 2012 paper we acknowledged that the metrics we used were necessarily simplifying. In fact, it is appropriate to think of fish passage as a three-stage process, including:1) approach, in which a fish approaches a fishway to a point where they are able to detect the entrance; 2) entry, in which the fish actually does enter the structure; and 3) passage, for those fish that have entered. We detailed this clearly in our original paper and elsewhere (Castro-Santos *et al.* 2009; Castro-Santos and Perry 2012; Castro-Santos and Haro 2010), and find it puzzling that Williams and Katopodis should present this concept as though it were an original idea in their comment. As we clearly stated in our paper, we combined approach and entry phases in our meta-analysis. In some cases we had to assume that fish that had approached an entrance had in fact entered, because the methods employed were not able to adequately discriminate between arrival to within a few meters of the entrance and actual entry. This was a necessary compromise that we made in order to apply the rubric to even the small subset of papers that approximated the data required for our analysis. Given that our primary conclusion was that existing studies failed to adequately describe passage metrics, we feel that we appropriately and directly addressed this issue in the original paper.

Appropriate Designation of Sampling Units

The third primary criticism leveled by Williams and Katopodis is the allegation that we improperly identified sampling units by treating studies within years as independent measures, and that we biased results by including studies with fewer than 10 individuals. We disagree with both of these points. Since passage can and does differ between years, and there is no reason to believe that one year affects another, it is reasonable to consider these to be independent observations. A more valid criticism might have been to suggest that we included site as a random variable, effectively treating individual years as repeated measures within a site. This approach might have made sense, had there been a greater abundance of studies that met our criteria. As it was, however, the available data were too sparse to support this approach, and we maintain that it was, and is, reasonable to consider individual years to be separate, independent observations.

We also disagree with the assertion that we should not have used studies with small sample sizes. In logistic regression, the sampling unit is the individual observation - in this case, whether an individual fish succeeded or failed to enter or pass. Studies with small sample sizes have higher variance than those with large sample sizes, and contribute much less to the estimate of the regression parameters: sample size is included in the analysis, and each observation is weighted accordingly. This means it is completely appropriate to include studies with both large and small sample sizes in the same analysis, because logistic regression explicitly accounts for the underlying variance of each study. (Allison 2012; Bolker *et al.* 2009; Faraway 2005; Gelman and HIll 2007).

Williams and Katopodis (2016, this issue)identified other studies that they felt were inappropriate for inclusion in our analysis for various reasons, such as fishways that included lamprey traps, etc. In each of these cases, studies were treated equally and subjected to the same rubric. These studies fit the criteria, and the fishway designs were functionally similar to existing fishways, and so they were deemed appropriate for inclusion in our dataset.

Conclusions Supported by Data

Given the concerns and objections that were raised, it is not surprising that Williams and Katopodis asserted that our conclusions were not supported by our data. However, had they considered their own arguments more carefully, they would have realized that in most cases they were requesting removal of data, and that the identified errors, once corrected, would only reinforce our original conclusions: passage performance is highly variable, and insufficient studies have been performed to adequately assess whether and to what extent given fishway designs can be broadly recommended for various species.

The most revealing figure in support of this conclusion was the box-whisker plots showing the range of attraction and passage performance for each fishway type (see Bunt *et al.* 2012 - Figure 2). We provide the corrected figure here (Figure 1). The changes in the results were subtle: Mean attraction to pool-and-weir fishways decreased from 77% to 59%, and decreased from 63% to 51% for vertical slot fishways. Passage efficiency decreased slightly for pool-and-weir fishways, with the mean shifting from 40% to 38%. Vertical slot fishways showed a small increase in passage, with the mean shifting from 45% to 51%. Both Denil and nature-like fishway types were generally unchanged with respect to both attraction and passage efficiency. However, we made minor adjustments to the sample sizes for Denil and nature-like fishways based on re-examination of Franklin (2009), which resulted in a slight increase in mean passage efficiency from 70% to 73% for nature-like fishways.

As with the original analysis, and in contrast to attraction efficiency, passage efficiency of nature-like fishways was generally better than through technical fishways (Figure 1 [which corresponds to Figure 2 in Bunt *et al.* 2012] and Table 2). The most important conclusion from these data, however, is not the mean value for either efficiency or any of the fishway types, but their respective ranges. As in the original paper, we continue to see tremendous variability in performance among all fishway types. This has not changed, and if anything, the effect has grown more dramatic. With the exception of attraction to Denil fishways, which had a minimum of close to 20%, both attraction efficiency and passage efficiency for all fishway types ranged from near 0% to 100%. Denil fishways had the fewest studies of any fishway type, and the reduced range for this group probably reflects the absence of data, rather than any intrinsic benefit with respect to attraction.

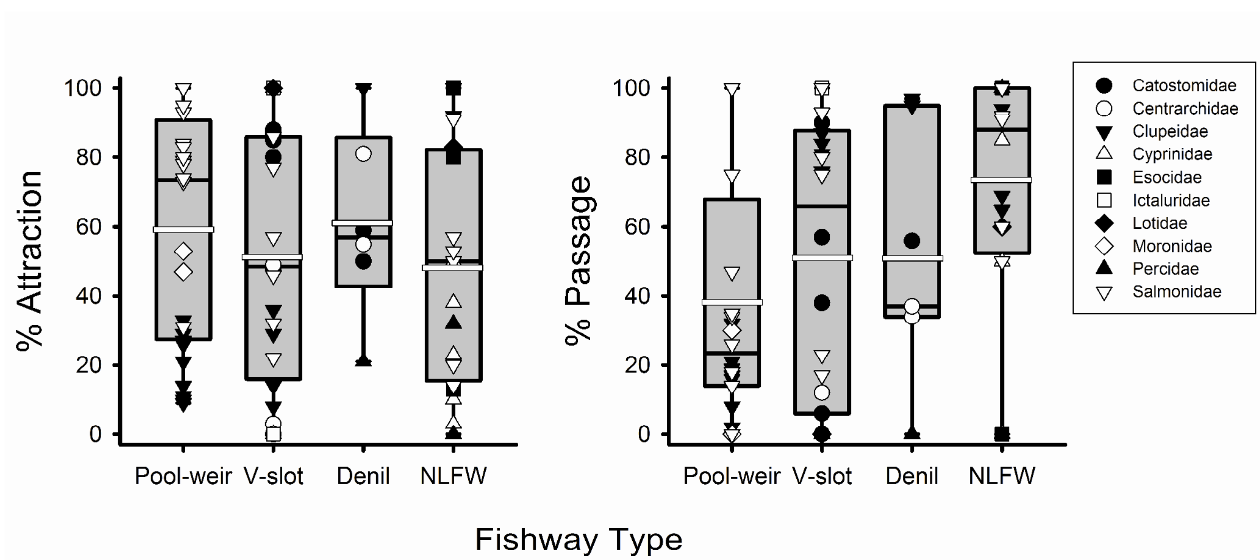

Figure 1. Box-whisker plots summarizing attraction and passage efficiencies of the four primary fishway types: pool-and-weir ('Pool-weir'), vertical slot ('V-slot'), Denil-type ('Denil'), and nature-like fishways ('NLFW'). Data are presented as mean (white horizontal line) and median (black horizontal line), inter-quartile range (boxes), maximum, and minimum (whiskers). In addition, values are presented taxonomically (points) to illustrate how each family performed.

Principal Components Re-Analysis

In the interest of thoroughness, and recognizing the changes to the original Appendix 1, we have also re-run the Principal Components Analysis. The purpose of this approach was to address the dependence among design factors(e.g., pool-and weir fishways are often built with greater slope and height than nature-like fishways, and more likely to be designed specifically to pass salmonids). Each component emphasized different aspects of these relationships, and was used to identify factors that affect attraction and passage (Table 2). The eigenvectors for the attraction components were largely unchanged, and the greatest change in magnitude from the original paper among these components was 0.11, but was usually less than 0.04. Their

Table 1. Summary of meta-analysis data from 17 studies that examined movement of 26 fish species at barriers to upstream fish migration.

Structure Type	n Evaluations	Slope (%)	ΔE (m)	Mean Attraction (%)	Mean Passage (%)	Pooled Attraction (%)	Pooled Passage (%)	Total Efficiency (%)	n Entering	n Exiting	n Fish
Pool-and-weir	28	8.1	13.77	59	38	51	55	28	4088	2231	8031
Vertical-Slot	25	11.1	2.01	51	51	56	51	29	2011	1032	3577
Denil	7	15.7	2.03	61	51	81	77	62	349	269	340
Nature-like	21	3.0	6.33	48	73	63	76	48	641	488	1010
Total	81	9.5	6.03	55	55	54	57	31	7089	4020	12958

effect on attraction did shift, however. In the original analysis, PC3 and PC4 were found to most strongly affect attraction, but the corrected analysis shows PC1to be marginally significant, and PC4 to be strongly significant.

The corrected values support the original conclusions that technical fishways tended to have better attraction than nature-like fishways, especially among coolwater and anadromous species (Table 2). The original coefficient for PC4 was interpreted to reflect the influence of studies of salmonids and clupeids at large fishways -- notably the superior attraction of salmonids at those structures. The only important change from the original analysis is the reduced significance of soft-rayed vs. spiny-rayed morphologies. The original analysis cautiously inferred superior attraction for soft-rayed species that no longer appears to be supported by the data, although in the new analysis, there is still evidence of superior passage by salmonids. In the original analysis, the significant PC3 value also appeared to align with reduced attraction to nature-like fishways. The loss of significance here is consistent with the slight elevation in attraction for this type coupled with reduced attraction to pool-and-weir as well as vertical-slot types (Figure 1).

More significant changes occurred with respect to the passage PCA. Here again the eigenvectors were mostly similar (average change in magnitude of PC1-PC3was 0.03), with the exception of PC4, which had an average change of 0.14 and a maximum change of 0.2. The changes to PC4 are important: in the original analysis, PC2 was strongly significant, and PC4 was only marginally so; in the corrected analysis, PC2 is marginally significant, but PC4 now emerges as strongly significant (Table 2). Eigenvectors show that PC2 was heavily influenced by whether a fishway was technical or nature-like, and by slope, with low-slope and nature-like fishways showing better passage performance. PC4 was mostly influenced by fishway height, or elevation change, with passage success declining with increased height. Thus the original conclusion is still supported: nature-like fishways and/or low slopes appear to have better passage performance than other designs, and passage success decreases with increasing fishway height. It is important to re-iterate (as we stated in the original publication), that nature-like fishways are nearly always built on very low slopes and with low overall height. Thus we are unable to differentiate between effects of design type, slope, and height due to the paucity of comparable studies.

Together the values point to superior overall passage by salmonids (largely driven by Pacific salmon), superior passage through nature-like and low-slope fishways, and reduced passage of non-salmonid species, especially through tall fishways. The correlations between species groups and fishway types and among fishway types, slope and height characteristics -- coupled with a small number of studies that report the data required to differentiate between entry and passage confirms our original conclusion: there are not enough performance data to clearly justify recommendations for any particular fishway type.

Table 2. Revised principal components and logistic regression analysis of attraction efficiency and passage efficiency data. Attribute values are eigenvectors with negative values correlated with reduced attraction/passage and positive values correlated with increased attraction/passage. The first four attributes are dichotomous variables that were coded for the PCA with the left term being assigned 0, and the right term being assigned a value of 1 (e.g., for soft-rayed/spiny-rayed, soft-rayed = 0 and spiny-rayed = 1). PC1 = principal component 1; PC2 = principle component 2; PC3 = principal component 3; PC4 = principal component 4.

	Attraction				Passage			
Attribute	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Soft-rayed / Spiny-rayed	0.433	-0.484	0.748	-0.136	0.363	-0.054	0.870	-0.296
Anadromous / Potamodromous	0.639	0.112	-0.162	0.743	0.539	0.193	0.002	0.383
Warmwater / Coolwater	-0.601	0.065	0.503	0.618	-0.547	-0.040	0.135	-0.478
Technical / Nature-like	0.204	0.865	0.402	-0.218	0.073	0.704	-0.163	-0.267
Slope (%)	---	---	---	---	0.177	-0.676	-0.201	-0.037
Height	---	---	---	---	-0.491	0.079	0.398	0.681
Principal Components Analysis								
Eigenvalues	1.830	1.053	0.719	0.398	2.203	1.576	0.853	0.595
Proportion of Variance	0.458	0.263	0.180	0.099	0.367	0.263	0.142	0.099
Cumulative Proportion	0.458	0.721	0.901	1.000	0.367	0.630	0.772	0.871
Logistic Regression Analysis								
Coefficient	-0.310	0.136	0.040	1.657	-0.263	0.478	-0.286	-1.176
P - value	0.077	0.614	0.885	<0.001	0.102	0.061	0.431	<0.001

CONCLUSIONS

Throughout the Discussion in the original paper, we very clearly stated that the taxonomic scope was intentional, and there were not yet enough data to recommend any particular fishway type for passage of most species. The notable exception was and remains Pacific salmon, of which large proportions enter and pass through pool-and-weir fishways at large dams on the west coast of North America. However, it should be recognized that a semelparous life history, coupled with strong motivation to migrate upstream and near-obligate philopatry, makes Pacific salmon perhaps the least challenging group for which to provide passage. We suspect that if comparable studies were performed with Pacific salmon at other fishway types they would also pass well.

Results and conclusions from our original paper, and this subsequent re-analysis shows that fishway design recommendations for various fish species (including salmonids) should be viewed as preliminary and applied with caution. The data that are required for objective comparison of passage performance are lacking for all groups, and we reiterate our call for standardized and properly applied evaluations of fishways globally[1]. Similar conclusions were described independently by Noonan *et al.*(2012) in a paper published concurrently with Bunt *et al.* (2012; see also Cooke and Hinch 2013 and Foulds and Lucas 2013). Most importantly, future evaluations should be performed using consistent and appropriate techniques that separate components of approach, entry, and attraction. Passage studies should also address variability in migratory motivation (i.e., behavioral and physiological synergistic effects of species/interspecies/gender specific rheotacticity coupled with olfaction and other migratory cues), as well as presence of competing risks. Williams and Katopodis touched on this in their comment. However, they failed to point out that solutions to this problem exist, and are in fact becoming increasingly common. Time-to-event analysis allows for control of effects of covariates that change over time, for variability in individual motivation, and for entry by fish into multiple fishways (Castro-Santos and Haro 2003; Castro-Santos and Perry 2012; Zabel *et al.* 2008; Zabel *et al.* 2014). The methods are uniquely appropriate for analyzing movement and telemetry data, as well as for providing metrics of passage performance that can be objectively compared across sites.

Finally, our original meta-analysis was performed in response to a perceived and real need. The claim by Williams *et al.* (2012), that reductionist approaches are

[1]When the original study was published, there were few data available from South America, Asia or Africa. It is widely believed in these regions, that various North American or European-derived fishway designs do not function effectively, and appear to be of little ecological or economic value (Pelicice and Angostino 2008 but see also Fontes *et al.* 2012) and Wagner *et al.* 2012) for examples of successful passage).

sufficient to 'develop a fishway that will pass most upstream migrants of any species over a dam of just about any height' is difficult to reconcile, given the evidence supported by empirically-derived field data, general observation, and the complexity that arises from the multitude of physical and biological variables that affect fish passage. Focus on basic biology, and ecohydraulics has largely failed to provide effective fish passage solutions(Castro-Santos *et al.* 2009), and we correctly anticipated that by comparing performance of existing structures, we would inspire further investigation. The information presented in the special issue of River Research and Applications in which Bunt *et al.* (2012) was published, clearly shows that all aspects of fish passage are not fully understood; common sense dictates that good science, meaningful debate, and objective and appropriate quantification of performance of existing structures will lead the way to future success in the evolving field of fish passage research.

ACKNOWLEDGEMENTS

We thank Stephanie Choo-Wing, Dana Eddy, and Andrea Curley for assistance with data collection and processing, as well as extensive cross-referencing with original articles. Thanks also to Russell Perry for important improvements to the final manuscript.

REFERENCES

Aarestrup K, Lucas MC, Hansen JA. 2003. Efficiency of a nature-like bypass channel for sea trout (*Salmo trutta*) ascending a small Danish stream studied by PIT telemetry. Ecology of Freshwater Fish 12: 160-168. DOI: 10.1034/j.1600-0633.2003.00028.x

Allison PD. 2012. Logistic Regression using SAS: Theory and Application. SAS Institute, Cary, NC.

Beasley CA, Hightower JE. 2000. Effects of a low-head dam on the distribution and characteristics of spawning habitat used by striped bass and American shad. Transactions of the American Fisheries Society 129: 1316-1330. DOI: 10.1577/1548-8659(2000)129<1316:EOALHD>2.0.CO;2

Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MH, White JS. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology & Evolution 24: 127-135.

Bunt CM. 2001. Fishway entrance modifications enhance fish attraction. Fisheris Management and Ecology. 8: 95-105.

Bunt CM. 2003. Fish passage, critical habitat, and effects of barriers on movement of Northern pike in the Welland River West and Oswego Creek. Prepared for Niagara Peninsula Conservation Authority and the Niagara Restoration Council by Biotactic, Kitchener, Ontario.

Bunt CM, Katopodis C, McKinley RS. 1999. Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. North American Journal of Fisheries Management. 19: 793-803.

Bunt CM, Cooke SJ, McKinley RS. 2000. Assessment of the Dunnville fishway for passage of walleyes from Lake Erie to the Grand River, Ontario. Journal of Great Lakes Research 26: 482-488. DOI: 10.1016/S0380-1330(00)70709-X

Bunt CM, Castro-Santos T, Haro A. 2012. Performance of fish passage structures at upstream barriers to migration. River Research and Applications. 28:457-478.

Calles EO, Greenberg LA. 2005. Evaluation of nature-like fishways for re-establishing connectivity in fragmented salmonid populations in the River Emån. RiverResearch and Applications 21: 951-960. DOI: 10.1002/rra.865

Calles EO, Greenberg LA. 2007. The use of two nature-like fishways by some fish species in the Swedish River Emån. Ecology of Freshwater Fish 16: 183–190.DOI: 10.1111/j.1600-0633.2006.00210.x

Castro-Santos T. 2004. Quantifying the combined effects of attempt rate and swimming capacity on passage through velocity barriers. Canadian Journal of Fisheries and Aquatic Sciences. 61: 1602-1615.

Castro-Santos T. Adaptive fishway design: a framework and rationale for effective evaluations. 2012. Koblenz, Germany, Monitoring, Funktionskontrollen und Qualitätssicherung an Fischaufstiegsanlagen. 2. Kolloquium zur Herstellung der ökologischen Durchgängigkeit der Bundeswasserstraßen. Ref Type: Conference Proceeding. pp 76-89.

Castro-Santos T, Cotel A, Webb PW. 2009. Fishway evaluations for better bioengineering -- an integrative approach. In Challenges for diadromous fishes in a dynamic global environment. AJ Haro, KL Smith, RA Rulifson, CM Moffit, RJ Klauda, MJ Dadswell, RA Cunjak, JE Cooper, K.L. Beal, TS Avery (eds). American Fisheries Society, Symposium 69, Bethesda, MD pp. 557-575.

Castro-Santos T, HaroA. 2003. Quantifying migratory delay: a new application of survival analysis methods. Canadian Journal of Fisheries and Aquatic Sciences. 60: 986-996.

Castro-Santos T, Haro A. 2006. Biomechanics and fisheries conservation. In Fish physiology volume 23: fish biomechanics. Edited by RE Shadwick and GV Lauder. Academic Press, New York pp. 469-523.

Castro-Santos T, Haro A. 2010. Fish guidance and passage at barriers. Fish locomotion: an eco-ethological perspective. P Domenici, BG Kapoor (eds). Science Publishers, Enfield, New Hampshire. 62-89. ISBN 9781578084487

Castro-Santos T, Haro A, Walk S. 1996. A passive integrated transponder (PIT) tagging system for monitoring fishways. Fisheries Research. 28: 253-261.

Castro-Santos T, Perry RW. 2012. Time-to-event analysis as a framework for quantifying fish passage performance. In Telemetry Techniques. NS Adams, JW Beeman, J Eiler (eds). American Fisheries Society, Bethesda, MD pp. 427-452.

Cooke SJ, Hinch SG. 2013. Improving the reliability of fishway attraction and passage efficiency estimates to inform fishway engineering, science and practice. Ecological Engineering. 58:123-132.,

FarawayJJ. 2005. Extending the Linear Model with R: Generalized Linear, Mixed Effects, and Nonparametric Regression Models. Chapman & Hall/CRC, New York.

Fontes HM, Castro-SantosT, MakrakisS, GomesLC, LatiniJD. 2012. A barrier to upstream migration in the fish passage of Itaipu Dam (Canal da Piracema), Paraná River basin. Neotropical Ichthyology 10: 697-704.

Foulds WL,Lucas MC.2013. Extreme inefficiency of two conventional, technical fishways used by European river lamprey (*Lampetra fluviatilis*). Ecological Engineering58: 423-433.

Franklin AE. 2009. Evaluation of nature-like and technical fish passes for the passage of alewife (*Alosa pseudoharengus*) at two costal streams in New England. Master's thesis, University of Massachusetts, Amherst.

Franklin AE, Haro A, Castro-Santos T, and Noreika J. 2012. Evaluation of nature-like and technical fishways for the passage of alewife (*Alosa* *pseudoharengus*) at two coastal streams in New England. Transactions of the American Fisheries Society. 141: 624-637.

Gelman A, Hill J. 2007. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press, New York.

Gowans ARD, Armstrong JD, Priede IG. 1999. Movements of adult Atlantic salmon in relation to a hydroelectric dam and fish ladder. Journal of Fish Biology 54: 713-726. DOI: 10.1111/j.1095-8649.1999.tb02028.x

Karppinen P, Mäkinen TS, Erkinaro J, Kostin VV, Sadkovskij RV, Lupandin AI, Kaukoranta M. 2002. Migratory and route-seeking behaviour of ascending Atlantic salmon in the regulated River Tuloma. Hydrobiologia 483: 23-30.

Lucas MC, MercerT, Armstrong JD, McGinty S, Rycroft P. 1999. Use of a flat-bed passive integrated transponder antenna array to study the migration and behaviour of lowland river fishes at a fish pass. Fish.Res. 44: 183-191.

Lundqvist H, Rivinoja P, Leonardsson K, McKinnell S. 2008. Upstream passage problems for wild Atlantic salmon (*Salmo salar* L.) in a regulated river and its effect on the population. Hydrobiologia 602: 111-127. DOI: 10.1007/s10750-008-9282-7

Naughton GP, Caudill CC, Keefer ML, Bjornn TC, Stuehrenberg LC, Peery CA. 2005. Late-season mortality during migration of radio-tagged adult sockeye salmon (Oncorhynchus nerka) in the Columbia River. Canadian Journal of Fisheries and Aquatic Science 62: 30-47.

Naughton GP, Caudill CC, Peery CA, Clabough TS, Jepson MA, Bjornn TC, Stuehrenberg LC. 2007. Experimental evaluation of fishway modifications on the passage behaviour of adult Chinook salmon and steelhead at Lower Granite Dam, Snake River, USA. River Research and Applications 23: 99-111 DOI: 10.1002/rra.957

Noonan MJ, Grant JWA, Jackson CD. 2012. A quantitative assessment of fish passage efficiency. Fish and Fisheries. 13: 450-464.

Pelicice FM, Agostinho AA. 2008. Fish-passage facilities as ecological traps in large Neotropical rivers. Conservation Biology. 22: 180-188.

Pon LB, Cooke SJ, Hinch SG. 2006. Passage efficiency and migration behaviour of salmonid fishes at the Seton Dam Fishway. Final Report for the Bridge Costal Restoration Program, Project 05. Se. 01, BC Hydro, Vancouver, British Columbia.

Pratt TC, O'Connor LM, Hallett A, McLaughlin RL, Katopodis C, Hayes DB, Bergstedt RA. 2006. Balancing habitat fragmentation and control of invasive species: Enhancing selective fish passage at Sea Lamprey control barriers. Transactions of the American Fisheries Society. 138: 652-665.

Roscoe DW, Hinch SG. 2008. Fishway passage, water diversion and warming temperatures: Factors limiting successful spawning migration of Seton-Anderson watershed sockeye salmon. Final Report for the Bridge Costal Restoration Program, Project 07. BRGH 01, BC Hydro, Vancouver, British Columbia.

Sullivan TJ. 2004. Evaluation of the Turners Falls fishway complex and potential improvements for passing adult American shad. Masters thesis, University of Massachusetts Amherst, US.

Wagner RL, Makrakis S, Castro-Santos T, Makrakis MC, Pinheiro-Dias JE, Fuster-Belmont R. 2012. Passage performance of long-distance upstream migrants at a large dam on the Paraná River and the compounding effects of entry and ascent. Neotropical Ichthyology 10: 785-795.

Williams JG, Armstrong G, Katopodis C, Larinier M, Travade F. 2012. Thinking like a fish: A key ingredient for development of effective fish passage facilities at river obstructions. River Res.Applic. 28: 407-417.

Williams JG and Katopodis C. 2016. Commentary-Incorrect Application of Data Negates Some Meta-analysis Results in Bunt *et al.* (2012): Commentary on Bunt *et al.* (2012) RRA. River Research and Applications this issue.

Zabel RW, Burke BJ, Moser ML, Peery CA. 2008. Relating dam passage time of adult salmon to varying river conditions using time-to-event analysis. Am.Fish.Soc.Symp. 61: 153-163.

Zabel RW, Burke BJ, Moser ML, Caudill CC. 2014. Modeling temporal phenomena in variable environments with parametric models: An application to migrating salmon. Ecological Modelling 273: 23-30.

APPENDIX 1: This study is meant to enhance and clarify interpretations based on a re-examination of all of the papers that were analyzed. Due to the usefulness of the data, we have re-published the corrected Appendix in its entirety:

Location	Structure Type	Slope	Elevation Change (m)	Monitoring Method	Attn (%)	Pass (%)	Total Eff.	n Entering	n Exiting	n	Species	Source
Town Brook (Billington St. Fishway 2006) - Plymouth, MA	Pool/weir	0.140	0.91	PIT	29	21	6	28	6	96	Alewife (*Alosa pseudohargengus*)	Franklin 2009, Pers. Comm.
Connecticut R. — (Cabot 1999) MA, US	Pool/weir	0.100	20.11	PIT	33	19	13	99	19	299	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. — (Cabot 2000) MA, US	Pool/weir	0.100	20.11	PIT	21	17	11	154	27	717	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. –- (Cabot 2001) MA, US	Pool/weir	0.100	20.11	PIT	26	16	7	140	22	544	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. — (Cabot 2002) MA, US	Pool/weir	0.100	20.11	PIT	27	2	1	152	3	563	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. (Spillway 1999) – MA, US	Pool/weir	0.100	10.67	PIT	14	17	14	42	7	299	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. (Spillway 2000) – MA, US	Pool/weir	0.100	10.67	PIT	10	8	3	73	6	717	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. (Spillway 2001) – MA, US	Pool/weir	0.100	10.67	PIT	9	32	3	47	15	544	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. (Spillway 2002) – MA, US	Pool/weir	0.100	10.67	PIT	11	14	2	63	9	563	American Shad (*Alosa sapidissima*)	Sullivan 2004
Neuse R. - (Quaker Neck Dam 1996) NC, US	Pool/weir	0.080	2.03	Radio	100	0	0	12	0	12	American Shad (*Alosa sapidissima*)	Beasley & Hightower 2000
Neuse R. - (Quaker Neck Dam 1997) NC, US	Pool/weir	0.080	2.03	Radio	29	0	0	4	0	14	American Shad (*Alosa sapidissima*)	Beasley & Hightower 2000
(Stornorrfors D. 1995) Umeälven, Sweden	Pool/weir	0.075	18	Radio	73	0	0	22	0	30	Atlantic salmon (*Salmo salar*)	Lundqvist *et al.* 2008
(Stornorrfors D. 1997) Umeälven, Sweden	Pool/weir	0.075	18	Radio	84	26	22	46	12	55	Atlantic salmon (*Salmo salar*)	Lundqvist *et al.* 2008
(Stornorrfors D. 1999) Umeälven, Sweden	Pool/weir	0.075	18	Radio	83	34	28	50	17	60	Atlantic salmon (*Salmo salar*)	Lundqvist*et al.* 2008

(Stornorrfors D. 2001) Umeälven, Sweden	Pool/weir	0.075	18	Radio	79	18	14	55	10	70	Atlantic salmon (*Salmo salar*)	Lundqvist *et al.* 2008
(Stornorrfors D. 2002) Umeälven, Sweden	Pool/weir	0.075	18	PIT/Radio	78	47	37	385	181	493	Atlantic salmon (*Salmo salar*)	Lundqvist *et al.* 2008
(Stornorrfors D. 2003) Umeälven, Sweden	Pool/weir	0.075	18	PIT/Radio	83	35	29	325	114	391	Atlantic salmon (*Salmo salar*)	Lundqvist *et al.* 2008
(Stornorrfors D. 2004) Umeälven, Sweden	Pool/weir	0.075	18	PIT/Radio	93	14	13	468	66	503	Atlantic salmon (*Salmo salar*)	Lundqvis t*et al.* 2008
(Stornorrfors D. 2005) Umeälven, Sweden	Pool/weir	0.075	18	PIT/Radio	80	47	38	360	169	450	Atlantic salmon (*Salmo salar*)	Lundqvist *et al.* 2008
Kola Fijord (Lower Tuloma 2000) - Russia	Pool/weir	0.037	19	Radio	31	75	23	4	3	13	Atlantic salmon (*Salmo salar*)	Karppinen *et al.* 2002
R. Tummel (Pitlochry D. 1995) – Scotland	Pool/weir	0.048	15	Radio	74	100	74	29	29	39	Atlantic salmon (*Salmo salar*)	Gowans *et al.* 1999
Snake R. (Lower Granite Dam 2001) - WA, US	Pool/weir	0.066	11.9	Radio	100	100	100	472	472	472	Chinook Salmon (*Oncorhynchus tshawytscha*)	Naughton *et al.* 2007, Pers. Comm.
Snake R. (Lower Granite Dam 2002) - WA, US	Pool/weir	0.066	11.9	Radio	100	100	100	291	291	291	Chinook Salmon (*Oncorhynchus tshawytscha*)	Naughton *et al.* 2007, Pers. Comm.
Snake R. (Lower Granite Dam 2001) - WA, US	Pool/weir	0.066	11.9	Radio	100	100	100	173	173	173	Steelhead (*Oncorhynchus mykiss*)	Naughton *et al.* 2007, Pers. Comm.
Snake R. (Lower Granite Dam 2002) - WA, US	Pool/weir	0.066	11.9	Radio	100	100	100	344	344	344	Steelhead (*Oncorhynchus mykiss*)	Naughton *et al.* 2007, Pers. Comm.
Columbia R. (Fishway Rocky Reach 1997) - WA, US	Pool/weir	0.063	27.7	Radio	95.1	100	95.1	233	233	245	Sockeye Salmon (*Oncorhynchus nerka*)	Naughton *et al.* 2005, Pers. Comm
Neuse R. - (Quaker Neck Dam 1996) NC, US	Pool/weir	0.080	2.03	Radio	47	0	0	7	0	15	Striped Bass (*Morone saxatilis*)	Beasley & Hightower 2000
Neuse R. - (Quaker Neck Dam 1997) NC, US	Pool/weir	0.080	2.03	Radio	53	30	16	10	3	19	Striped Bass (*Morone saxatilis*)	Beasley & Hightower 2000
Connecticut R. (Gatehouse D. 1999) – MA, US	V-slot	0.056	2.4	PIT	36	87	31	91	79	251	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. (Gatehouse D. 2000) – MA, US	V-slot	0.056	2.4	PIT	29	81	23	73	59	256	American Shad (*Alosa sapidissima*)	Sullivan 2004

Connecticut R. (Gatehouse D. 2001) – MA, US	V-slot	0.056	2.4	PIT	14	84	11	49	41	358	American Shad (*Alosa sapidissima*)	Sullivan 2004
Connecticut R. (Gatehouse D. 2002) – MA, US	V-slot	0.056	2.4	PIT	8	76	6	25	19	316	American Shad (*Alosa sapidissima*)	Sullivan 2004
Big Carp R. (2003) – ON, CA	V-slot	0.067	0.4	PIT	100	100	100	2	2	2	Brown Bullhead (*Ameiurus nebulosus*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook (2003) – ON, CA	V-slot	0.210	0.93	PIT	0	0	0	0	0	1	Brown Bullhead (*Ameiurus nebulosus*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook (2003) – ON, CA	V-slot	0.210	0.93	PIT	57	100	57	4	3	7	Brown Trout (*Salmo trutta*)	*Pratt et al. 2009,* Pers. Comm.
Big Carp R. (2003) – ON, CA	V-slot	0.067	0.4	PIT	100	0	0	1	0	1	Burbot (*Lota lota*)	*Pratt et al. 2009,* Pers. Comm.
Big Carp R. (2003) – ON, CA	V-slot	0.067	0.4	PIT	0	0	0	0	0	1	Common Shiner (*Notropiscornutus*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook (2003) – ON, CA	V-slot	0.210	0.93	PIT	100	0	0	2	0	2	Creek Chub (*Semotilus atromaculatus*)	*Pratt et al. 2009,* Pers. Comm.
Seton River (Seton D. 2005) – BC, CA	V-slot	0.069	7.4	Radio	22	100	22	2	2	9	Pink Salmon (*Oncorhynchus gorbuscha*)	Pon *et al.* 2006
Cobourg Brook (2003) – ON, CA	V-slot	0.210	0.93	PIT	32	6	2	18	3	57	Rainbow Trout (*Oncorhynchus mykiss*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook(2005) – ON, CA	V-slot	0.210	0.93	PIT	58	43	25	26	6	57	Rainbow Trout (*Oncorhynchus mykiss*)	*Pratt et al. 2009,* Pers. Comm.
Big Carp R. (2003) – ON, CA	V-slot	0.067	0.4	PIT	51	11	6	26	3	53	Rock Bass (*Ambloplites rupestris*)	*Pratt et al. 2009,* Pers. Comm.
Big Carp R. (2004) – ON, CA	V-slot	0.067	0.4	PIT		0	0	6	0		Rock Bass (*Ambloplites rupestris*)	*Pratt et al. 2009,* Pers. Comm.
Big Carp R. (2005) – ON, CA	V-slot	0.067	0.4	PIT	29	50	15	2	0	66	Rock Bass (*Ambloplites rupestris*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook (2003) – ON, CA	V-slot	0.210	0.93	PIT	0	0	0	0	0	1	Rock Bass (*Ambloplites rupestris*)	*Pratt et al. 2009,* Pers. Comm.
Seton River (Seton D. 2005) – BC, CA	V-slot	0.069	7.4	Radio	77	100	77	23	23	30	Sockeye Salmon (*Oncorhynchus nerka*)	Pon *et al.* 2006
Seton River (Seton D. 2007) – BC, CA	V-slot	0.069	7.4	Radio	86	93	80	44	41	51	Sockeye Salmon (*Oncorhynchus nerka*)	Roscoe &Hinch 2008
Seton River (Seton D. 2008) – BC, CA	V-slot	0.069	7.4	Radio	86	80	69	51	41	59	Sockeye Salmon (*Oncorhynchus nerka*)	Roscoe &Hinch 2008
Big Carp R. (2003) – ON, CA	V-slot	0.067	0.4	PIT	86	35	30	349	132	409	White Sucker (*Catostomus commersoni*)	*Pratt et al. 2009,* Pers. Comm.

Big Carp R. (2004) – ON, CA	V-slot	0.067	0.4	PIT	97	91	88	392	353	449	White Sucker (*Catostomus commersoni*)	*Pratt et al. 2009,* Pers. Comm.
Big Carp R. (2005) – ON, CA	V-slot	0.067	0.4	PIT	97	66	64	348	197	394	White Sucker (*Catostomus commersoni*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook (2003) – ON, CA	V-slot	0.210	0.93	PIT	80	7	6	297	17	373	White Sucker (*Catostomus commersoni*)	*Pratt et al. 2009,* Pers. Comm.
Cobourg Brook (2005) – ON, CA	V-slot	0.210	0.93	PIT	85	11	9	180	11	374	White Sucker (*Catostomus commersoni*)	*Pratt et al. 2009,* Pers. Comm.
East River (Steeppass 1 2007) - Guilford, CT	Denil	0.296	0.9	PIT	100	97	97	146	141	146	Alewife (*Alosa pseudohargengus*)	Franklin 2009, Pers. Comm
East River (Steeppass 2 2007) - Guilford, CT	Denil	0.096	0.29	PIT		95		91	86		Alewife (*Alosa pseudohargengus*)	Franklin 2009, Pers. Comm
Grand R. (Mannheim Weir East) – ON CA	Denil	0.200	2.15	Radio	55	33	18	29	10	53	Smallmouth Bass (*Micropterus dolomieu*)	Bunt *et al.* 1999
Grand R. (Mannheim Weir West)– ON CA	Denil	0.100	2.15	Radio	82	36	30	43	16	53	Smallmouth Bass (*Micropterus dolomieu*)	Bunt *et al.* 1999
Grand R. (Dunnville) – ON, CA	Denil	0.105	4.4	Radio	21	0	0	5	0	24	Walleye (*Sander vitreus vitreus*)	Bunt *et al.* 2000
Grand R. (Mannheim Weir East) – ON CA	Denil	0.200	2.15	Radio	59	38	22	19	7	32	White Sucker (*Catostomuscommersoni*)	Bunt *et al.* 1999
Grand R. (Mannheim Weir West)– ON CA	Denil	0.100	2.15	Radio	50	55	28	16	9	32	White Sucker (*Catostomus commersoni*)	Bunt *et al.* 1999
East River (Nature-like fishway 1 2007) - Guilford, CT	Nature-like fishway	0.071	0.97	PIT	92	69	63	212	146	231	Alewife (*Alosa pseudohargengus*)	Franklin 2009, Pers. Comm.
East River (Nature-like fishway 2 2007) - Guilford, CT	Nature-like fishway	0.071	1.19	PIT		65		141	91		Alewife (*Alosa pseudohargengus*)	Franklin 2009, Pers. Comm.
Town Brook (Rock Ramp 2006) - Plymouth, MA	Nature-like fishway	0.042	1.33	PIT	100	94	94	103	97	103	Alewife (*Alosa pseudohargengus*)	Franklin 2009, Pers. Comm.
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	50	50	25	2	1	4	Baltic Vimba (*Vimba vimba*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	20	92	18	26	24	132	Brown Trout (*Salmo trutta*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	57	50	29	4	2	7	Brown Trout (*Salmo trutta*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2002) - Sweden	Nature-like fishway	0.025	9.25	PIT	14	91	13	35	32	253	Brown Trout (*Salmo trutta*)	Calles & Greenberg 2005

R. Eman (Upper Finsjo 2001) - Sweden	Nature-like fishway	0.018	2.7	PIT	50	100	50	12	12	24	Brown Trout (*Salmo trutta*)	Calles & Greenberg 2005
R. Eman (Upper Finsjo 2002) - Sweden	Nature-like fishway	0.018	2.7	PIT	53	100	53	17	17	32	Brown Trout (*Salmo trutta*)	Calles & Greenberg 2005
Tirsbaek Brook (1999/2000) - Denmark	Nature-like fishway	0.017	2.2	PIT	91	60	55	30	18	33	Brown Trout (*Salmo trutta*)	Aarestrup *et al.* 2003
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	83	60	50	5	3	6	Burbot (*Lota lota*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	38	86	33	13	11	34	Chub (*Squalius cephalus*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	10	100	10	1	1	10	Common Bream (*Abramis brama*)	Calles & Greenberg 2007
Oswego Crk. (Canborough Weir) – ON, CA	Nature-like fishway	0.040	1	RADIO	100	100	100	5	5	5	Northern Pike (*Eso xlucius*)	Bunt 2003
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	13	0	0	1	0	8	Northern Pike (*Esox lucius*)	Calles & Greenberg 2007
Welland R. (Port Davidson Weir) – ON, CA	Nature-like fishway	0.037	0.65	RADIO	80	100	80	8	8	10	Northern Pike (*Esox lucius*)	Bunt 2003
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	32	100	32	8	8	25	Perch (*Perca fluviatilis*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	23	50	12	10	5	44	Roach (*Rutilus rutilus*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	3	0	0	1	0	31	Rudd (*Scaridinus erythropthalmus*)	Calles & Greenberg 2007
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	50	100	25	7	7	14	Tench (*Tinca tinca*)	Calles & Greenberg 2005
R. Eman (Lower Finsjo 2001) - Sweden	Nature-like fishway	0.025	9.25	PIT	0	0	0	0	0	4	Zander (*Stizostedion lucioperca*)	Calles & Greenberg 2007