META-ANALYSES, METRICS AND MOTIVATION: MIXED MESSAGES IN THE FISH PASSAGE DEBATE

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ABSTRACT

Over recent years there has been increasing challenge to the accepted wisdom that the environmental impacts of river engineering can be adequately mitigated through the installation of infrastructure, such as fish passes. This has led to a debate on the value of fish passage with some arguing that increased research and development will advance solutions for a variety of structures that are suitable for multiple species and transferable to different regions. Others suggest that policies and management strategies should reflect the realisation that current mitigation technology frequently fails and can itself have negative impacts. Meta-analyses of the results of studies on fish passage effectiveness has led to the challenge of conventional views by highlighting lower than expected efficiencies, wide variation between and within fish pass designs, and bias towards consideration of a limited number of commercially important species mainly from northern temperate regions. Results of meta-analyses can also be controversial and difficulties can arise when nuances associated with individual studies are lost, and when metrics used are not standardised. Intrinsic variation in fish passage efficiency between and within species due to differences in patterns of movement and motivation may not be considered, and in many situations current metrics are not appropriate. Quantification of variation in trends in fish passage efficiency over time and with spatial scale is lacking and should be the focus of future reviews. It is time to accept that fish passage does not provide a universally effective mitigation solution,

particularly when designs and strategies are transferred to other regions and species for which they were not originally designed. Admitting to cases of failure is an essential first step to advancing water resources planning and regulation based on well-informed decision-making processes.

KEY WORDS: fish pass efficiency; fishway; attraction efficiency; diadromous; fish migration; dams

INTRODUCTION

Volume 28 of *River Research and Applications* (2012) includes a special issue (4) entitled, "*Fish Passage: An Ecohydraulics Approach"*. The publication represents the culmination of several years of work by a team of researchers brought together through a Leverhulme Trust funded international network grant. The aim of the programme was to bridge key gaps in the field of fish passage research identified (Kemp 2012). These gaps were: (1) between disciplines, including the behavioural ecology of fish, fluid dynamics, and engineering; (2) between approaches and methodologies, for example, empirical experimental and field-based research and modelling; (3) between theoretical and applied science; (4) among regions, with participants representing North and South America, Europe and Asia; and (5) among generations, with senior researchers working closely with those in the early stages of their career. A further outcome of the Leverhulme network programme was the stimulation of debate in the sphere of fish passage research and application.

In this issue, Williams and Katopodis provide a commentary on the meta-analysis conducted by Bunt et al. (2012), published in the special edition as part of the Leverhulme network outputs. After careful and thorough scrutiny of some of the original data presented, Williams and Katopodis outline their concerns related to the incorrect assignment of attraction and passage metrics to specific fishway types, and the misinterpretation and/or incorrect application of most of the data relating to two types of fishway, the “pool-and-weir” and “vertical slot” designs. In response, Bunt et al. recognise and admit to errors in the information previously presented and provide a corrected version with reanalysis of the data and new results. Bunt et al. emphasise that after this re-analysis the broad conclusions of the original paper remain unchanged. Rarely has data used in analysis of fish passage effectiveness been as rigorously and closely scrutinised as in the case described here, and the debate generated should be of interest to the wider community.

Based largely on the outcomes of the Leverhulme international network, this paper provides an overview of the debate initiated during the development of the special issue and that has since progressed over recent years. Interested researchers and practitioners in this field are encouraged to read Bunt et al. (2012) and others papers published in that issue along with the resulting commentary and response presented here. This paper will not focus on the details of the commentary and subsequent response, as the readers will no doubt form their own opinions and conclusions based on the information presented. Instead, some broader points related to the approaches adopted, metrics used, and overall construct of the debate are discussed. Further, the implications of the debate, within the wider context of employing fish passage to mitigate for the negative ecological impacts of river engineering, will be highlighted.

META-ANALYSIS, THE TRADITIONAL NARRATIVE, AND THE FISH PASSAGE DEBATE

Bunt et al. (2012) present a meta-analysis describing fish passage effectiveness for different designs. The quantitative review of the results obtained from multiple studies using a meta-analysis approach has been widely adopted in the medical and social sciences for decades (Schulze 2004). Although narrative reviews remain the most common method employed in the biological and ecological sciences, the value of meta-analysis is increasingly recognised and its use more frequently adopted for a wide variety of data (Gurevitch and Hedges 2001).

In the sphere of fish passage research, the power of meta-analysis to identify biases in understanding and gaps in knowledge is exemplified by Roscoe and Hinch (2010) and Noonan et al. (2012). Based on the premise that fishways and other passage facilities frequently prevent or delay the passage of fishes, the Roscoe and Hinch (2010) meta-analysis results from a review of 96 peer-reviewed scientific articles that report the effectiveness of fish passage monitoring. Important biases and gaps are identified. The majority of studies focus on adult fish and Salmoniformes. Those conducted in the tropics tend to consider a broader taxonomic scope than those that focus on temperate regions. Consideration of physiological factors during fish pass evaluation is rare. Environmental, structural, and behavioural mechanisms for passage failure are considered in most North American studies, but in only half of those conducted in Europe, South America, and Australia. Few studies monitor the migration of the subject species once they exit the focal fish passage facility. Noonan et al. (2012) also describe clear biases in a quantitative assessment of fish passage efficiency, in this case based on 65 scientific articles. Supporting Roscoe and Hinch (2010), fish other than the Salmoniformes are infrequently considered and when aggregated, the passage efficiency for both upstream and downstream moving fish is lower for non-salmonid species. Similar to Bunt et al. (2012), the Noonan et al. (2012) study highlights variation in efficiency between fishway design, although the results differ. They find that pool-and-weir, pool-and-slot, and natural fishways exhibit the highest efficiencies; Denil and fish locks / elevators the lowest. For upstream moving fish, the efficiency is lower when fishway slope is high, but increases with fishway length and water velocity, indicating hydrodynamics likely exert an important influence. The conclusions obtained from such quantitative reviews provide solid foundations on which to base future recommendations and changes in policies.

In the special issue of *River Research and Applications*, Bunt et al. (2012) present a meta-analysis to assess the effectiveness of different fishway designs for upstream moving fish. Focusing on 19 studies that report both attraction and passage efficiency (based on detection of individually marked fish approaching and passing the fishway), they find that attraction is highly variable between designs and descends in order from pool-and-weir, vertical slot, Denil, to nature-like. There is an inverse relationship between mean passage and attraction efficiency, with the highest passage for nature-like fishways, followed by Denil, vertical slot, and pool-and-weir. Of relevance to the current debate, they conclude that, in most cases, existing data are not sufficient to support fishway design recommendations and that more information is needed to design optimal fish passage solutions. In the same issue, Williams et al. (2012) provide a traditional narrative to highlight a historic bias in fish passage research towards economically important salmon in North America and Europe and describe the decades of trial and error required to develop effective facilities. Also of relevance, they suggest that, with sufficient laboratory testing, it is possible to determine hydraulic conditions that fish will actively use as a conduit and develop a fishway that will effectively pass most upstream migrants of any species over a dam of just about any height. This viewpoint is further reinforced by Katopodis and Williams (2016) who continue to emphasise that when sufficient hydraulic and biological knowledge exists for a species, it is possible to construct successful fishways and that with continued advances in science it is hoped that facilitates will one day be created that all species will be able to successfully pass. It is this positive perspective that for some represents one side of the current debate (T. Castro Santos and C. Katopodis pers. comm.). A very different perspective is articulated by Brown et al. (2013) in a paper entitled, "*Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies*". The authors argue that low passage efficiencies from the first dam to the spawning grounds (mean = 3% for American shad *Alosa sapidissima*) indicate failure. They suggest it is time to admit fish passage does not provide an effective strategy to restore populations of diadromous species and that other options, such as dam removal, may be more appropriate. Superficially, such perspectives appear to represent differing positions in a polarised argument.

METRICS, MOTIVATION, AND TRENDS IN EFFICIENCY

The strength of meta-analyses to provide quantitative analysis to summarize knowledge, re-evaluate or integrate conclusions from past studies, and justify recommendations for future research and policy is well-demonstrated. When conducted appropriately, meta-analysis provides a powerful and rigorous alternative to the more traditional, narrative discussions that attempt to make sense of a rapidly expanding literature (e.g. Glass, 1976). However, the results of meta-analyses can also be controversial, with several difficulties that can arise from using meta-data identified (see Greco et al. 2013 for an interesting discussion related to health). A common challenge when aggregating and comparing results collected in multiple studies by different researchers over a range of spatial and temporal scales is the potential for a lack of standardisation in approach and metrics used. In this issue, Williams and Katopodis make considerable effort to define the nomenclature used, including for *fish passage effectiveness*. While recognising that attraction, entrance and exit, and time to pass are accommodated in their measure of effectiveness, they fail to provide definitions for the important underpinning efficiency metrics on which this is based. Nevertheless, it is clear that definitions provided in the published literature do vary and the quantitative review of studies that report metrics for measuring different things is problematic, leading to difficulties in their interpretation. It is the recognition of this that is driving current efforts to develop standards for the evaluation of fish passage solutions in Europe (Washburn et al. 2015).

Both Noonan et al. (2012) and Bunt et al. (2012) attempt to identify relationships between fishway design and passage performance. Williams and Katopodis (this issue) criticise this approach and argue that the hydraulics created by the fish pass, rather than the design *per* *se*, is a key factor that governs efficacy, and that common designs can vary considerably in size and slope. While the relationship between hydrodynamics and fish response is undoubtedly a key factor, a focus on analysing performance of different fishway designs is both logical and pragmatic. Guidance on the provision of fish passage solutions (e.g. Armstrong et al. 2010) tend to focus on fishway design, providing recommendations for selection based on specific scenarios of slope, head, and discharge. Rarely are hydrodynamic conditions encountered at fishways adequately recorded in studies of fish passage performance and until they are, the use of design type as a proxy for hydrodynamics, which in the passageway at least can be generalised, makes sense. However, approaches that focus on physical and hydrodynamic characteristics of fish passes (or indeed screening systems) alone, while ignoring inter- and intraspecific variation in behavioural ecology can quickly run into difficulty. One of the greatest challenges of comparing effectiveness of fishway design among studies, and particularly among species, is the limited consideration of variation in patterns of movement and levels of motivation displayed. As already illustrated by Roscoe and Hinch (2010) and Noonan et al. (2012), fish passage research is biased towards the Salmoniformes. The majority of studies focus on the migratory life-stages of anadromous salmonids during which synchronous, seasonal, highly active, and directed movements to reach spatially distinct habitats (e.g. the ocean as smolts, Moore et al. 1998 for Atlantic salmon *Salmo salar*; or river spawning grounds as adults, Hinch and Rand 2000 for sockeye salmon *Oncorhynchus nerka*) within a finite period of time are exhibited. Passage performance metrics, such as attraction, entrance and passage efficiency, and time to pass (a measure of delay) cater well for this movement strategy. High efficiencies, usually reported as percentages, and low time to pass, are considered positive outcomes. However, the movement ecology of many other families of fish is by nature very different and may be far less synchronous, regular, active, and directed. Using a single example to illustrate this point, Zigler et al. (2003) observe large variation in movement of paddlefish (*Polyodon spathula*) in the upper Mississippi catchment based on radio-telemetry data. Some individuals display high site fidelity, others demonstrate long movements (> 420 km of the study site), some groups exhibit synchronous spring migrations, whereas others do not, and probable spawning movements occur in both the upstream and downstream directions.

Conceptually, the movements of different life-stages and species of fish might be visualised as positions on a continuum of advection-diffusion processes, with directed migrants having a higher advection coefficient than those that are not (Jonzén et al. 2011; McKenzie et al. 2009). Traditional passage performance metrics may be inappropriate for fish with low advection coefficients that show a propensity for more random, non-directed searching motions. Some may consider these species / life-stages to be less motivated to pass structures than directed migrants; yet fragmentation of habitat may be equally as damaging from an ecological perspective. This may explain, at least partially, why some fishway designs appear less efficient for non-salmonids (Noonan et al. 2012) and why interpretation of passage performance when comparing between species should be undertaken with both caution and appreciation of diversity of movement patterns. For example, values of efficiency for fish passes designed primarily for salmon are difficult to interpret when applied to white sturgeon (*Acipenser transmontanus*) on the lower Columbia River. Relative to the number of fish available in the estuary, the numbers passing the most downstream dams annually are relatively low (Parsley et al. 2007), although it remains unclear what proportion of the population would be expected to ascend the river in the absence of river engineering (Jager et al. 2016).

Even among the salmonids, there is considerable variation in migratory patterns, with some species (e.g. pink salmon, *Oncorhynchus gorbuscha*) exhibiting relatively fixed patterns of anadromy, whereas other demonstrate variability in traits such as the timing of migration, age at migration, or whether to migrate at all (Bond et al. 2015). Within a species, variation in movement strategies among populations and life-history stages are well-documented, as is the case within populations. For example, brown trout (*Salmo trutta*) can exhibit continuous variation between the extremes of freshwater residency and anadromy (e.g. Etheridge et al.

2008) and for those that are not anadromous, patterns of movement vary between components that are described as stationary (high site fidelity) and mobile (e.g. Bridcut and Giller 1993; Diana et al. 2004). Indeed, recent research has described autumn and spring seaward migratory phenotypes among juveniles, with spring migrants exhibiting higher motivation and faster rates of travel (Winter et al. 2016). Furthermore, patterns of movement within individuals can change over fine spatial and temporal scales. A downstream migrating juvenile salmon (smolt) passively transported with the current will display a highly advective motion as the displacement increases linearly with time. However, smolts frequently exhibit periods of activity that limit displacement, which while not diffusive, reflect reduced advection. For example, seaward migrating coho salmon (*O. kisutch*) smolts move in the direction of the current and hold for extended periods in areas of low current velocity, a pattern described as saltatory (Moser et al. 1991). When viewed at fine resolution scales, downstream migrating juvenile salmonds are known to actively reject areas of abrupt velocity transition encountered followed by repeated periodic approach and further rejection (e.g. Kemp et al. 2005). Such intraspecific diversity in movement also likely contributes to the variability in fish passage performance metrics reported for different studies.

Previous fish passage focused meta-analyses have neglected to investigate trends in pass performance over the historic timescale of fishway developments. Differences in opinion in the fish passage debate may to some extent, reflect variation in experience dictated by spatial and temporal scales over which fishways have been developed, and target species for which they have been designed. When focusing on a limited number of species at the catchment scale, improvements in fish passage efficiency may be observed over time if sufficient resources are allocated to a process of incremental improvement through research and development driven by well-established legislative obligation (e.g. the Columbia River) (Figure 1 – line A). Under an alternative scenario, efficiency may remain unchanged over long periods of time in regions where there is insufficient legislation or lack of enforcement to ensure adequate resources are allocated to robust monitoring of effectiveness and further research and development to facilitate incremental improvement (Figure 1 – line B). Conversely, effectiveness may decline overall when viewed from a global scale perspective in which fish passage solutions are transferred from regions where they were originally developed for a limited number of species to different biogeographic areas in an effort to cater for the needs of multiple species / communities (Figure 1 – line C). In such cases, not only may overall efficiency decline, but there might also be unintended negative consequences, including enhanced spread of non-native fishes, genes, diseases and contaminants carried by wild and hatchery fish (McLaughlin et al. 2013). Future meta-analyses that attempt to quantify changes in fish passage efficiency over time and between regions, and the occurrence of unintended consequences, will likely prove useful.

MIXED MESSAGES IN THE FISH PASSAGE DEBATE

Although conducting and interpreting meta-analyses that attempt to summarise the results of multiple studies on fish pass effectiveness can be challenging, efforts to quantify the variability in passage performance associated with specific designs have proven useful because they provide a basis on which to challenge conventional wisdom. A serious impediment to advancing effective fisheries management and conservation practices stems from an often-held and generally unchallenged view that the negative environmental impacts of river engineering, such as the construction of impoundments, can be effectively mitigated, (e.g. through the provision of fish passes). To some extent, this perspective has arisen from frequent reference in the literature to often-cited examples of well-designed and effective fish passes, such as some of those developed on the Columbia River for upstream moving salmon resulting from several decades of extensive research (Williams 2008). Indeed, it is true that several fish passes installed at the Columbia River dams do work well once salmon find and enter them, although delay continues to exert a challenge (Caudill et al. 2007) and can have important ecological implications (e.g., high energetic expenditure while congregation of high densities of fish may attract predators or facilitate the transfer of disease, McLaughlin et al. 2013). However, it is advisable to interpret consensus apparent in the literature with care, not least because of the potential for publication bias in which positive results demonstrating the effectiveness of solutions may be more likely to reach the public domain. Improved understanding of where and why mitigation efforts fail to work, as well as might be expected, or indeed may themselves have negative effects, will help advance more balanced perspectives.

An important question in the development of fish passage solutions around the world is: How transferable are lessons learnt on efficient design and operation between regions and species? Experience from the Columbia River has been widely referred to when considering mitigation of impacts of planned dam construction in different regions (e.g. Ferguson et al. 2011 in reference to the Mekong River). For example, in a review of existing research on fish passage and its application to the construction of large dams on the Mekong River (Schmutz and Mielach 2015), citation of examples from the Columbia River occurred no less than 13 times. Further, in a study referring to the Xayaburi Dam currently under construction on the mainstem Mekong River in Laos, Baumann and Stevanella (2012) suggest that fishways developed for fish fauna of temperate regions work relatively well when transferred to tropical rivers. It appears that ignoring poor performance of some fishways, or at least high variability in effectiveness, is common and the paradigm that fish passes provide a universal panacea for the mitigation of negative effects of river engineering on fish populations persists. This portrayal is misleading in two ways: first, when viewed from a catchment perspective, the delivery of effective fish passage has not always been achieved, even on the Columbia River, for many species including salmon. Second, fish passage does not necessarily provide effective solutions when applied elsewhere and in some cases may be environmentally damaging (e.g. Pelicice and Agostinho 2008; McLaughlin et al. 2013).

While acknowledging the importance of the Columbia River as a focal point for high quality research related to fish passage, predominantly in relation to Pacific salmon (*Oncorhynchus* species), limitations and failings must also be recognised. This point is illustrated through the consideration of the decline of Pacific lamprey (*Entosphenus tridentatus*) populations, an anadromous species of high cultural and conservation significance. Until relatively recently, the traditional fishways on the mainstem dams were inadequate to facilitate effective upstream passage of adults motivated to reach spawning grounds. Using radio-telemetry, Moser et al. (2002) observed that only 3% of tagged lamprey were able to pass the three most-downstream dams in the lower Columbia River. Driven by such observations and the desire to conserve populations, lamprey specific fish passes have subsequently been developed (Moser et al. 2011). Even for Pacific salmon, catchment scale restoration of stocks through the provision of fish passes has proven an impossible goal, with an estimated loss of one-third of historic habitat (Nehlsen et al., 1991). In one case, it is estimated that 1491 barriers in the Willamette and Lower Columbia River catchment block 14,931 km of stream, resulting in the loss of >40% of stream habitat to anadromous fishes (Sheer and Steel, 2006).

Inefficient fish passage may reflect the application of solutions to species / guilds and regions for which they were not originally designed. Historic development of fish passage in Europe, dating back to at least the seventh century (Sanz Ronda and Martínez de Azagra, 2013), likely represents a combination of river engineering associated with early demographic advance and perhaps the more common occurrence of anadromy at northerly latitudes (McDowall 1988). Despite this long legacy of mitigating for environmental impacts of impoundments, ineffectual fish passage continues to be widely demonstrated in Europe for some species, including those exhibiting motivated and directed migrations. For example, based on the results of a PIT telemetry study on the Yorkshire Derwent, the passage efficiency for a Denil fish pass, a design commonly employed in the UK, for upstream migrating adult lamprey (*Lampetra fluviatilis*) is 0%, even though attraction efficiency is nearly 92% (Foulds and Lucas, 2013). The reader may be forgiven for concluding that such results reflect a lack of interest in this species during the design of fish passage solutions, perhaps due to a lack of commercial or conservation significance. However, historically lamprey were highly valued in England[1], and some fisheries continue in southwestern Europe and northern Baltic countries. Further, lamprey are of high conservation concern, with all three species found in the UK (*L. fluviatilis*, *L. planeri* and *Petromyzon marinus*) listed under Annex II of the European Union Habitats Directive (92/43/EEC).

In contradiction to the view of Baumann and Stevanella (2012), the application of fish passage solutions developed in northern temperate regions to the tropics, sub-tropics, and neo-tropics is challenging for a multitude of reasons. Not only does the climate and geophysical template (e.g., geology, geography, river type) vary between regions, but so does fish species richness and abundance, diversity of life histories, body morphologies, swimming capabilities, and behaviours. It is perhaps unsurprising, therefore, that the validity of employing not only fish pass designs, but associated management strategies developed in northern temperate regions, has been questioned. Insightful challenges to commonly held views on fish passage have recently emerged from South America, particularly Brazil. There, the scale of many reservoirs means that they, in addition to the dams that create them, pose insurmountable barriers to the movement of eggs, larvae, and adults of many species, potentially rendering fish passage an ineffectual conservation tool (Pelicice et al. 2015; Pompeu et al. 2012 also in the special edition of RRA). Compared to those in many northern regions, the more diverse fish communities that inhabit such systems exhibit a higher complexity of life history and patterns of movement between critical habitats spatially distributed both up- and downstream of dams. Under such circumstances, the provision of fishways may enhance the probability of creating ecological traps in which individual fitness

[1] The city of Gloucester provided monarchs with a pie containing lamprey sourced from the River Severn at Christmas and on other special occasions, a tradition that was re-enacted for Queen Elizabeth's II golden jubilee in 2012 (although the lamprey were not locally sourced). King Henry I reputedly died of 'a surfeit of lampreys' in 1135.

is reduced for fish that select to use them (Pelicice and Agostinho 2008). Restoration or conservation of populations will not be facilitated if passage through a fishway increases the probability of predation (Agostinho et al. 2012) or results in those that are successful becoming disoriented in a large reservoir as they attempt to find spawning tributaries, especially if fish are able to access essential habitat in the absence of a fish pass. Perhaps more importantly, in the tropics buoyant eggs and larvae of many long distance migrants are evolved to be carried with the river currents to shallow alluvial habitat during the short time window of development. These life stages produced from successful reproduction upstream that are then unable to reach rearing areas that may be tens or even hundreds of kilometres downstream (due to the presence of a large reservoir) can be considered lost from the system.

DISCUSSION

Over recent years, the often held view that fish passes provide an effective mechanism to mitigate the impacts of impoundments on fish populations has been challenged. When viewed superficially, it appears that there are two sides to a polarised argument. On the one hand, there is an optimistic vision of the advancement of fish passage solutions for almost any type of barrier given sufficient effort and resources allocated to laboratory testing of fishway designs that accommodates fish response to hydraulics (e.g. Williams et al. 2012; Katopodis and Williams 2016). On the other hand, based on quantifying the wide variability in efficiency of existing fishways (e.g. Bunt et al. 2012; Noonan et al. 2012), others argue that many are ineffectual and it is time to recognise the failure of fish passage as a robust environmental impact mitigation strategy. At best, it provides only a partial solution; a half-way technology (Brown et al. 2013). Evidence for the unintended consequences (McLaughlin et al. 2013) and negative impacts of fish passes themselves (e.g. through altering predator prey dynamics, Agostinho et al. 2012, and creating ecological traps, Pelicice and Agostinho 2008), further reinforces the pessimistic perspective. A more realistic conclusion might be that the allocation of substantial resources to improve the design of fish passes for multiple species/guilds to a level of efficiency that will enable ecological rehabilitation is unlikely achievable globally within the timescales necessary to prevent further excessive deterioration. In view of the continued priority given to the development of water and energy resources at the expense of other ecosystem services (such as fisheries) it is critical to ensure that current policies and practices are based on evidence and are fit for purpose. That the effectiveness of fish passage as an appropriate environmental impact mitigation strategy is currently being scrutinised and questioned reflects an important first step on the road to achieving more sustainable resource management.

The polarised fish passage debate, on closer inspection, provides nuanced arguments in which there is agreement on several points - principally that the provision of effective fish passage for multiple species is challenging. Furthermore, instead of considering two sides of a single argument, it is more appropriate to view the debate as representation of positions on a continuum of differing opinion. Examples of areas of consensus include:

1) fish passage research and application is biased towards salmonids, and hence northern temperate regions;

2) the structural design of fishway types correlates with passage performance, even if the causal relationship is driven by the hydraulics created;

3) conditions encountered vary within fishway type, as well as between them, hence explaining some of the variability observed;

4) designs that appear to work well for some species (e.g. Pacific salmon on the Columbia River) have been installed elsewhere in the world with the expectation that they will work and yet often they do not;

5) there is a lack of information (e.g. on swimming capability and behavioural response to hydrodynamics) on which to base effective fish pass design for most species in the world, (e.g. in South America and Asia);

6) concerns exist about the lack of standardised information to quantify passage.

Despite the identification of points of agreement, however, the debate is important in initiating reflection on the role of fish passage in river infrastructure planning and development and the probable effectiveness of future policies.

The Williams and Katopodis commentary raises concerns about the incorrect use of some data by Bunt et al. (2012), which serves to highlight risks that can be inherent in meta-analyses more generally (Greco et al. 2013). In response, Bunt et al. (this issue) recognise and rectify errors made and provide the results of a re-analysis of the corrected data. It is clear, to this author at least, that attempts to quantitatively summarise the wider published literature on fish passage through meta-analyses (e.g. Roscoe and Hinch 2010; Noonan et al. 2012; and Bunt et al., 2012) have an important role to play in setting future research agendas through challenging conventional views. Further investigation of how fish passage effectiveness has changed over time and among regions is recommended as a useful avenue of future research.

For a long time it has been well recognised that river development and associated engineering delivers a variety of societal benefits (e.g. supply of water to industry and agriculture), but has negative impacts on natural capital, including fisheries. One logical and unescapable truth is that the mitigation of impacts through fish passage represents the result of a compromise in which fisheries and conservation is invariably valued lower than the interests of the principal aim of development (e.g. to irrigate land or to generate electricity). Acknowledging the balance of this trade-off emphasises the fact that fish passage and other mitigation strategies will never fully compensate for negative impact of water resource development and utilisation and thus will only provide the partial solution described by Brown et al. (2013). That this is indeed the case is evidenced by the fact that freshwater is one of the most vulnerable to anthropogenic activity of all ecosystems (Malmqvist and Rundle, 2002; Dudgeon et al., 2006) and that flow regulation and abstraction has caused severe declines in the range and abundance of many freshwater vertebrates (Strayer and Dudgeon, 2010). A fundamental question for society is: How much unsustainable development has been consented to based on a myth that fish passage solutions compensate for impacts of river engineering? Future resource planning and management must be based on well informed decision making processes that recognise the variability in fish passage effectiveness, and that it will usually provide only a partial solution, and in some cases can lead to negative outcomes.

As part of trade-offs in the water resource and environment nexus, there is a need to improve the quality of information on which to base decisions. Through recognising that fish passes will only partially ameliorate the environmental costs imposed by river infrastructure, there is a need to better evaluate fishway effectiveness and define levels of efficacy needed to maintain or restore populations. Standardised metrics to measure attraction and passage efficiency and length of delay will prove useful, especially if future analysis enables accommodation of levels of motivation for attempted passage. In other scenarios, when directed goal-oriented migratory movements are less well defined, other means to assess the potential of fish passes to restore and / or maintain viable fish populations, e.g. through facilitating adequate gene flow, must be developed (Pompeu et al. 2012). Finally, holistic analysis of cumulative anthropogenic impacts and realistic estimates of the effectiveness of mitigation at the catchment scale is required to inform planners, developers, and regulators on the most appropriate actions relative to aims set. More sustainable infrastructure development will occur only through enhancing the quality of information on which to conduct robust and sound decision making. Appreciating the potential for ineffective or failed environmental impact mitigation will alter the attributed value of alternative options leading to more fully informed judgements on whether or not to develop future infrastructure, repair, rebuild, or modify existing assets, or to remove dams and conserve sites (potentially entire rivers) based on more accurate cost: benefit analyses.

ACKNOWLEDGEMENTS

I thank Martyn Lucas (Durham University) and Jesse O'Hanley (University of Kent) for comments on an early draft.

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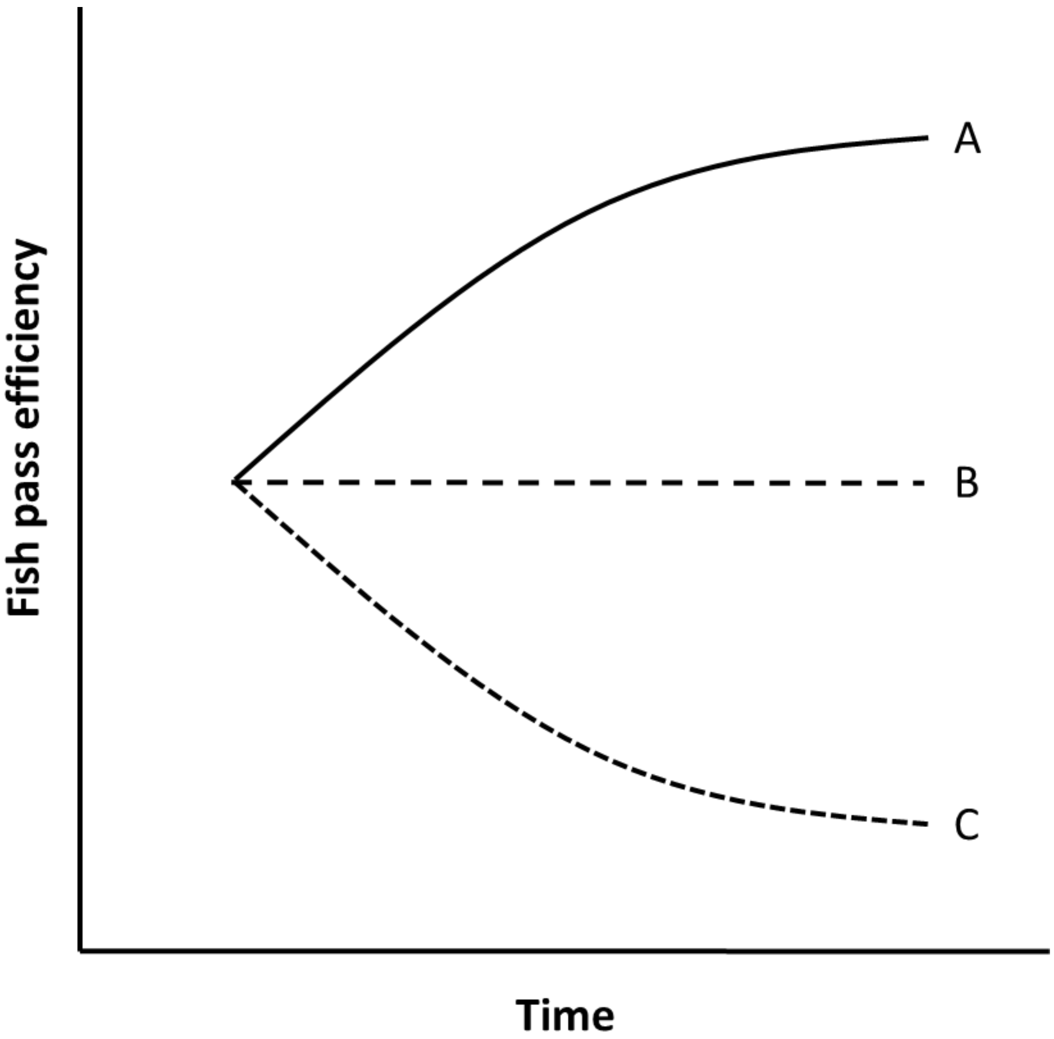
Figure 1. Variation in fish passage efficiency over time for three alternative hypothetical scenarios. Scenario A illustrates enhanced passage efficiency for a single or a limited number of species at the local scale (e.g. river catchment) as a result of monitoring and incremental improvement, perhaps driven by the requirements of legislation (solid line). In scenario B (dashed line), efficiency remains unchanged, perhaps due to a lack of monitoring and improvement driven by a process of research and development. When viewed from a global perspective the efficiency of fish passes may decline when transferred to regions and for species for which it was not originally designed (scenario C, dotted line). Experience of specific scenarios likely influence individuals perspective in relation to the fish passage debate.


A
B
C
Fish pass efficiency
Time