FISH PASSAGE RESEARCH IN THE SOUTHERN HEMISPHERE: CHALLENGES, LESSONS AND THE NEED FOR NOVEL SOLUTIONS

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Fish passage research for Southern Hemisphere species lags significantly behind that for Northern Hemisphere species. This is despite there being a relatively high prevalence of diadromous species relying on free access between marine and freshwater environments to complete their life cycles. With an emphasis on New Zealand experiences, this paper discusses some of the challenges associated with transferring knowledge and methods from the Northern Hemisphere, and highlights the need for novel approaches for progressing fish passage research in the Southern Hemisphere. One of the most significant challenges is that many Southern Hemisphere fish species undertake their main upstream migrations as small bodied juveniles that range in size from 15-60 mm. This precludes the use of most state-of-the-art biotelemetry methods (e.g. PIT and acoustic tagging) for studying behavior, because tags are too large. It also means there is a need for greater focus on the impact of small instream structures, e.g. culverts, on connectivity. A further constraint is that the fundamental ecology and basic swimming capabilities of many Southern Hemisphere fish species are poorly understood, limiting the ability to establish whether existing solutions are transferable. The unique behavior of some Southern Hemisphere species (e.g. the ability to climb wet surfaces) opens up new avenues of fish passage research and a need for innovative approaches to finding solutions. To maximize these opportunities there is a need to embrace inter-disciplinary approaches and improve knowledge sharing.

1 INTRODUCTION

To design effective fish passage solutions, there is a need to understand the life cycles, habitat preferences, behaviors and swimming abilities of the fish species to be provided for. Knowledge of these characteristics is reasonably well researched for many Northern Hemisphere fish species, allowing the creation of relatively robust design criteria for fishways. However, for many Southern Hemisphere species this is not the case, and there are still notable knowledge gaps regarding basic ecology and the capabilities of even some of the most common fish species. Furthermore, in contrast to the salmonid species that have historically been the focus of much of the fish passage research in the Northern Hemisphere, there is a significant number of species in the Southern Hemisphere that undertake their main upstream migrations as weak-swimming juveniles. Consequently, many of the traditional fishway designs from the Northern Hemisphere are largely ineffective for the native species of the Southern Hemisphere due to their differing biological characteristics. These differences also provide challenges for transferring current state-of-the-art methodologies that have evolved for large bodied fish to the Southern Hemisphere.

The focus of this paper is to discuss some of the challenges associated with transferring knowledge and research methods from the Northern Hemisphere to research on Southern Hemisphere fish species. Additionally, we look to highlight some of the opportunities for developing novel and innovative techniques for understanding and finding solutions for these unique species.

2 STATE-OF-THE-ART IN FISH PASSAGE RESEARCH

A variety of experimental and field-based approaches have evolved in the field of fish passage research. Much of this innovation was originally driven by the need to develop fish passage criteria for large-bodied anadromous salmonids and is consequently orientated towards characterizing their movements and behavior. More recently, interest has increased in understanding the requirements of other fish taxa, such as cyprinids and anguillids, which has resulted in further methodological developments. However, many of the approaches remain most suited to large-bodied fish.

Biotelemetry methods have been fundamental to enhancing our understanding of fish behavior in and around fishways. Passive Integrated Transponder (PIT) tags have been widely used due to their relatively low cost and suitability for a wide range of species. The small 8-12 mm PIT tags have further boosted the scope of this technology for tracking smaller fish, but for small-bodied fish <60 mm in length, the size of the tags still limits their applicability. Acoustic and radio tagging offer the opportunity to actively track individual fish behavior, providing more detailed information on the response of fish to different stimuli, but the battery life and physical size still limits the size of fish able to be tracked. For large-bodied fish, the combination of high resolution acoustic tracking with hydraulic modelling is proving to offer valuable insights into fish behavior at and around barriers and fishways [1]. New techniques such as accelerometry and electromyogram telemetry offer the opportunity for greater insight into swimming behavior and the energetics of fish in fishways [2].

Advances in technology for measuring the physical characteristics of flow within and around fishways offer the opportunity to better understand fish behavior under different hydraulic stimuli. Acoustic Doppler velocimetry (ADV) and particle imaging velocimetry (PIV) offer the ability to characterize hydraulics at higher spatial and temporal resolutions than ever before. When combined with videography, this has helped to gain greater insight in to the significance of turbulence and three-dimensional flow characteristics for understanding fish behavior and their ability to pass different structures [3].

Greater computational capabilities have also opened up options for improved modelling studies to help inform the design of fishways. Computational fluid dynamics (CFD) offer the ability to simulate hydraulic dynamics in two and three dimensions, helping to understand the evolution of flow fields under different flows and fishway designs. The capability to link this to fish behavior through bioenergetic and agent based modelling facilitates an improved mechanistic understanding of fish responses to hydraulic and physical stimuli, and therefore in how fishways can be improved to enhance their efficiency [4].

What is clear is that there is a need to adopt multiple complementary approaches for elucidating the biological requirements that define the design requirements of fishways. There is a need to integrate both field and laboratory based experimental work with in-situ empirical observations of fish behavior. Furthermore, an integrated ecohydraulic approach that combines both biological and engineering techniques is required to optimize outcomes. To date, much of the development in this field has occurred in the Northern Hemisphere, with a focus on large-bodied, strong swimming fish species. There has been recent progress in adapting some of these methodologies to weaker swimming and smaller fish, but the contrasting biological characteristics of many temperate Southern Hemisphere species presents significant challenges for transferring these methods and advancing the science of fish passage research in the Southern Hemisphere.

3 KEY CHALLENGES FOR FISH PASSAGE RESEARCH IN THE SOUTHERN HEMISPHERE

Despite many years of underpinning research, the efficacy of many fishways operating in the Northern Hemisphere is still sub-optimal, particularly with respect to catering for multiple species. Key challenges include understanding attraction flows, quantifying and optimizing passage efficiency, developing solutions for complex species assemblages, and catering for downstream migration. State-of-the-art techniques, and particularly the adoption of ecohydraulic approaches that combine ecological and engineering methods, are essential to progressing these challenges. However, the differing biological characteristics of some of the key Southern Hemisphere species means that transferring existing methods and approaches for undertaking fish passage research is not always suitable or feasible. Some of the key challenges are:

- The fundamental ecology of many species is poorly understood because they have not been well studied;
- The main upstream migrations of some of the key species take place during the juvenile life-stage when fish are small and weak swimming;
- The swimming capabilities of many species have not been well quantified;
- Some fish have evolved alternative means of locomotion, e.g. climbing, for overcoming obstacles.

The implications of these challenges for progressing fish passage research in the Southern Hemisphere are discussed below.

3.1 Fundamental ecology is poorly understood

A key aspect of designing effective fishways is to know when fish are migrating and where they are coming from and going to. In the absence of this knowledge, it is difficult to know what species need to be catered for, what size they will be at the time of migration, what flow conditions the fishway needs to be optimized for and where in a catchment passage has to be provided. There are many Southern Hemisphere species for which these fundamental ecological characteristics are still relatively poorly understood. For example, the spawning habitat of the pouched lamprey (*Geotria australis*) and the largest of the galaxiid species, the giant kokopu (*Galaxias argenteus*), have only been discovered in the last three years [5]. Furthermore, new species continue to be discovered, with fourteen taxonomically indeterminate taxa included in the most recent national threat rankings in New Zealand. To support fish passage research, there is therefore a need to enhance knowledge of these key life-cycle characteristics and habitat requirements.

3.2 Upstream migration as weak swimming juveniles

Another feature of many native freshwater fish species in the Southern Hemisphere is the prevalence of diadromy. In New Zealand, the majority of the most widespread native fish species have a diadromous life-cycle, with the main upstream migration most frequently occurring during the juvenile life-stage, when fish are small-bodied and 15-60 mm total length. This presents two particular challenges for fish passage research. Firstly, due to the small size and weak swimming ability of these fish at the time of migration, seemingly small obstructions in waterways can significantly impede upstream passage. Baker [6], for example, demonstrated that fall heights of as little as 100 mm restricted passage of juvenile common bully (*Gobiomorphus cotidianus*) and inanga (*Galaxias maculatus*). Consequently, there is a need to consider fish passage solutions that cover a much wider range of obstacles compared to those for adult salmonids which would have no problem overcoming a fall height of 100 mm. Secondly, the small body size of fish at the time of migration means that biotelemetry methods are largely excluded as an option for studying fish behavior during migration for many species. The advent of smaller tags has increased the scope for adopting biotelemetry methods for investigating adult life stages and large bodied species. However, alternative methods are still required for elucidating in-situ behaviors of juvenile migrants. The use of Dual Frequency Identification Sonar (DIDSON) has shown some promise in this area, but the ability to distinguish between species of small-bodied fish such as juvenile galaxiids is still limited. Experimental methods that utilize high resolution videography for monitoring fish behavior offer another possible avenue for dealing with the challenges of working with small fish. Netting allows evaluation of numbers of fish moving, but is restricted in terms of monitoring detailed behavioral information.

3.3 Swimming capabilities are poorly quantified

Optimal design of fishways requires knowledge of fish swimming performance. Variation in swimming performance between fish species is high and therefore presents one of the main challenges in catering for multi-species assemblages. While considerable work has been carried out to understand the swimming performance of many of the key Northern Hemisphere species, evaluation of swimming performance in Southern Hemisphere species has been relatively limited. There are few published studies of swimming performance for New Zealand fish species, for example, and these are limited with respect to the number of species, life stages and environmental parameters tested [7, 8]. This limits the ability to theoretically evaluate the suitability of traditional fishway designs for use in the Southern Hemisphere. It also constrains the ability to define robust fishway design criteria for native species, contributing to a lack of confidence in proposed solutions and guidelines. Furthermore, it limits the ability to develop mechanistic models of fish performance and utilize bioenergetic approaches for understanding fish behavior. There is a significant need for research in this area that also takes into account the potential role of turbulence in influencing swimming capabilities.

3.4 Alternative forms of locomotion

A relatively unique feature that has evolved in some Southern Hemisphere species is the ability to climb wet surfaces during the juvenile life stage. In New Zealand, this occurs in the widespread species *Galaxias fasciatus*, *G. brevipinnis*, *G. argenteus* and *G. postvectis*, and also in *Gobiomorphus huttoni*, in addition to the anguillid species. Migratory adult pouched lamprey also possess the ability to climb wetted surfaces. New Zealand's waterways are often characterized as being relatively short and steep, and it is thought that the development of the capability to climb may be related to the need to overcome the challenges of migrating inland to adult habitats in the middle to upper reaches of these streams. The utilization of this alternative form of locomotion presents a challenge in terms of understanding and characterizing the different climbing strategies, especially between large and small-bodied species. It also requires a different way of thinking about optimizing fish passage, with different features required to take advantage of this strategy that may not be consistent with traditional approaches for fishway design.

4 THE NEED FOR NOVEL SOLUTIONS AND INNOVATIVE APPROACHES

In the face of continued development of waterways in the Southern Hemisphere, there is a need for rapid progress towards developing robust and effective fish passage design criteria that cater specifically for the unique characteristics of diverse native fish communities. Due to some of the features identified above, direct transfer of existing state-of-the-art fish passage research methods will not always be possible. Consequently, there is a need to seek out novel and innovative approaches for advancing fish passage knowledge. Developing techniques for studying and characterizing the behavior of small-bodied fish is a key priority and is fundamental to progressing fish passage research in the Southern Hemisphere. Finding ways of capturing and exploiting the climbing capabilities of some species also offers the opportunity for new avenues of research. Taking advantage of this capability has been the basis of several studies in New Zealand that have resulted in novel solutions for enhancing passage of these fish species at instream barriers [9, 10].

5 SUMMARY

Embracing the interdisciplinary approaches typified by the ecohydraulic discipline should be central to progressing fish passage research in the Southern Hemisphere. It is the integration of biological and engineering techniques that have driven new advances in the field of fish passage research. There is a need now to look at how existing state-of-the-art techniques can be transferred and adapted for use on Southern Hemisphere species and to seek new methods that suit the unique characteristics of some of these fish communities.

REFERENCES

[1] Piper, A. T., Manes, C., Siniscalchi, F., Marion, A., Wright, R. M. and Kemp, P.S. “Response of seaward-migration European eel (*Anguilla Anguilla*) to manipulated flow fields”, *Proceedings of the Royal Society B*. Vol. 282, No. 1811, (2015)

[2] Silva, A. T., Hatry, C., Thiem, J. D., Gutowsky, L. F. G., Hatin, D., Zhu, D. Z., Dawson, J. W., Katopodis, C. and Cooke, S. J. “Behavior and locomotor activity of a migratory catostomid during fishway passage”, *PLoS ONE*, Vol. 10, No. 4, (2015)

[3] Silva, A. T., Katopodis, C., Santos, J. M., Ferreira, M. T. and Pinheiro, A. N. “Cyprinid swimming behavior in response to turbulent flow”, *Ecological Engineering*, Vol. 44, (2012), pp 314-328.

[4] Weber, L. J., Goodwin, R. A., Li, S., Nestler, J.M. and Anderson, J. J. “Application of an Eulerian-Langrangian-Agent method (ELAM) to rank alternative designs of a juvenile fish passage facility”, *Journal of Hydroinformatics*, Vol. 8, No. 4, (2006), pp 271-295.

[5] Franklin, P. A., Smith, J., Baker, C. F., Bartels, B. and Reeve, K. “First observations on the timing and location of giant kokopu (*Galaxias argenteus*) spawning”, *New Zealand Journal of Marine & Freshwater Research*, Vol. 49, No. 3, (2015), pp 419-426.

[6] Baker, C. F. “Effect of fall height and notch shape on the passage of inanga (*Galaxias maculatus*) and common bullies (*Gobiomorphus cotidianus*) over an experimental weir”, *New Zealand Journal of Marine & Freshwater Research*, Vol. 37, (2003), pp 283-290.

[7] Mitchell, C. P. “Swimming performances of some native freshwater fishes”, *New Zealand Journal of Marine and Freshwater Research*, Vol. 23, (1989), pp 181-187.

[8] Plew, D. R., Nikora, V. I., Larned, S. T., Sykes, J. R. E. and Cooper, G. G., “Fish swimming speed variability at constant flow: *Galaxias maculatus*”, *New Zealand Journal of Marine & FreshwaterResearch*, Vol. 41, (2007), pp 185-195.

[9] Baker, C. F. and Boubée, J., “Upstream passage of inanga *Galaxias maculatus* and redfin bullies *Gobiomorphus huttoni* over artificial ramps”, *Journal of Fish Biology*, Vol. 69, (2006), pp 668-681.

[10] David, B. O. and Hamer, M. P. “Remediation of a perched stream culvert with ropes improves fish passage”, *Marine and Freshwater Research*, Vol. 63, No. 5, (2012), pp 440-449.