1

Indigenous Engagement & Inclusion In Fish Passageway Initiatives

Phil Duncan[1]

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Over these millennia Indigenous people of Australia have sustainably managed their lands, waters and natural resources for the health of their Countries and their peoples. Our traditional ecological knowledge, like our stories, are passed down from generation to generation and continue up until this day. This allowed us to live in a symbiotic relationship with the land and water. We used it, we lived from it, we nurtured it. Our use was sustainable, and continues so today, where it can.

It is through the survival of, our stories such as this, our culture, and our traditional ecological knowledge, that my people have been able live in the driest inhabited continent on earth for tens of thousands of years, or since our Dream Time.

Phil's presentation is about showcasing the need to include Indigenous peoples in the management of our freshwater environments to ensure the long term sustainability of fish populations, aquatic habitats and the protection of sites that have significant cultural heritage relevance to Indigenous peoples. The case study highlighted in my presentation is related to the construction of a fish ladder for fish migration on the Brewarrina weir and the significant need to ensure the consultation process with the Traditional Owners, the Ngemba people, the Brewarinna Local Aboriginal Land Council and the range of key stakeholder groups, are carried out in an inclusive manner that is also culturally appropriate. It also highlights how the project management group negotiated the pathway to ensuring that the Ngunnhu were not impacted on and the construction of the fish ladder was designed around keeping the Ngunnhu working for cultural education and tourism.

Working with Indigenous people and engaging them affords them the opportunity to be involved in carrying out their responsibility to care for their country.

2

Fish Passage; the Art of the Possible

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Migratory freshwater fish provide essential food security and livelihoods globally. Yet regulation of large rivers continues to be a major threat. Providing passage for migratory fish holds promise of sustaining populations, but it also has an inconsistent history. In recent decades increasing knowledge of fish ecology has led to more appropriate fish passage objectives; whilst understanding the influence of fishway hydraulics (e.g. turbulence and water velocity) on fish passage, has greatly improved designs.

Worldwide, there is a fundamental enthusiasm for fishways but, despite successes, variable quality and effectiveness persist. This can be partly due to budget constraints, but more often it is an insular approach to design. We know that engineers and biologists are needed, but asset owners and operators are also essential, because they know what is practical in their region, and they will live with the result. Peer review at all stages of a project should also be encouraged. A constructive approach for governments or agencies responsible for water management is to establish an expert group, which provides review of designs by experts and stakeholders to ensure consistency and practicality; and education and training to encourage mentoring and continuity of skills.

A project focus on site-specific issues and internal fishway design can overlook broader aspects of fish life cycles and ecology, with detrimental impacts on populations. For example, lentic impoundments, upstream of dams/weirs, create hydraulic barriers that drifting larvae of riverine fishes cannot negotiate. Mitigating these impacts may involve selection of the dam to avoid major migration routes – providing lotic reserves - or, a radical departure in present dam design / operation. Regardless of the measure, research on the behavioural ecology of drifting larvae and spatial scale of migrations is urgently required.

Funding for fishways needs to be strategic, both at a project and catchment scale. Cost estimates of fishways require detailed concepts for the Business Case, early in the project timeline. Unfortunately, underestimates are often used, leading to compromises in detailed design when budgets are fixed. This often happens in large hydropower projects which, for example, may not provide 10% of flow for fish passage – a fundamental design criterion – because the Business Case has assumed most of the flow will be used for power generation.

Funding is also mostly dedicated to capital expenditure, leaving monitoring under-resourced and focused on *passage efficiency*. The more complex, but equally important assessment of *attraction efficiency* is relegated to a few species or not undertaken. Nonetheless, monitoring techniques have become increasingly sophisticated over the last decades, so funding issues would seem potentially solvable by articulating these benefits to stakeholders early in the project development phase.

Ultimately, project-based funding does not sustain long-term research, which is left to government agencies and universities. Engineering and ecological research is essential to foster innovation and to develop performance indicators that recognise life history strategies (e.g. short-lived semelparous species and long-lived iteroparous species) and integrate with population models. Funding for strategic research is presently a minor fraction of capital expenditure on fishways. Conceivably, new funding models are needed where water infrastructure projects contribute a percentage to long-term research projects.

Providing fish passage captures imaginations and is a powerful tool in mitigating the impact of dams and weirs. There have been great successes at low-level barriers and issues of variable quality are solvable. Nevertheless, sustaining migratory fish populations in regulated rivers, including facilitating the passage of all life stages past large dams, remains a major challenge.

3

Hydropower symposium opening presentation.

Hans-Petter Fjeldstad[1]

1. Chair of the ANNEX XIII, Hydropower and Fish - IEA-Hydro

TBA

4

The Xayaburi fishpass system – design concept and development

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2. Xayaburi Power Company Limited, Muang Chantabouly, Vientiane, Lao PDR

The Xayaburi project is the first one to be built on the Lower Mekong and therefore it was particularly difficult to design the fishpassing facilities since no direct reference and only very little data were available in the initial design phase.

In the beginning the project was required to carry out additional fish studies and re-design large parts of the fishpass structures.

The studies carried out addressed questions of species, biomass and fish swimming abilities.

The design improvements comprised the following:

1) Downstream migration: the facilities were improved in order to be operational all year round instead of only during the flood season. This required an increase in size of the affected galleries and the project also introduced a pump station in order to minimize losses in energy production during the low flow season. The exit channel was improved by hydraulic modelling to provide optimal flow conditions for the fish.

2) Upstream migration: The original concept of a fishladder spanning the total height of the dam was replaced by a combined system of a fishladder and a vertical lock system. The nature of the fish ladder was changed from a single slot ladder to a hybrid multislot ladder; also the dimensions of the ladder were increased substantially due to the expected biomass and to provide acceptable energy levels in the pools.

Upstream fishpassing commenced in early 2015 through the Navigation Lock. The lock is equipped with specific water feed systems allowing upstream fish migration through the construction period.

The construction of the permanent fishpassing facilities, both for up- and downstream migration are substantially complete. Both systems will commence operation by the end of 2018 when the reservoir is impounded to the full height and the relevant systems have been finalized and commissioned.

5

Modification of Navigation Locks for upstream fish migration

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The 1,285 MW Xayaburi Hydroelectric Power Project is the run-of-river project along the Mekong River. The project comprises of a Navigation Lock, Spillway, Powerhouse, and a complex system facilities for upstream and downstream fish migration.

As run-of-river project, Xayaburi is constructed in two stages, stage 1 being the time from start of construction to river diversion, and stage 2 from river diversion to completion. The stage 1 comprises of the Navigation Lock, the Spillway and parts of the Intermediate Block. The second stage includes the remaining part of the Intermediate Block together with the Powerhouse, the permanent Left Bank Fish Passing Facilities and the Transmission System. During the stage 2, while the Fish passing facilities are constructed, the Navigation Lock is used as a passway for the fish to migrate upstream

For that the Navigation Lock was modified by adding a specific water feed system to generate the required attraction flows within downstream of the lock. This way upstream migrating fish can easily find the entrance of the lower lock chamber. Increased flow in the Upper Lock Chamber guides fish out of the Lock.

Since May 2015 upstream migration through the Navigation Lock has taken place on regular basis. Normally several locking cycles are performed during the day and the night. The number of cycles depends on the season and the observed migration patterns.

In order to allow monitoring of the actual fish migrating through the Navigation Lock and to improve the operating cycles, the number and sizes of fish are monitored and determined by means of a hydro acoustic camera.

This camera is installed at the upper lock exit that all of fish exiting the lock must pass this camera.

The paper will focus on the monitoring techniques and data evaluation which is aided by special software like Echoview.

6

Assessing the effectiveness of first fish passage facility to enhance sustainability of inland fishery resources in Indonesian River: a case study in Komering River, South Sumatera, Indonesia

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Inland capture fisheries in Indonesia deliver food security and income for rural households and also serve as a valuable source of protein and important micro-nutrients. Nevertheless, inland fisheries are becoming increasingly threatened by riverine development projects, such as dams and weirs as means for rapid development in response to increasing population and demand for agriculture products and hydropower generation. That potentially decrease capture fisheries productivity through any changes in fish migration, reproduction and biodiversity of aquatic populations due to the existence of river barrier.

The Indonesian government is recognized the importance of fishways as appropriate mitigation measures of alleviate possible impacts from such migration barrier to increase the sustainability of fishery resources. However due to the limited information, the first fishway in Perjaya Dam was built based on solutions developed in North America and was not suitable in the local context. The Perjaya Dam blocked the Komering River, the river that has a high biodiversity, recorded at least 55 species of fish found in the system, comprised 21 genus from 5 families (Balitoridae, Cobitidae, Cyprinidae, Schilbeidae and Sisoridae).

The research aims to investigate effectiveness of existing migration facilities in maintaining riverine productivity. A field-based adaptive-management approach has been applied for this type of work where as sampling and collecting representative samples of the fish community were conducted in the upper, down stream and within the fishway of Perjaya Dam, Komering River.

7

Influence of hydraulics on the dowsntream migratory route of Atlantic salmon (S*almo salar*)

Ana Teixeira da Silva[1], Richard D. Hedger[1], Karl Øystein[1], Finn Økland[1], Kim M. Bærum [1], Henrik Baktoft[1], Hans-Petter Fjeldstad[1], Torbjørn Forseth[2]

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The interaction between hydrodynamics and the upstream migration of fish has been investigated in several studies over the past few years, but there has been a relative lack of investigation into the effects of hydraulics on the downstream migration of fish. In Norway, mortality associated with downstream migration is strongly related to hydropower production. However, there is a poor understanding of how fish choose their migratory routes, which limits the development of measures to mitigate the impact of anthropogenic structures on fish migration. The current study aimed to analyze the effect of hydraulics on the choice of downstream migration route of Atlantic salmon smolts (*Salmo salar*) in the proximity of an intake to a hydropower plant in Norway. We combined computational fluid dynamic modeling with 3-Dimensional acoustic telemetry positioning of a group of tagged smolts to investigate the interaction between fish and the flow dynamics, and to determine the influence of this interaction on fish migratory routes. A Hidden Markov Model was used to predict migratory routes based on the relations found between the hydraulic variables and fish behaviour. Results showed relationships between fish migratory routes and the different components of flow velocity. The knowledge acquired in this study is expected to inform opportunities and decision making in aquatic resources management and engineering design to increase fish survival past hydropower intakes and other anthropogenic structures.

8

Behavioural guidance of outmigrating eels in a large river system

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Finding solutions for safe downstream passage for outmigrating eels on large river systems where the only passage route available is through hydroelectric facilities has proven extremely challenging. American eels outmigrating from the North American Great Lakes must pass through two such facilities, resulting in ~40% mortality annually on a portion of the population where recruitment has declined by >99% over the past 3 decades. A bi-national, collaborative effort of industry and government agencies

to develop techniques for guiding and capturing eels above the hydroelectric facilities to reduce turbine mortality is ongoing since 2013. The collaborative, named the Eel Passage Research Center, has used a phased approach of developing white papers to inform the selection of guidance technologies most likely to meet management objectives, assessing those technologies (light, flow, electricity, sound (vibration), and electromagnetic field) at a variety of spatial scales, and assessing *in situ* migration pathways at likely collection areas above the two hydroelectric facilities. Light, and possibly sound (vibration), are now being considered in the construction a prototype guidance system that is expected to be deployed in 2020.

9

Evolution of the fish sorting and debris handling system at the Swift Hydroelectric Project Floating Surface Collector for juvenile salmonids

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The Swift Floating Surface Collector (FSC) began operation in 2012 and was the third of eight large scale surface collectors installed in the Pacific Northwest region of the United States since 2008. Downstream fish collection and sorting at Swift Dam was a key component of the Lewis River reintroduction program that reestablished passage of anadromous salmonids past PacifiCorp's three large hydropower dams (510 MW Lewis River Hydroelectric Project) that blocked fish passage beginning in 1931. The Swift FSC floats to accommodate reservoir fluctuation of 90 feet and attracts fish with pumped surface flows of 600 cfs. After passing through a large V-screen, fish and debris enter a fish separator system designed to separate fish by girth into fry (≤3" long), smolts (≤10" long), and adult fish (>10"). The separator system was designed as an evolution of similar systems studied on the Snake, Columbia, Yakima, and Cowlitz Rivers, and was optimized on lessons learned and to accommodate space constraints on the floating structure. Swift dam is the most upstream project on the Lewis river, so all flow entering the collector is unregulated and carries a heavy debris load. Operations staff are finding this system collects more debris than any of the other new FSC's in the region. Several modifications to provide better debris exclusion, handling, and processing have been made and others are currently under design. These modifications also improve fish attraction, sorting, collection, and safety conditions for the operational staff. This presentation will review the original design goals and details, improvements made through 2017, highlight a new system currently under design planned to be operational in late 2018, and describe other ideas under consideration for adaptive management implementation. Lessons learned can be utilized at other downstream fish collectors with high debris loading.

10

Fishway targets should support population viability - Metapopulations, habitat shifts and gene flow

Martin A Wilkes, James Angus Webb, Paulo Santos Pompeu, Luiz GM Silva, Andrew Vowles, Cindy Baker, Paul Franklin, Oscar Link, Evelyn Habit, Paul Kemp

Globally, fishways are increasingly gaining a reputation for failing to meet conservation goals in certain circumstances. This can be explained by the continuing dominance of diadromous species from the Northern Hemisphere (e.g.Salmonidae) in the science and management of fish passage internationally. Most species have very different life histories, swimming abilities and spatial ecologies to the iconic species of the North, meaning that most fishways do not work well for most fish. This is an especially severe problem in the Global South, where fishways designed for salmonids may exacerbate already serious issues with invasions. Most fish do not undertake long migrations between critical habitats clearly separated in space, yet individual movement and gene flow is critical to the long-term viability of their populations. We review recent, important advances in spatial ecology for dendritic river networks. In doing so, we aim to better define what it means to achieve effective fish passage. By combining critical habitat assessment with metapopulation modelling, undertaking analysis of climate change-driven habitat shifts, estimating adequate gene flow, we recommend a new framework for fishway target-setting and monitoring which is suitable for a wide range of species, including salmonids. We encourage the scientific and management community to take up and develop this framework.

11

Why landscape connectivity matters to fish populations.

John Koehn[1], Charles Todd[1]

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One of the objectives of providing fish passage is to improve fish populations. Connectivity at large scales is difficult to implement, especially given the costs and time-frames involved. Indeed, the need for fish passage over multiple barriers and large scales is often questioned. With limited evidence available to indicate improvement to populations, this can be a hard proposition to prosecute. Golden perch is a wide-ranging, mobile fish species of thee Murray-Darling Basin (MDB) in south-eastern Australia. It has migratory movements of both adults and juveniles, in addition to drifting eggs and larvae. It is a popular angling species, but like most native MDB fishes, it must compete for both water and habitat access with irrigation needs and infrastructure. This species is distributed across the MDB (almost 1 M km^2) and this paper utilises new knowledge of the movements of this species through its inclusion in a metapopulation model to illustrate how actions in any location have the ability to alter populations in other regions of its range. Reinstatement of key flow components, together with connectivity, both of which greatly affect movements, are vital to the management of golden perch populations. Predictions from population modelling provide theoretical

indications of the need for landscape-scale connectivity, and the potential benefits to golden perch populations. This approach may be applicable to prosecuting the case for fish passage for many other species.

12

Move it or lose it: restoring movement pathways for fish in freshwater rivers

Jason Thiem[1]

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Widespread anthropogenic development has resulted in interruptions to key movement corridors for fish within freshwater ecosystems. This has contributed to numerous global, regional and local declines in both diadromous and potamodromous fish populations. The construction of additional dams, particularly in developing countries, further threatens fish populations. Major advances in engineering and construction techniques have been made over the past few decades, improving our ability to reconnect individual streams and watersheds. Additionally, novel techniques have been developed enabling us to elucidate the causes and consequences of passage success and failure past individual barriers. These include techniques to measure variables such as swimming performance, the application of field physiological tools and the remote measurement of activity rates. However, despite this progress there are very few documented examples of recovery of fish populations or communities in reconnected systems. Watershed-scale planning and cross-jurisdictional collaborations are required to achieve more meaningful outcomes across ecologically relevant scales. A number of regional case studies from south-eastern Australia will be presented that demonstrate the value of restoring movement pathways for both individual species and fish communities.

13

Passage of pouched lamprey (*Geotria australis*) in vertical-slot fishways

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In rivers worldwide, dams, weirs and tidal barrages impede the upstream spawning movements of anadromous lamprey, with subsequent impacts on population viability. Fishways are commonly used to mitigate the impact of barriers on fish migration, but the utility of these structures for southern hemisphere lamprey (e.g. *Geotria australis* and *Mordacia mordax*) remains largely unexplored. In this study we implanted PIT (passive integrated transponder) tags into 55 pouched lamprey (*Geotria australis*) near the mouth of the River Murray, Australia, and assessed upstream passage through a series of vertical slot fishways on 10 main channel weirs (~3.5 m height), across 800 km of river. The fishways comprised two different designs: 1) 1:32 slope, 0.3 m slot width, 1.4 m/s maximum water velocity and turbulence of 47 W/m^3; and 2) 1:22 slope, 0.3 m slot width, 1.7 m/s maximum water velocity and turbulence of 87 W/m^3. A total of 25 lamprey ascended one or more fishways, with 133 successful ascents recorded across the ten fishways. We compare the two fishway designs with regards to passage efficiency – the proportion of individuals detected at the entrance of a fishway that successfully ascended the fishways – and ascent rates, and conclude that both vertical slot fishway designs effectively facilitate the passage of pouched lamprey and likely other lamprey species.

14

Upstream passage and attempt behaviour at a sloping weir by migrating adult river lamprey: are studded tiles effective in improving longitudinal connectivity?

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3. Environment Agency, York, United Kingdom

The performance of weir-mounted studded tiles for passing upstream-migrating lamprey (*Lampetra fluviatilis*) was compared with unmodified parts of a Crump flow-gauging weir and with use of a bottom-baffle fishway on the River Derwent, Northeast England. Equidistantly-studded tiles were fixed horizontally on the weir face near the right bank, forming a 1m-wide treatment lane, neighboured by a tileless control lane. A bottom-baffle fishway was present at the right bank, alongside a hydropower tailrace. Two further left-bank controls enabled, together with right-side controls, comparison of lamprey attraction relative to the dominant flow on the right side. Downstream and upstream ends of the right-hand weir-face lanes and of the fishway, downstream ends of the left-hand weir face lanes, and the entrance of the hydropower tailrace area were instrumented with PIT antennas (n=9 total). Of 395 PIT-tagged lamprey, over 10 release sessions in early winter 2017 (turbines on for 21/43 days), 363 (91.9%) were detected at any of the antennas (mean ± SD minimum delay: 14.8 ± 8.9 days). All lamprey detected at the left-bank antennas (attraction efficiency AE: 255/395 (64.6%)) were detected elsewhere also. The fishway was ineffective (AE: 343/395 (86.8%); passage efficiency PE: 5/343 (1.5%)). However, overall passage using the studded-tile corridor doubled (44/395 *cf* 22/395) relative to the adjacent bare weir-face route (AE tiled lane: 172/395 (43.5%); PE tiled lane: 44/172 (25.6%) - AE control lane: 257/395 (65.1%); PE control lane: 22/257 (8.6%)). Fewer PIT detections were logged at the turbine tailrace and fishway entrance, respectively, when turbines were on (n=441 and n=700; median [range] river discharge turbines-on: 18.7 [10.5-36.3] m^3 s^{-1}) compared to turbines-off conditions (n=1005 and n=2457; discharge: 36.2 [10.4-52.3] m^3 s^{-1}). While improved passage efficiency was achieved using surface-mounted studded tiles, further *in situ* evaluations are needed to optimize their performance.

15

Quantifying the fine-scale behaviour of spawning run river lamprey (*Lampetra fluviatilis*) approaching a low-head weir retrofitted with studded tiles

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Fish passes (or fishways) designed to mitigate for the impeded movement of migratory fish at anthropogenic structures (such as dams and weirs) often function poorly. This is particularly the case for anguilliform species such as lamprey (*Petromyzon* spp. and *Lampetra* spp.). Poor swimming capability (in comparison to e.g. salmonids) and a lack of understanding of behaviour in response to hydrodynamic cues are considered key reasons limiting the performance of mitigation measures. A field study employing Passive Integrated Transponder (PIT) and fine-scale (sub-metre) acoustic telemetry was conducted on the River Derwent (Yorkshire, UK) in Winter (November – December) 2017. The aim of the study was to assess river lamprey behaviour and passage at a low-head weir retrofitted with studded tiles designed to aid upstream movement. In this talk, the acoustic telemetry data will be presented, outlining fine-scale behaviour and weir approach routes of lamprey in relation to hydrodynamics that were measured using a remotely operated Acoustic Doppler Current Profiler. How this data can be quantified into "behavioural rules" to parameterise Agent Based Models will be discussed and examples provided. Such models will enable better predictions of fish movements to be made as they encounter anthropogenic structures and guide the design of more effective mitigation measures, such as fish passage and screening systems.

16

Swimming in a 3D world: sediment deposition affects passage and behavior of juvenile rainbow trout in a baffled laboratory flume

Jason Duguay, Brendan Foster, Jay Lacey, Theodore Castro-Santos

Recent work suggests fish exploit low velocity recirculation zones in the wake of baffles to take refuge from challenging hydraulic conditions during ascent through baffled culverts. Yet in situ, it is likely that sediment deposes in the lee of baffles modifying the recirculation zone. The practical implications of how sediment deposition in the wake zone may affect passage efficiency is little understood. In our study, we employed high-speed 3D fish tracking using a direct linear transformation method, time-resolved stereo particle image velocimetry, videography and telemetry techniques to test the effects of sediment deposition on passage metrics and behaviors of juvenile rainbow trout attempting passage of an experimental flume. Controlled station-holding behavior, suggestive of flow-refuging, was absent within the recirculation zones of the clear bed trial, while such behavior was noted when sediment was present. Maximum distances of ascent on initial attempts were higher and ground-speeds were on average faster within the sediment deposition condition. Our results suggest sediment blocking the recirculation zone of weir baffles modifies the flow field to the benefit of passage.

17

Stairs Pipe culverts: flow simulations and implications for European and Brazilian fishes

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The passage of migratory species has been the main focus of mitigation actions related to environmental impacts due to large barriers. Recently, smallest barriers have been found to be the cause of reduction on fish community. A culvert fishway can improve the fish passage in small streams and has been widely studied. In Belgium, the model known as stairs pipe culverts have been built in the field since 2008. This kind of culvert is an adaptation of the traditional drainage culvert that combines the baffles and the pools, which are based on Denil and the pool fish ladders. There are different baffles: the first (with an angle of 30° horizontal) working as a weir, raising the water level upstream and creating a small pool; the second (with an angle of 60° vertical) concentrating the flow, braking the water velocity and creating a counter current. The aim of this study was to obtain the velocity field and pool depth for two flowrates (40L/s and 60L/s) and two slopes (5% and 6%) with numerical models. The 3D volume of fluid (VOF) model was applied. An unstructured mesh was used to incorporate the baffles layout. According to the numerical results obtained, the flowrate increase (10 L/s) created increment in maximum vorticity (50%) in pools, water depth (around 10 to 50%) and maximum velocity (10 to 25%) along the entire culvert. The slope increase (1%) induced reduction in water depth (around 11 to 22%). The maximum velocity in the flow for tested flowrates and slope could be a barrier for European weak swimmer species, such as *Abramis brama*, and for small wide spread species in Brazil, such as *Piabarchus stramineus.*

18

Fish passage hydrodynamics New Zealand context

Morten MK Knapp[1], John JM Montgomery[2], Colin CW Whittaker[1], Paul PF Franklin[3], Cindy CB Baker[3], Heide HF Friedrich[1]

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New Zealand is home to 57 native freshwater fish species, of which a considerable number are diadromous, having to move between freshwater and saltwater at least once during their lifecycle. The economic utilisation of New Zealand rivers has largely been carried out without fish migration behaviour in mind, resulting in thousands of structures that prevent fish migration up- and downriver. Remediation of existing structures, especially culverts, and construction of new, more fish friendly, structures requires in-depth knowledge of the needs of the target fish species. In April 2018, the New Zealand Fish Passage Guidelines were released, providing a design framework to enable fish passage in new and existing structures. In support of the new guidance, our project aims to gain insight into the swimming behaviour and performance of inanga (*Galaxias maculatus*) under various hydraulic conditions, in particular when swimming upstream, which is not well understood. For this purpose, we are designing a new experimental setup in a 600 mm wide flume at the Water Engineering Laboratory at the University of Auckland. We will study hydrodynamics of fish passes with roughened surfaces, baffles and energy dissipators. We will evaluate sensor equipment used to enable flow and fish tracking, with the intention of tracking individual inanga at critical cross sections. This will allow us to study fish response to turbulence, boundary layers, resting zones and wetted margins. We aim to gain valuable insight into design methods and materials that best help inanga, and potentially other members of the family Galaxiidae, with their migration. Eventually, the project aims to provide guidelines suitable for retrofitting existing and building new structures.

19

Teasing out the impacts of hydropower on fisheries in the Lower Mekong Basin

Ian Cowx[1], Cate Brown[2], Nam So[3]

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2. Southern Waters, Cape Town, South Africa

3. Mekong River Commission, Vientiane, Laos PDR

Economic development in the Mekong region has brought with it considerable environmental change, with more to follow. The river has already been highly modified by a plethora of perturbations, but hydropower is the most transparent in the public eye. However, other forces are in action not least disconnection of the flood plains for agriculture, aggregate extraction and growing urbanization. These have all impacted on the fish and fisheries and the capacity delivery aquatic food products from the system, but the system has to date remained largely resilient, or has it? This paper reviews the outputs of Mekong River Commission's Council Study and Vietnamesae Government Mekong Delta Study to tease out the role of hydropower development in the widespread changes being observed in the system and how fisheries have responded. The methodologies behind the studies and the future prospects of the river and how the fisheries may be impacted will be presented. Finally, opportunities that may help to mitigate future development scenarios, especially with respect to hydropower development will be explored.

20

Understanding mortality mechanisms in hydro power plants: implications for Mekong hydropower development

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Fluid shear arises when two bodies of water, travelling at different velocities, intersect. Fish entrained at the interface of these two water masses will experience shear stress; which can be harmful. The stress magnitude is dependent on waterbody mass and velocity; and the fish impact largely related to body size. Elevated shear stress occurs where rapidly flowing water passes near spillways, across screens and within turbine draft tubes. A flume was used to determine critical tolerances of silver shark (*Balantiocheilos melanopterus)* to different shear stress rates generated by a high velocity jet. Fish experienced higher levels of injury and mortality as shear stress was increased. Excessive shear forces had damaging impacts on fish. Mortality occurred at shear levels higher that 600/s. It is important that developers should attempt to model potential shear profiles expected during turbine passage in selected designs. These data will be critical to determine potential impacts on fish. If the likelihood of adverse impact is high, then alternative designs which have lower shear stress should be explored.

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Assessing fisheries and environmental impacts and proposing policy recommendations for sustainable development of Mekong River Basin

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Since its establishment in 1995, the Mekong River Commission (MRC) has been involved in the collection of data and the development of models, both conceptual and mathematical, aimed at demonstrating and improving the understanding of the

functioning of aquatic ecosystems and links between the people and the river, and aiding policy and decision-making in the Lower Mekong River Basin.

The objective of basin-wide fisheries and environmental assessment is to provide clear and comparable information on the impacts of proposed hydropower and other key sector developments on the aquatic ecosystems and their fisheries and other aquatic resources of Mekong River downstream of the China border, inclusive of the Tonle Sap Great Lake and the Mekong Delta. The DRIFT Flows process and Decision Support System (DSS) referred to in the MRC Council Study as the BioRA-DSS, were used to organise existing MRC data, information in the international scientific literature and expert opinion from a highly-qualified and experienced team of river scientists to provide a systemic and systematic picture for the LMB, Tonle Sap River, Tonle Sap Great Lake and the Mekong Delta ecosystems in terms of (1) their ecological condition; (2) possible future changes in condition as a result of development-driven changes in the water flow, sediment supply and transport, water quality, and lateral and longitudinal connectivity as described through the evaluation of the water-resource development scenarios; and (3) predictions of change in abundance/area/concentration (relative to baseline) for a range of key fish and other bioresources indicators. Last but not least, policy recommendations were proposed for Mekong countries' Prime Ministers and Ministers of Water Resources for basin planning and sustainable management and development of the Mekong River Basin.

22

Megadams and goliath catfish management in Amazonian scale: "running against the wind"

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Biodiversity conservation in the Amazon River basin is historically an unparalleled task but in the last decade, due to the construction of big dams, management of long distance migratory fish is proving even more challenging. The "dourada" *Brachyplatystoma rousseauxii* is a goliath catfish species that performs the longest potamodrous migration (5,700 km) in the world. However, since adults reach the spawning areas located in the Andean tributaries, they probably do not return to lower portions of the basin and its behavior after spawning is still unknown. In the Madeira River, one of the main routes to spawning areas, two hydropower plants (without river-free stretch between them) started to run very recently (2011/2013). A large-scale telemetry and egg and larvae studies are investigating the behavior of goliath catfish species in the area after the impoundments. Douradas captured downstream the Santo Antônio Dam, tagged with combined acoustic and radio transmitters (CART) were not detected passing the 900 m long fishway. In the Santo Antônio reservoir, dourada´s larvae in different development stages (pre-flexion to juvenile) were collected throughout the year. Based on this evidence and in the data presented above, it is supposed that larvae collected in the Santo Antônio´s reservoir are product of spawning that occurred in the headwaters of tributaries of Madeira River. Considering the scenario where numerous new dams are planned for the upper portion of the Madeira River basin, the data gathered in this study is an important contribution for the management and conservation of goliath catfish in Amazon basin.

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Assessing the swimming ability and performance of *Schizothorax oconnori* to cross velocity barriers in fishway

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It is necessary to explore a new experimental protocol of which the experimental channel has similar flow field with fishway to study the swimming ability. Firstly, the critical swimming speed (101.01±20.86cm/s) and the burst swimming speed (196.94±21.80cm/s) of fish were acquired in swim chambers by velocity increment tests. Secondly, based on the critical swimming speed of fish and the designed flow speed at vertical slot of some Hydropower Station's fishway (110.00cm/s), an experimental channel with vertical slots for testing volitional swimming ability of fish was built by setting different trapezoid barriers in the channel. After this, the swimming tests of *Schizothorax oconnori* to cross water velocity barriers were carried out with two different barrier layouts. For one layout, the channel has four steps in two gradients (the flow speed in velocity barrier of condition 1 was 101.55±14.87 cm/s, while condition 2 was 114.63±24.28 cm/s), for the other layout, the channel has only one step (the flow speed in the 160 cm long velocity barrier of condition 3 was 137.45±17.63cm/s). 93.33% fish in condition 3 cross the single step barrier successfully in a swimming speed of 209.43±21.76 cm/s; the swimming speeds(214.01±30.64cm/s) in all three conditions were not significantly different from burst swimming speed of fish (P>0.05). The swimming trajectories of fish and the corresponding flow field show that the time cost and path length for fish to swim upstream is closely related to the path fish choose. Fish reduce its time cost and path length to swim upstream by taking advantage of flow which is in the same direction with fish movement. This method and result of this research could provide reference for fish design, modification and evaluation.

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CFD modeling of fish exclusion screens

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Fish screens or exclusions are a common design option to prevent the movement of aquatic organisms into hydroelectric, irrigation or other types of water withdrawal structures. To ensure proper functioning of the exclusion screens, state and federal agencies have regulatory requirements for the hydraulic conditions near the screen. These include limitations on the allowable velocity components normal (approach velocity) and tangential (sweeping velocities) to the screen. Approach velocities must be limited to prevent the impingement of fish on the screens, while minimum sweeping velocities are required to prevent debris build up. Additional design targets include ensuring uniformity of flow over the surface of each screen.

In the current practice, physical laboratory tests are often required in the design stage to ensure that the exclusion screens meet regulatory requirements for target species. However, the progress made with commercially available Computational Fluid Dynamics (CFD) tools, in conjunction with improvements with available computational hardware, allow us now to envisage using such numerical modeling solutions for detailed studies of fish screen hydraulics.

In this study we evaluate using a CFD model as a design tool for fish exclusion screens. Drawing on measured data from fish screens tested at the United States Bureau of Reclamation (USBR) hydraulics laboratory, we validate the results of a numerical model with measured USBR data, and evaluate the range of model setup options using both porous objects and porous baffles to represent the screens. We evaluate numerical options and discuss how these can be defined to maximize the accuracy and efficiency of the simulation.

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Ultrasound to guide American shad toward a spillway

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To minimize mortality, Hydro-Québec's power station located on the Des Prairies River (Montréal, Canada), used to stop its operation for one hour every day during the post spawning migration of American shad (*Alosa sapidissima*). The corresponding water volume was then spilled (via the spillway) to produce a preferential flow for the fish. It was shown that during this period, up to 95% of the shads located in front of the power station swam away from it, toward the spillway. However, during the remaining hours of operation there was a high probability that shad would go through the turbines to complete their journey back to the ocean. To reduce this potential mortality, Hydro-Québec has been experimenting since 2006, with an ultrasound barrier operating at a minimum noise level of 168 dB ref 1µPa at 125 kHz to prevent shads from approaching the power station. From our experimental and bibliographical data, these values have to be met to ensure the success of the American shad guidance. Consequently, since 2010 the power station did not have to stop its operation during the American shad downstream migration. A final prototype developed with Hydro-Quebec's Research Institute is now in use. Plans are made to guide American shad to an alternative route where no power station is present.

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Group behavioural responses of cyprinids to artificial acoustic stimuli: implications for fisheries management

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Physical screens are considered a necessary mitigation strategy, restricting access to hazardous areas (*e.g*. turbine intakes or extraction points) and guiding fish to safer preferred routes. Whilst this precautionary approach is considered fit for purpose, fish interactions at such interfaces have been observed to cause stress, injury and mortalities where high sweeping approach velocities exist. Alternative or collaborative systems may allow for improvements where effectiveness of physical screens alone are limited (*e.g.* repelling small sized larval/ juvenile stages).

A number of acoustic guidance systems have been deployed to date, however efficiencies of such devices are measured using relatively simplistic metrics (*e.g.* percentage deflection or attraction). Results are highly variable, with some systems observing little to no deflection. Current approaches testing efficiencies are based on methods which provide limited information surrounding the wild behaviour of migratory fish. Furthermore, many studies investigating fish bioacoustics pay limited attention to the entirety of the acoustic field to which fish are exposed.

The auditory system is exceptionally important to most aquatic species due to its information provisioning, however various challenges need addressed to extrapolate useful informative data which could develop working behavioural deterrents. Life-history strategies, life-stages, species specific hearing capabilities (*i.e.* directivity index, sensitivity, and critical ratio), and the propensity for a sound to elicit a repeatedly effective behavioural response (*i.e.* signal detection theory and effects of habituation) are all areas that require thorough investigation.

Utilising model cyprinid species (in possession of morphological hearing specialisations), groups of fish were video recorded under controlled conditions and exposed to differing acoustic stimuli. Behaviours were quantified and analysed, alongside appropriate mapping of tested acoustic fields. This talk summarises past and ongoing experiments of a PhD project investigating group behavioural responses to sound. Results may better inform fisheries engineering design of acoustic behavioural deterrents for conservation and control purposes.

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Fish deterrents and screen designs

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Fish deterrents are an essential addition to water diversion systems that conserve fish populations whilst protecting water management infrastructure.

This paper discusses fish screen designs required to avoid the high fish mortality rates resulting from entrainment in irrigation pipes, water diversions systems and hydropower intakes.

Fish protection is an important element of managing water intakes. Fish protection often defined as fish exclusion, includes, not only limiting entrainment of fish at intakes, but also protecting fish from injury or mortality resulting from operation of the intake.

Currently, in Australia and New Zealand there are real concerns about the effectiveness of many traditional fish exclusion technologies already in use.

Over a number of years, AWMA undertook an extensive international review of Fish Exclusion Screen technologies. This paper shares their findings by presenting the operational performance details and features of the innovative technologies available in the market and discussing their suited applications.

Australian manufactured fish exclusion screen technologies adhere with the USEPA 316(b) compliant design requirements and the NIWA Fish screening: good practice guidelines for Canterbury.

There are currently two screen designs that are in accordance with industry best practice, manufactured in Australia and available under full quality and industry compliance; Cylinder Screens and Engineered Polymer Travelling Screens.

The cylinder screen is used for submerged intakes and designed to protect fish from being entrained in a diversion as well as preventing them from being impinged on the screen surface.

The Travelling Screens is a chainless screen design using a unique engineered polymer material. This screen delivers advantages others can't offer; lower ownership costs, operational efficiency and reliable performance.

This paper reviews the theory of traditional screens and provides insight into the innovative methodologies now available, to ensure the importance of fish health and water wealth are both paramount.

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Screening the Cohuna Channel to keep native fish in Gunbower Creek

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Fish entrainment into irrigation channels is an issue globally. In the USA and Europe, self-cleaning screens are used to limit fish movement into waterways, hydroelectric power stations and pump houses. In some cases, legislation requires it, which has resulted in a well-established and innovative industry. Fish entrained in irrigation channels are usually exposed to poor quality habitat, low-to-no over winter flows, increased predation, injury or death from irrigation pumps, and generally have no passage to return to the natural system.

The Arthur Rylah Institute has highlighted the extent of fish losses in gravity fed diversions in Victoria, with electrofishing surveys of 59 irrigation channel sites in the Murray Valley and Torrumbarry Irrigation areas collecting over 10,000 juvenile and adult fish from ten native species. A larval drift study undertaken by the North Central Catchment Management Authority (CMA) in Gunbower Creek in November-December 2017 revealed that approximately 5500 native fish larvae from four species, including more than 160 Murray cod larvae are being entrained per day in the Cohuna Channel during the peak larval drift period.

To prevent these losses, North Central CMA, in partnership with the Victorian Environmental Water Holder and AWMA Water Control Solutions, are installing Australia's first self-cleaning irrigation channel screen to prevent fish entrainment from Gunbower Creek into the Cohuna Channel. The Cohuna screen has been designed to suit the needs and spawning strategies of Murray-Darling Basin fish species. The design builds on the extensive knowledge of AWMA, and their industry partners in the USA, to factor in local hydrology and ensure that the delivery of irrigation water is not impeded.

This presentation will outline findings from larval drift and adult fish pump out studies in the Gunbower Creek and Cohuna Channel system and the challenges associated with designing, constructing and installing Australia's first irrigation channel screen.

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Partial migration: some causes, consequences and connectivity

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River connectivity implies free passage for migrating fish, yet not all fish individuals migrate in spite of full connectivity. Such partial migration can be driven by a variety of factors, and fish migration propensity can have delicate implications for conservation and passage solutions. Using European cyprinids as model organisms and a PIT system to monitor migration, this presentation describes seasonal changes in predation risk (P) and growth opportunity (G) as drivers of seasonal migration between lakes and their connected streams. Although the P/G ratio convincingly describes seasonal timing of migration at the population level, individual migration probability and behaviour vary substantially with fish individual e.g. body condition, animal personality, migration history, or size- and predator-specific risk of predation. Fitness tradeoffs in migration decisions can affect survival and consequently phenotypic and genotypic composition in migratory fish populations, and such selective forces can be imminent also for fish passage solutions that do not consider phenotypic diversity in the migratory fish populations they are aimed to aid.

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Exploring outcomes and assumptions of successful fish passage in the Murray-Darling Basin using individual-based modelling.

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Fragmentation of river systems by dams and weirs is a major factor in the decline of riverine fishes, due to interruption of migratory pathways. The leading strategy for mitigating these impacts has been installation of fish passage structures. This strategy assumes that successful upstream migration is required to ensure reproduction and recruitment. However recent studies of Neotropical potamodromous fishes have shown that this strategy may be flawed, creating situations where fish may follow migration cues towards less favourable habitats for successful recruitment than those downstream, known as an ecological trap. Whilst the need for unrestricted movement in potamodromous fishes is recognized, the evaluation of fishways rarely considers how factors beyond upstream movement of fishes influence conservation success.

While data is lacking on factors such as migratory habits, habitat availability and migratory motivation, modelling hypothesised behaviours along migratory pathways in response to environmental cues, can assist with identifying potential recruitment scenarios. In this study, individual-based modelling (IBM) is used to explore how presence of fish passage infrastructure can act as an ecological trap depending on the availability of suitable spawning and nursery areas upstream and downstream of migration barriers. The model simulates hypothesised effects of facilitating fish passage on recruitment and abundance of Murray cod and Golden Perch in a regulated low-land river.

Behavioural rules and parameters are assigned to individuals, based on existing data and assumptions about migratory behaviour, habitat requirements and environmental parameters. Scenarios of recruitment are compared under two fish migration paradigms: 1) that successful recruitment and conservation is dependent on unrestricted upstream migration, or 2) that successful conservation is achieved through improved access to quality habitats. We anticipate that IBM will contribute to identifying knowledge gaps and testable hypotheses in the study of fish passage, migratory behaviour and recruitment of potamodromous fishes in regulated systems.

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The migrations of amphidromous species: implications for fish passage and water infrastructure

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Amphidromous species undertake a number of migrations throughout their life-history, migrating to sea immediately after hatching in freshwater, migrating back to freshwater after a pelagic larval period, and potentially undertaking adult spawning migrations. Amphidromous species are therefore likely to be highly susceptible to water infrastructure, having different migratory directions, objectives, and requirements at different life stages. We review the current state of knowledge on the migrations of amphidromous species, identifying the requirements for successful migrations, and potential threats during these migrations from water infrastructure associated with anthropogenic activities. Downstream spawning migrations were found to be common in numerous amphidromous taxa, and spawning migrations and the hatching of eggs are often associated with natural changes in flow regime, highlighting the need for bidirectional fish passage, and the potential for artificial flow alteration to negatively affect reproduction. Once hatched, larvae migrating downstream were found to be highly susceptible to numerous hazards associated with water infrastructure, including larval retention and starvation in freshwater, increased mortality due to expedited migration, entrainment and impingement at water intakes, and barotrauma and physical damage associated with weirs and turbines. Distinct patterns of larval drift (spatial and temporal) may provide opportunities to alleviate mortality during larval emigration. While in-stream barriers inhibit the upstream migrations of amphidromous postlarvae and juveniles, climbing abilities are common, allowing for creative solutions facilitating upstream migration. Overall, much of the focus on amphidromous fish passage has been placed on upstream migrating postlarvae and juveniles, while the requirements of migrating adults and larvae, which may be far more susceptible to water infrastructure, have largely been ignored. This life-stage bias represents a key research gap that must be addressed to safeguard amphidromous species in future.

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Development of a fish passage inventory and evaluation of success rates of major fish passages on fish movements through barriers in regulated river systems of China

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Many river systems in China are highly regulated. The ecosystems structure and functions of these river systems are threatened by barriers such as irrigation and hydropower dams restricting fish movements for reproductive and food habitats. To overcome this challenge, several fish passages are built. However, the inventory and potential of fish passages are not well investigated. In this study, we have developed a fish passage inventory by identifying the type, the location and time, we have then evaluated the effectiveness or success rates of fish passage types. Out of 222 fish passage facilities are in use globally, 73 fish passages

are in China, where the pool-type fishways are accounted for 87.7%, followed by nature like and lifting type, each accounted for 4.1%. We evaluated the lifting height to slope ratios of a fish passage is a function of success rates for fish passing through the barrier. Among 24 pool-type fishways analyzed, slope tended to decrease with increasing lifting heights and showed potential implications for fish movements through the barriers. The Changzhou Fishway (Peral River) and the Cuijiaying Fishway (Yangtze River) showed greater potential of fish crossings. Forty species of fish successfully passed through the Changzhou Fishway from 2011 to 2014, where four species, *Pelteobagrus vachelli*, *Squaliobarbus curriculus*, *Hemiculter leucisculus* and *Anguilla japonica* made the successful crossing, with 29.1%, 16.8%, 14.7%, and 12% respectively. From the Cuijiaying Fishway, eleven species made a successful passing in 2012 alone, in which three species *Pelteobagrus vachelli*, *Hemiculter leucisculus* and *Distoechodon tumirostris* made 46%, 16% and 13% successful crossings. When many dams in China are facing critical challenges to adopt the right type of fish passages, the pool-type fishways with variable adjustments of lifting heights to slopes could be a good option for successful fish crossing in regulated river systems.

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De-congesting London: Improving River Connectivity for Lowland River Fishes in Urban Streams

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Weir construction has fragmented many lowland rivers, resulting in the exclusion of some fish populations from suitable habitat. A cheap retrofit fishway for sloping weirs with a gradient of ~1:5 is the Low Cost Baffle (LCB) solution, a series of notched baffles perpendicular to flow on the downstream weir face, generating an angled passage route across the weir face. To test the degree to which LCBs can pass upstream-moving fish at steeper weirs, LCBs were fitted onto a 1:3.3-sloping weir face, in an urban tributary of the River Thames, England. The study also compared the passage of wild and stocked fish (the latter are employed to facilitate population recovery in restored English rivers). Passive Integrated Transponder (PIT) antennas were positioned on the weir to record the upstream movement of PIT-tagged barbel (*Barbus barbus*; n_{stock} =120), chub (*Squalius cephalus*; n_{stock} =119; n_{wild} =194), dace (*Leuciscus leuciscus*; n_{wild} =50), and roach (*Rutilus rutilus*; n_{wild} =30). Over six months, more stocked fish attempted passage (58.9%) than wild (14.6%; χ^2_1 =26.7, p <0.001), but there was no difference in successful passage (stock =34.0%; wild = 40.0%; χ^2_1 =0.5, p =0.49). Stocked fish took longer to complete passage (mean =9.3 hrs) than wild (mean =3.3 hrs; $t_{47.3}$ =2.1, p =0.04). This study finds that LCBs can facilitate passage for lowland-river fishes at steep urban weirs that cannot readily be removed. Although some fish failed to pass the weir, others succeeded on several occasions. This could be a result of inter-individual variation in motivation rather than LCB inadequacy. This study also indicates that stocked and wild fish exhibit similar passage success, a finding with important management implications.

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Novel fishway entrance modifications to improve passage for native fish

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Healthy riverine ecosystems require passage routes at dams for a broader array of species than has historically been targeted. Hence, fishway entrance modifications were made at a large Columbia River dam in northwestern USA. These modifications were designed for Pacific lamprey *Entosphenus tridentatus*, a species of conservation concern. They feature a variable-width entrance weir and flow disrupters to create velocity heterogeneity near the bottom without affecting attraction flows for salmon and shad. Passive integrated transponders and radio transmitters were used to assess both lamprey and Chinook salmon (*Oncorhynchus tshawytscha*) passage. Entrance efficiency at the modified entrance was compared to that at a similar, but unmodified entrance before and after modifications. No statistically significant differences in entrance efficiencies were observed for lamprey or salmon. Additionally, a lamprey passage structure (LPS) was installed to provide a lamprey-specific route from tailrace to forebay elevation (31 m). Lamprey were counted as they exited the structure. Pacific lamprey successfully ascended the LPS, with annual counts increasing from 48 in 2010 to 3851 in 2016. Radiotelemetry indicated that Pacific lamprey resumed upstream passage after LPS use and traveled at rates similar to those of tagged Pacific lamprey that did not use the LPS.

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Improving the conservation status of Arctic grayling: combining laboratory, field and modeling techniques to support the agency-irrigator decision making process

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Recovering and improving the conservation status of Arctic grayling (*Thymallus arcticus)* populations is a United States Fish and Wildlife priority goal. While grayling are widespread in much of Canada and Alaska and in parts of Europe and Asia, they are a species of special conservation concern in Montana. In 2006, a Candidate Conservation Agreement with Assurances program for the Big Hole River Watershed was established to facilitate conservation. There is concern that barriers, such as irrigation diversions, may limit the movement of grayling. The purpose of this study was to determine the passage efficacy of Denil fishways installed at irrigation diversions to provide passage for grayling in the Big Hole River Watershed. We have implemented a tiered approach that combines laboratory studies (2015-2017) with field investigations (2017-2018) to evaluate passage efficacy. A unique, multi-faceted technique for assessing landscape connectivity in the field will be presented along with lessons learned. Direct and indirect assessments of fishways in the Big Hole River Watershed were completed in 2017-2018. Direct assessment involved passive integrated transponder (PIT) tags to directly monitor grayling movements at field installations. Indirect assessments defined fish movement through a range of Denil flow conditions based on lab data, hydraulic models of the field sites, and characterization of seasonal hydrology. We have developed a decision-support tool to identify effective and less effective fishways, identify and prioritize retrofitting of less effective fishways, and improve passage design criteria for grayling.

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The effects of fishway entrance design on the passage time of adult American shad

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A common problem among fishways is attraction and entry. Competing flows and complex hydraulics in and around the fishway can at times hinder passage and result in significant migration delays. The purpose of this study was to evaluate how flow conditions at a fishway entrance and the structural design of the entrance can affect entry. In most instances, a fishway entrance consists of a fully submerged hydraulic control (e.g. gate) located at the downstream end of an open channel that guides fish to the main body of the fishway (e.g. lift, pool-and-weir). Changes to this hydraulic control design can influence the hydraulics (e.g. entrance jet velocity, flow pattern) and thus attraction and entry performance. To address these issues, a study was performed in 2016 and 2017 with upstream-migrating, adult American shad (*Alosa sapidissima*) which documented the performance of a variety of hydraulic controls under a limited number of conditions. Submergence depth (i.e. the height difference between the tailwater elevation and the gate crest) and river temperature were shown to be the main drivers in performance. Gate type was also significant, where the novel reversed overshot gate performed the best followed closely by the standard overshot gate. The vertical gate, by far the most common among fishways, performed much worse than the other two gate types. Additional trials in 2018 evaluated the effect of different water surface elevation drops across the gate for American shad and blueback herring (*Alosa aestivalis*). The results of these studies provide guidance to state and federal resource agencies and the hydropower industry on methods to improve fishway attraction and entry rates.

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Arctic Grayling and Denil Fishways: Research to Determine Swimming and Passage Capabilities of Grayling in Relation to Fish Barriers

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Arctic grayling, Thymallus arcticus are a species of special concern in Montana, USA and have been petitioned for Endangered Species listing. The only populations native to the lower 48 states were in Michigan and Montana; the Michigan population is now extinct. Irrigation diversions are common to the river systems in Montana. They provide necessary water diversion for agriculture, but can be barriers to fish movements. Denil fishways have been installed in irrigation diversions to provide fish passage. Their efficacy for grayling passage has not been well studied. This research followed a stepwise progression from determining base line swimming ability of grayling to performing laboratory experiments to test passage through Denils over a range of water depths. We characterized swimming and passage abilities using a swim chamber, an open channel flume, and a Denil installed within the open channel flume to determine the passage capabilities of grayling in relation to barriers. We performed Usprint tests in a swim chamber to measure the maximum velocity a grayling could swim for 15 s; the approximate maximum duration sprint swimming can be sustained. We tested the “volitional” swimming performance of grayling in an open channel flume to determine passage success, maximum ascent distances and maximum sprint speed over a range of water velocities. We performed Denil laboratory trials focused on evaluating design parameters such as water depth, velocity, and Denil slope and length. We report passage success on a series of trials using two Denil lengths (1.83 m and 3.66 m) at varying hydraulic conditions. This project paired engineers and biologists to develop metrics that can be used to assess barriers and design passage ways to restore habitat connectivity for grayling. Few research projects have followed such a progressive line of study and this work might serve as a model for other research efforts.

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Reducing slope improves small fish passage through a Denil fishway

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TBA

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Fish Passage Considerations though Slip-Lined Culverts with and without Baffles

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Culvert rehabilitation, which typically includes sliding a smooth-walled liner inside an existing host culvert pipe, is often a cost-effective alternative to culvert replacement for many applications where the culvert has reached the end of its useful life. When a smooth-walled pipe is used to reline a corrugated existing culvert pipe; the culvert flow velocities typically increase, the corresponding flow depths decrease, creating a potential barrier to fish passage, relative to the original culvert flow condition. In an effort to provide some baseline data for fish passage through baffled culvert liners, fish passage behaviors of wild brown trout through prototype-scale 0.61 m diameter, 18 m long smooth-walled, baffled and non-baffled culverts were observed in the laboratory under a variety of culvert slopes and discharges. The baffles significantly increased the range of culvert slopes and discharges over which the fish could successfully pass. The baffled culvert hydraulic roughness coefficient (Manning's *n*) increased 274% (approximately equivalent to corrugated metal pipe values), relative to the non-baffled culvert.

In an effort to evaluate the effectiveness of computation techniques for baffled culvert design, turbulent free-surface flow conditions through a weir-baffled lined culvert were also simulated numerically using a three-dimensional numerical model utilizing three different turbulence models. Experimental velocity data, acquired using Particle Image Velocimetry, were used to assess the ability of these turbulence models to predict the turbulent flow characteristics for various culvert slopes and discharges. Comparisons between the measured and computed flow field velocity and turbulent kinetic energy data resulted in reasonably good agreement, particularly using the Renormalized Group *k-e*model, with the resulting undulating supercritical flow profiles, which featured recirculating eddies downstream of each baffle.

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Improving fish swimming performance through the provision of roughened channel beds: implications for culvert remediation efforts in Australian waterways

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Culverts act as hydrological barriers to fish movement by severely altering the hydrodynamic conditions within the channel environment. The widespread use of culverts has caused significant declines in freshwater fish populations worldwide. To address this issue, culvert remediation through the provision of naturalistic substrates to induce bed roughening, has proved effective at increasing the likelihood of fish passage in a variety of European and North American fish species. Whether culvert roughening is similarly efficacious for small bodied Australian fishes and the physiological basis for why roughening might be beneficial to fish, are largely unknown. Here, we found that in most cases, the provision of a roughened bed substrate generally improved swimming performance by reducing the metabolic cost of swimming in seven out of nine Australian fish species examined, however the relative impact of different bed roughness designs (i.e. relative size of rocks and their spacing), differed across species. However, one species was detrimentally affected and one gleaned no benefit from the provision of a roughened substrate environment, suggesting that not all species may benefit from this type of culvert remediation. Traversable culvert modelling suggests that substrate roughening would increase the likelihood of successful passage, with many species capable of swimming at higher bulk velocities in the presence of a roughened culvert bed. Our data show that culvert bed roughening can improve swimming performance in many small-bodied Australian fish, indicating that this is likely to be an effective remediation strategy to improve passage of native fish through culverts. But because not all species may benefit equally from bed roughening, we need to understand species-specific hydrodynamic requirements to inform tailored, context-specific, remediation approaches.

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Baffles versus beams: strategies to improve fish passage through culverts.

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Historically, culvert designs have focused primarily on their requirement to move water underneath civil infrastructure, without much concern for the up-stream movement requirements of endemic fish populations. However, it is increasingly recognised by ecologists and infrastructure managers alike, that culverts are a major cause of habitat fragmentation in freshwater ecosystems and a significant contributor in the decline of freshwater fish populations globally. To address this, various culvert remediation

designs have been implemented, including the installation of vertical baffles and the provision of naturalistic (rock) substrates. While remediation strategies generally aim to reduce the velocity of water flowing through the structure, there is often resistance to their use because reduced culvert discharge can negatively impact upstream flooding while also resulting in debris clogging and increased culvert maintenance costs. In addition, baffles markedly increase water turbulence which may be detrimental to passage by some fish species or size classes. Here we present some novel remediation designs that exploit the reduced water velocity in boundary layers along the culvert wall to enhance fish passage without significantly compromising discharge capacity. These longitudinal designs produce an expanded reduced velocity zone along the culvert margins that generate minimal turbulence. We show that these novel designs are significantly advantageous to the swimming endurance and traversability for six small-bodied Australian fish species. We also provide data on how and why some culvert baffle designs may impede small-bodied fish passage at high water velocities. This has broad implications for fish community structure where baffles have been implemented to facilitate the passage of large bodied, commercially important fish species.

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Issues and design considerations when negotiating fish passage at everyday road causeways

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Most older Australian road causeways were constructed prior to the implementation of fish passage policy and legislation and act as low-head weirs. These structures reduce fish passage, particularly upstream migrations, and negatively impact upon the distribution of native fish populations, particularly within catchments where multiple causeway structures exist. These structures can also contribute negative impacts on river morphology placing further stress on native fish populations. Age, engineering standards and increased traffic demand mean that many of these structures now require major maintenance work or complete replacement.

Prior to undertaking causeway maintenance or replacement works, legislation within some jurisdictions requires asset owners to obtain approval from fisheries regulators. The approval process provides an opportunity to implement best practice fish passage techniques to ensure that the upgraded or replacement structure will provide an effective, long-lasting level of fish passage. Achieving an effective, long-lasting level of fish passage can be a difficult task for regulators because fish passage requirements are just one of many competing objectives that asset owners must meet. Within New South Wales (NSW), the ability to achieve effective, long-lasting fish passage outcomes at causeways has proved to be a challenge, particularly where budgets are constrained, or where causeways are now acting as bed control structures that are stabilising upstream habitat.

To highlight the challenges associated with achieving positive outcomes for fish passage and to show what has and has not worked regarding causeway fish passage options, including rock ramp fishways, we will detail the recent design consultation process that occurred for the Sawyers Gully causeway upgrade project in northern NSW, and detail a cross-section of previously attempted causeway remediation designs. We will conclude by detailing the final agreed design of the Sawyers Gully causeway upgrade project that meets fish passage criteria, and also the economic, social, and environmental objectives.

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A Cross-section of Hydraulic Design Solutions to Address Vertical Profile Constraints at Road Crossing Design Projects

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The effect of weir crest width and discharge on passage performance of a potamodromous cyprinid

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Contrarily to the vast literature on dams, much less is known about the effects on fish movements of the far more numerous small weirs. This study aims to evaluate the negotiation performance of the Iberian barbel (*Luciobarbus bocagei*), a medium-sized potamodromous cyprinid, facing a small broad-crested experimental weir with varying widths of the weir crest (W), and discharges (Q). Hydrodynamics over the crest and downstream the weir were characterized with a flow probe and a 3D Acoustic Doppler Velocimeter. Fish negotiated all configurations W×Q tested, registering a total of 273 upstream passages and 192 downstream passages. However, the number of fish that approached, attempted, and successfully ascended and descended the weir varied among configurations, emphasizing the complex interaction of factors on passage performance. Discharge proved to be preponderant on both upstream (F = 5.48; P = 0.008) and downstream passage (F = 6.66; P = 0.009), while the influence of the width of the weir crest was more evident on downstream passages (F = 5.16; P = 0.016). Results from this study are expected

to be useful to identify potential migration obstacles and may be applicable to other cyprinid species with similar life-history requirements.

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Fish Passage Challenges and Opportunities in Indonesia

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The construction of dams, weirs, irrigation infrastructure and regulators impact connectivity among habitats and can facilitate rapid declines in riverine biota; especially fish. Indonesia is a tropical island country with an abundance of monsoonal rivers. Massive expansions in hydropower and irrigation infrastructure are planned over the next two decades and mitigation measures will be needed to protect migratory fish. Most Indonesian freshwater fish need to migrate between habitats to complete essential life history stages. So strategies are urgently needed to mitigate the barrier effects of river infrastructure to ensure the long term sustainability of river fishes. A common tool used worldwide is the construction of upstream and downstream fish passes. Only two fish passes exist in Indonesia. One at Peryaja Irrigation Dam on the Komering River (Sumatra island) and another on Poso Dam on the Poso River (Sulawesi island). Neither of these structures have been assessed and many other projects are proceeding without considering potential fisheries impacts. The proposed infrastructure upgrades over the next two decades provides a once-in-a-generation opportunity to ensure that migratory fish are adequately protected from infrastructure projects. But there is an urgent need to collect and apply ecological and hydrological criteria to develop functional fish pass designs. A research for development approach where new information is applied, in an adaptive sense, to new projects will protect fisheries resources which form a source of food and livelihoods for many.

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Stress indicators in *Prochilodus lineatus* breeders during migration through a fish ladder

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Fishways should attenuate the blockage of migratory routes imposed by dams. However, when fish ladders are poorly designed, they may cause excessive stress. This study evaluated if fish ladder transposition was a stressful event for *Prochilodus lineatus* in the Porto Primavera Dam, Paraná River, Brazil. Were analyzed the body weight, standard length and plasma concentrations of cortisol, glucose, lactate, chloride and hematocrit in 48 adult fish sampled at downstream, into the fish ladder and upstream. Data were analyzed by two-way ANOVA and Fisher–LSD post-hoc test. Correlation between lactate concentrations and, fish weight and standard length was determined using Pearson correlation. The significance level was 5%. Females were heavier and longer than males ($F_{1, 42}$ = 20.47; P = 0.001), and both sex collected upstream of the dam also had a greater weight ($F_{2, 42}$ = 5.05; P = 0.011). While cortisol and chloride concentrations did not vary, the both glucose concentrations increased significantly in the ladder compared to downstream (P < 0.001) but did not varied between fish from downstream and upstream (P = 0.31). Female glucose values were higher than those of males ($F_{1, 42}$ = 5.30; P = 0.026). There was an increase in lactate concentration in the ladder ($F_{2, 42}$ = 3.81; P = 0.03) and a negative correlation between lactate concentration and body weight (P = 0.027; ρ = -0.548) and between lactate concentration and standard length (P = 0.011; ρ = -0.613). Hematocrit values decreased in the ladder ($F_{2, 42}$ = 4.66; P = 0.015). These results show that although the intense physical exertion of the fish in ladder transposition demanded high metabolic requirements and activated anaerobic pathways, it was not a stressful condition. We propose that physiological indicators should be used as criteria in projects for fishways, as well as post-construing assessment.

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Effectiveness of a fish ladder for two Neotropical migratory species in the Paraná River

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Hydroelectric dams have threatened the conservation of migratory fish species by blocking the migration routes, and fishways are the most common mitigation strategy. We evaluated the effectiveness of the fish ladder of Porto Primavera Dam in the severely regulated Upper Paraná River, for two Neotropical migratory fish species. Overall, 563 fish (447 *Megaleporinus obtusidens* and 116 *M. piavussu*) were PIT-tagged and monitored continuously for 4 years with the RFID system. The fish were released at eight places at upstream and downstream areas and on the left and right banks: DLN (downstream-left near the ladder; < 100 m), DLF (downstream-left far; 1.200 m), DRN (downstream-right near; 1100 m), DRF (downstream-right far; 2.100 m) ULN (upstream-left near; < 100 m), ULF (upstream-left far; 1.400 m), URN (upstream-right near, 1.200 m) and URF (upstream-right far; 2.400 m). The fish performed two-way movements through the fish ladder, ascending and descending, as well as some individuals realized both movements throughout the monitoring. Entry proportion ranged from 0 to 38.5%, and was highest for the downstream release site on the left bank, nearest the ladder. Entry times ranged from 1.5 to 449.9 days. Passage percentages were 80% for fish release downstream and 100% for fish released upstream. The upstream and downstream median transit time was 0.86 and 0.93 hours, respectively and was not significant (Log-rank test, $x^2 = 0.053$; $p = 0.817$). Although our study evidenced that entry was poor everywhere and nonexistent from the right bank, performance of ascending and descending passage of *Megaleporinus* spp. through the fish ladder of Porto Primavera was high. If guidance entry conditions can be improved this fishway design holds promise as an effective solution, although additional structures may be required to achieve this.

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Upstream passage of adult sea trout (*Salmo trutta*) at a low-head weir with an Archimedean screw hydropower turbine and co-located fish pass

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The exploitation of riverine systems for renewable energy has resulted in large numbers of small-scale hydropower schemes on low-head weir. Although considered a clean and 'green' energy source in terms of emissions, hydropower can impact upstream migrating species by diverting flow away from viable routes over the impoundment and attract fish towards the turbines outfall. In an attempt to reduce this negative effect, hydropower outfalls with co-located fish passage entrances are recommended; utilising turbine flows to attract fish towards the fish pass. This study used acoustic telemetry to understand the performance of a co-located Larinier fish pass at a low-head hydropower scheme at a weir on the tidal Yorkshire Esk, England. The majority of the sea trout (anadromous *Salmo trutta* L.) that approached the impediment were attracted to the hydropower and co-located fish pass. Fish ascended through the pass under a wide range of river flows, tide heights, downstream river levels and hydropower flows, and there was no evidence that the hydropower operation affected fish pass ascent. The information presented is urgently required to inform management decisions on the operation of hydropower schemes during the migratory period of salmonid fish, and help determine best practice designs and operation at these facilities.

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Dam removal Europe: refuting myths and supporting professionals

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The removal of dams and weirs has been happening for decades. Since the 90's a few countries have increased this tendency. USA has already removed at least 1,300 dams. What very few people know is that in Europe there have been over 3,500 barriers demolished already.

In some European countries, like France, Sweden, Spain, Finland and UK dams are mainly being removed due to existing legislation, safety and security, the need to reach a good ecological status of their rivers for the Water Frame Directive and/or economical reasons. However, the lack of awareness, knowledge, support by decision makers and funding for dam removal are generally bottlenecks and most of the times is the cause of many dam removal failures. In addition, the Renewable Energy Directive requires the EU countries to fulfil at least 20% of its total energy needs with renewables by 2020, and amongst these renewables is hydropower. All this makes dam removal projects tremendously difficult to those who are willing to start removing old and useless dams, and automatically makes dam removal an uncomfortable subject to bring up for politicians.

Europe requires a shift towards adaptive management of stream barriers, one that maximizes benefits and minimizes impacts, one that keeps efficient dams and removes obsolete and abandoned dams. The goals of Dam Removal Europe (www.damremoval.eu) are to improve citizens' awareness about removing dams and refute myths, create a reference community of professionals, experts and starters, who generates and shares knowledge about dam removal and putting dam removal on the agenda of policy makers, directors and managers.

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Capturing the WIIFMs: a citizen handbook tool for influencing public perception of dam removal and fish passage projects

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Community support for dam removal is a crucial element for project success, especially where dams are publicly owned and publicly accessible. Effective community engagement can be a daunting task for fish passage professionals for numerous reasons:

- Dam removal advocates are challenged to communicate scientific information to non-scientists in a science-minimizing, fact-adverse culture;
- Removing dams for fish passage benefits is not perceived by the average citizen as relevant;
- Dam removal advocates provoke the fear of change because such projects threaten the community with a perceived loss;
- average citizens lack the imagination to envision their river without the dam.

American Rivers has developed the Citizen Handbook to capture the What's In It For Me (WIIFM) to influence public perception of dam removal for fish passage benefits. This cost-effective and scalable handbook is a tool for scientists, engineers, and fish passage advocates to present technical information to an often contrarian lay audience in an accessible and engaging manner. Featuring graphics and visual examples, the handbook presents benefit-risk and benefit-cost analyses for commonly-expressed public concerns: recreation access; community and infrastructure; public safety; ecological; and cost. Each of these issues is explored via dam-in and dam-out scenarios that invert the public's often-emotional perception of losses and gains by emphasizing the benefits that accompany dam removal compared to losses and/or missed opportunities connected to dam retention.

American Rivers' presentation will highlight the Allegheny River Citizen Handbook as a case study. Focusing on five federally-owned, defunct commercial navigation dams near Pittsburgh, Pennsylvania, the handbook was developed to build a local constituency for their removal. The presentation will summarize experiences and outcomes resulting from the community engagement process that invites stakeholders to envision the suite of ecological and community benefits and to capture the WIIFM that removal of this iconic infrastructure could provide.

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Dam Removal: When Less is More

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Dam removals come in all shapes and sizes, with a myriad of different issues that impact the final design, sediment management, and channel restoration approaches selected. Some projects require a more "engineered" design when critical infrastructure is at risk; however, many dam removal projects can be designed with a "less is more" approach, letting the river do the work, and setting the river back on a trajectory to restore itself. We will discuss multiple successful dam removal projects that we purposefully designed to avoid "heavy handed" approaches. For these projects, an upfront understanding of the channel's equilibrium slope, history of sediment deposition, and understanding of potential risks and impacts were critical to the final design choices made. Habitat building blocks were added as needed, however grade controls, hard armoring, extensive plantings, and active channel reestablishment were avoided. The upstream channels were allowed to remain dynamic and re-establish themselves. Examples of completed projects such as the Tannery Dam removal in New Hampshire and the Pleasant Grove mitigation site and dam removal in New Jersey will be described as well as other dam removals throughout the greater northeastern US. While a "less is more" approach is not always attainable, we will discuss the benefits of this approach, such as ease of constructability, and how to look for the right opportunities to apply this approach.

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Damming a bedrock cut to daylight a buried stream under an abandoned railroad crossing in the Eel River Canyon of northwest California

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The Eel River historically supported one of the largest salmon and steelhead runs in California. but populations have dramatically declined. As part of recovery efforts, fish passage assessments were conducted at crossings on tributary streams. An assessment along the now-defunct Northwestern Pacific Railroad, constructed in the early 1900's through the remote Eel River Canyon, identified a severe barrier at the confluence of Woodman Creek, a 63 km^2 drainage. During railroad construction the lower 100 meters of channel was buried with fill material 20 meters deep, and the stream was rerouted into a narrow cut through bedrock, discharging directly into the river, creating a 5 meter tall bedrock waterfall that blocked fish access to the watershed. In the 1990's the rail was abandoned due to the unstable geology, and no public site access exists.

The project was initiated to remove the fill overlaying the historical channel and permanently plug the bedrock cut. Preliminary investigations involved use of seismic refraction and excavation of test pits to map the buried channel's depth, and configuration.

The subsurface investigations revealed a buried bedrock-boulder channel. The investigations indicated channel daylighting required excavation and disposal of 36,000 m^3 of fill.

Given the remoteness of the site, the bedrock plug must remain functional for the indefinite future. It was designed as an 8 meter tall earthen dam using material excavated from the rail embankment. A concrete sill and geomembrane liner in its core is designed to minimize seepage. Large rock placed in layers along the plug's exposed face is designed to resist scour and erosion from Woodman Creek on one side and the Eel River on the other side.

This presentation will describe site characterization techniques and design approaches employed to daylight the stream and building the plug, and methods used to overcome challenging construction logistics.

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Landscape scale adoption of barrier removal and floodplain restoration to help fish and people adapt to climate change

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The Taunton River, a ~1300 km2 watershed in Massachusetts, USA hosts one of the largest river herring runs in New England and is federally designated Wild and Scenic. Since 2005 2 unmaintained dams in the watershed caused high profile emergencies. Concern for public safety catalyzed statewide policy changes to expedite restoration permitting and increased funding. Record floods in the watershed in 2010 again highlighted the need for communities to plan pro-actively to increase their resilience in the face of extreme weather events. The Nature Conservancy and US EPA New England Region founded the Resilient Taunton Watershed Network (RTWN) to advance consideration and use of nature based solutions (NBS) to increase climate resilience, natural hazard mitigation, water quality and fish habitat goals. Healthy, intact natural systems provide multiple benefits to the challenges posed by climate change. Forests and wetlands sequester carbon, helping to limit global warming. Natural systems also enhance watershed resiliency by protecting biodiversity and limiting water pollution and flooding from heavy precipitation events. Members of the network have mapped green infrastructure resources as climate assets, developed case studies, and created a training program. Integrated strategies may lower overall adaptation costs and provide wide-scale multi-criteria benefits.

In 2016, the statewide Municipal Vulnerability and Preparedness program launched, providing communities state funding to complete vulnerability assessments and develop action-oriented resiliency plans to identify existing and future vulnerabilities and strengths related to extreme weather and climate hazards, and identify opportunities to act to reduce risk and build resilience. Certified communities are eligible for follow-up grant funding and other opportunities. The program was funded with $1M in 2017, and in 2018 proposed bond authorization for the program was $50M. Addressing climate risks to people and nature in a holistic framework is creating new opportunities to protect and restore fish habitat at landscape scale.

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Sequential fishways reconnect a coastal river

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River regulation infrastructure has been implicated in worldwide aquatic biodiversity loss. Instream barriers such as weirs prevent fish migration and the impact can be particularly severe for diadromous species. Fishways are frequently installed on in-stream barriers to reconnect migratory pathways and rehabilitate diadromous populations. We monitored a coastal fish community's response to fish passage restoration at ten predominantly low-level weirs in the lowland reaches of the Nepean River in south-eastern Australia. Pre-fishways, there was a gradient of reduced species diversity in an upstream direction including the absence of many diadromous species, despite the regular inundation frequency of most weirs. Post-fishways, species diversity was still greater in the downstream monitoring sites; however, there was evidence of a positive change in fish community structure from upstream sites. Most notably, three diadromous species rapidly expanded their distribution upstream and one amphidromous species expanded its downstream distribution. This study demonstrates appropriately designed successive fishways can successfully reconnect river systems for an entire fish community, encompassing species with a broad range of swimming abilities and diverse life histories.

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Fish barrier removal and river connectivity support glenelg river tupong populations.

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Tupong are a migratory native fish that inhabit estuaries, creeks and rivers, including the Glenelg River. Connectivity is thought to be a major factor influencing the health of the species, as Tupong require access to the sea and freshwater to complete their lifecycles.

Increases in river flow in spring and summer are thought to stimulate the movement of young Tupong from the ocean into coastal rivers and further upstream into freshwater reaches. Maintaining suitable freshwater habitat is critical to ensure the fish have sufficient habitat and food resources to feed, grow and breed. Adult Tupong then migrate back to the estuary or sea to spawn on large winter freshes.

Annual fish monitoring, from 2009 to 2018, coincided with the removal of 12 fish barriers along the Glenelg River. The fish monitoring showed tupong numbers have increased substantially in recent years and their range is now well over 300 km throughout the Glenelg River. Record numbers of young Tupong were recorded moving upstream from the estuary to the freshwater reaches in the most recent fish surveys (2018). This highlights the importance of removing fish barriers and connecting the Glenelg River with water for the environment as regulated base flows.

The removal of these fish barriers has opened up 977 km of waterways to fish movement in the Glenelg Catchment. Along with complementary works including reinstatement of instream woody habitat and the return of water for the environment, fish barrier removal has played an important role in supporting healthy populations of not only Tupong but other fish species in the Glenelg River.

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Monitoring the Penobscot River Restoration Project: Baseline Data to Inform Ecosystem Response

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Dam removal is increasingly being used as a tool to restore aquatic habitats and recover imperiled species. However, many presumed effects of dam removal (i.e. fish community changes, water quality improvements) are largely un-documented. Given significant investments being made in dam removal, rigorous monitoring is needed to elucidate ecological impacts and allow for informed decision making when allocating restoration resources. The Penobscot River Restoration Project in Maine, USA, is an innovative restoration project aimed at restoring self-sustaining populations of diadromous fish through increased connectivity via dam removals and fish passage improvements, while maintaining hydropower output. Beginning prior to dam removal in 2009, independent researchers began documenting baseline conditions via a multi-disciplinary, coordinated monitoring framework. The framework has continued through project implementation, following a before-after study design. Monitoring focuses on geomorphology, water quality, fish community, fish passage, habitat use, shoreline revegetation and marine-freshwater nutrient transfers. As before-after comparative analyses continue to unfold, this presentation aims to provide the most current results of this monitoring effort, highlighting several patterns which have emerged to-date: 1) all native diadromous species of fish are present in the river, many successfully reproducing on their own; 2) diadromous species persist despite access to only a small percentage of their historic habitat, many now beginning to increase in number; 3) the former lowermost dam, represented a near complete barrier to migration for most species and is now traversed by many similarly to free-flowing sections; 4) large changes to flow, sediment regime, and habitat (except in the immediate vicinity of the former dam sites) were unexpected and did not occur; and 5) water quality did not appear to be limiting for most species. This effort provides an objective, credible basis for evaluating ecosystem response to dam removal and a knowledge base to support restoration approaches in other systems.

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Fishways provide catchment-scale improvements to a diadromous fish population upstream of a barrier

Frank Amtstaetter, Justin O'Connor, Borg Dan, Dodd Lauren, Moloney Paul

Publish consent withheld

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Barriers benefiting biodiversity: when the lack of upstream fish passage is equally important

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The focus of improving fish passage in freshwater systems is largely to allow movement past physical or physiological instream barriers to reinstate catchment-wide connectivity lost through anthropogenic use of rivers since the 1800s, e.g. impoundment, diversion, hydropower, etc. Whilst this mainly benefits migratory fish species and vagile species with widespread distributions, improved fish passage also facilitates the spread of alien invasive species. Understanding situations where maintaining barriers to fish movement can be more beneficial to native species than reinstating historical connectivity is crucial to effective but balanced fish passage programs. In the Southern Hemisphere many small-bodied, non-migratory native fish species now only persist above natural or artificial instream barriers, particularly in small headwater streams at moderate (200 m) to high (> 1000 m) elevations. In Australia these species are primarily galaxiid fishes (Galaxiidae) and are impacted by predatory alien salmonids introduced from the Northern Hemisphere. While the existing or new instream barriers protect the threatened native species from extirpation and extinction some also disrupt historical connectivity across the tributary networks. We discuss the dynamics of headwater persistence of these threatened species in a changed landscape, implications for conservation management, and highlight examples of where construction of new, or preservation of current barriers, to upstream movement of invasive fishes far outweighs improving connectivity, particularly where the latter increases extinction risk. Increased awareness of the smaller, but

equally valuable, benefit of barriers to protect biodiversity is crucial to effective conservation management at the catchment-wide scale.

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Following the migration of glass eel and three-spined stickleback passing Europe's largest pumping station and world's largest sluice

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In order to quantify abundance, to study migration behaviour and to evaluate different fish passages along a 26 km long canal (North Sea Canal) in the Netherlands, a mark recapture experiment was carried out by tagging 6750 glass eel (*Anguilla anguilla*), 625 three-spined stickleback (*Gasterosteus aculeatus*) caught in marine environment and 625 three-spined stickleback caught in brackish environment in spring 2018. To reach the canal, migratory fish must pass a large complex of four large sea sluices, spill gates and Europe's largest pumping station. Twenty five groups could be distinguished using different combinations of fluorescent colours of Visible Implant Elastomer Tags.

The majority of the marked fish were released at the sea side and just behind a large tidal barrier (each group: 2000 glass eel and 500 stickleback). In addition, different groups of both species were caught and released locally at different sites along the canal to evaluate fish passage efficiency. Fish were recaptured in an extensive netting program of volunteers along the canal, twelve especially designed glass eel monitoring devices and professional fisherman who monitored fish passages along pumping stations or sluices.

Stickleback originally caught in brackish environment showed higher recapture rate (7.6%) compared to stickleback caught in the marine environment (2.8%). Also, fastest average migration speed was estimated on 0.09 m/s and migratory delay at the tidal barrier was limited since difference groups were recaptured in comparable ratio's and migration speeds. Glass eel were recaptured along almost all monitoring locations along the canal. Fastest, average migration speed was estimated at 0.02 m/s and the furthermost recapture was 28 km from release site after 26 days (average speed 0.01 m/s). Migratory delay at the tidal barrier seemed limited, however some individuals were caught after 23 days at the sea side and others were flushed out by the spill gates.

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Do silver eel find their way along sluices and pumping stations in highly regulated water systems

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In order to quantify abundance, to study migration behaviour and to evaluate passage success along a 26 long canal (North Sea Canal) in the Netherlands, a telemetry experiment was carried out by tagging 2630 silver eel (*Anguilla anguilla)*.

A network of 64 VEMCO receivers was used to detect movement of silver eel tagged with V9 (n=280), V9P (n=50) acoustics transmitters and 32mm HDX PITtag. In addition, 2300 silver eel were tagged with 32mm HDX pittags for mark recapture purposes and fish pass evaluation. Fisherman along the canal were equipped with manual PITtag readers in case of a recapture during (commercial) fisheries.

Within this study eleven locations were selected to evaluate escapement from of freshwater polder systems into the canal and eventually towards the North Sea. Individual variation in observed patterns was large and not all routes were efficient in terms of energy used. Some eel swam up and down the canal before reaching the sea, while others (groups) did not succeed in escaping at all, showing a large barrier effect. Also, some eel swam back towards the polder using sluices and eel seemed to prefer the main water flow instead of a fish passage along a pumping station or migration facilities in sluices. Successful escapement showed part of the silver eel were detected in the Lifewatch network along the Belgian coast. Based on recapture assessment at least 110.000 silver eel successfully migrated along the sluices of Ijmuiden.

This research was funded by a unique collaboration of different water boards and partners along the canal.

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Migration of juvenile American eels through 2 power generating stations in the St-Lawrence system

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During their upstream migration from the Sargasso Sea, the first anthropogenic obstacle encountered by juvenile American eel (*Anguilla rostrata*) in the St.-Lawrence River (Canada) is a large run-of-the-river hydroelectric power dam. The facility is located at Beauharnois, downstream of Lake Ontario, the largest and richest growth habitat of this river system. The second and last anthropogenic obstacle is another large run-of-the-river hydro dam, the Moses-Saunders power Dam, located 82km upstream of the Beauharnois generating station. Both facilities are equipped with eel ladders. From 2011 to 2015, 15,500 juvenile eels were Pit-tagged at the exit from the Beauharnois eel ladder and more than 40% were observed on the Pit tag detectors at the Moses-Saunders eel ladders within 7 years of the first tagging. Details on the upstream migration parameters of the St.-Lawrence juvenile American eel will be presented.

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Enhancing upstream passage solutions for juvenile eels: effects of climbing substrate and ramp placement

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Juvenile anguillid eels migrating into inland waters often face migration barriers. Upstream passage solutions normally consist of inclined ramps lined with a wetted climbing substrate. In this study, we compared the performance of three commonly used substrate types in a controlled experiment, using European eel as the test species. We also analyzed climbing behavior with videography and validated the experimental results under natural conditions at a hydropower plant. In addition, we investigated the effects of ramp placement. Studded substrate attracted more approaches and climbs and passed more eels at a higher climbing velocity than open weave and bristle substrates, results that were confirmed by the field validation. Moreover, ramps placed in the tailrace caught more eels in low than in high water velocities. To conserve anguillid eels, both safe routes for downstream-migrating adult silver eels and improved recruitment at the freshwater feeding life stage must be achieved. Optimizing ramp position and equipping upstream passage solutions with functioning climbing substrate are key factors to enhance the performance of eel ramps.

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eDNA as an efficient tool to assess the distribution of European eels upstream of pumping stations

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Concern over the status of European eel stocks is so great that the EU has specific legislation (The EC Eel Regulation (1100/2007)) for eel conservation. This is enacted in the UK through the Eels (England and Wales) Regulations 2009 Statutory Instrument (the Eel SI), which requires pumping stations abstracting greater than 20 cubic metres a day to be screened to prevent fish/eel entrainment. This legislation applies to all pumping stations, unless exempted by the Environment Agency, partly due to a lack of knowledge of fish and eel populations in pumped catchments. To ensure Eel SI compliance is informed by real-world evidence, 36 years (1979-2015) of traditional fish survey data (nets, traps and electric fishing) from upstream of 124 high priority pumping stations in England were reviewed. At least one eel was caught upstream of 50 pumping stations and no eels were caught from upstream of two. No eel surveys were performed upstream of 72 of the 124 pumping stations investigated. Traditional fish survey techniques are time consuming, labour intensive and, in some instances, inefficient for eels, and thus represent an unfeasible solution for filling the large eel distribution knowledge gap. Therefore, the potential for using Environmental DNA (eDNA) to assess presence or absence of eels in pumped catchments was investigated in combination with traditional survey techniques. Eel eDNA was detected in all instances an eel was caught and at a number of sites where no eels were caught, presumably due to the low number of eels in the river and/or the ineffectiveness of the traditional sampling technique. There were also instances when eels were not caught and no eel eDNA was detected. Preliminary findings suggest eDNA is a viable technique to assess the presence or absence of eels in pumped catchments to inform management decisions for Eel Regulations compliance.

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Exploring ways to deliver better fishway management

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Victorian Waterway Management Strategy provides the framework for government, in partnership with the community, to maintain or improve the condition of rivers, estuaries and wetlands so that they can continue to provide environmental, social, cultural and economic values and includes actions specifically aimed at fishway management in Victoria. This presentation discusses the history (and issues) with many of our current fishways and future fishway management in the context of the policy and actions

outlined in the Strategy. Actions and approaches to achieve these outcomes include recently released guidelines outlining contemporary performance, design and monitoring of fishways in Victoria and exploring ways to deliver better fishways. These fishway guideline documents are intended to create a consistent approach to fishway management across the state and together with potential future management strategies will ensure improved river connectivity into the future.

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The Alaska model of fish passage policy

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Since Alaska was a territory, safeguarding fish migration has been recognized both in state statutes as early as 1959 and in development of policy at local and interdepartmental levels. Implementation of these statutes over the years has resulted in relatively few dams or diversions on Alaskan fish-bearing waters with most of the policy emphasis in refining fish passage across road crossings, particularly culvert installations. Policy was supported by pioneering work in fish passage research, assessment and culvert design, so much so that it formed the basis of modern approaches to fish passage at road crossings across the nation. Collaborative efforts by Alaska Department of Fish and Game (ADFG), Transportation and Public Facilities (ADOT) and Tongass National Forest lead the way in development of state policy for road crossings. Over the past two decades, various agency practitioners, working with federal and local governments further refined policy into various design guidance and criteria. The creation of a Memorandum of Agreement between ADFG and ADOT in 2001 formed basic fish passage criteria statewide at road crossings and set the stage for local municipal development ordinances. In the early 2000's, some local governments, battered by a series of flood events, implemented improved road crossing ordinances and criteria that improved both flood conveyance and fish passage. These local efforts have resulted in some of the most robust criteria in the nation. The Alaska model of statutes, policy, local ordinances and criteria show how we can prevent the spread of barriers across the landscape yet continue to develop into the future.

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River connectivity and fish migrations a missing link in Water Resource Management in South Africa

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In South Africa, progressive water resource management legislation has resulted in new protection efforts to sustain water resources. The National Water act advocates the implementation of Resource Directed Measures (RDM) that; (1) classify the quality and associated use or protection vision of resources on appropriate regional scales, (2) establish the Resource Quality Objectives (RQOs) and (3) the Ecological Reserve for water resources that include the E-flows and associated quality of resources. This RDM approach includes the determination of water resource user requirements (user-specs) and ecological requirements (eco-specs) that are addressed in a trade-off process to establish suitable protection measures for important resources.

In many case studies in South Africa, the importance of river connectivity management and associated fish migrations are unknown and have not adequately been considered in RDM procedures. The Kruger National Park (KNP) in South Africa is a world-renowned conservation area that has five major rivers flowing in an easterly direction through the park from high resource use areas upstream of the park. *The KNP has been described as a series of important socio-ecologically important rivers within a sea of dams.* Although the RQOs and Ecological Reserve for these protection prioritised ecosystems have been established, and gazetted, the desired wellbeing of the systems has not being achieved. This has largely been attributed to river connectivity loss and disruptions of fish migrations.

To mitigate these omissions, the role of river connectivity and associated ecosystem processes has been proposed to be integrated into an adaptive, use and protection trade-off process for the RQO determination process for the rivers in the KNP. This has resulted in new resource protection requirements for these resources that have major consequences to resources availability for use. These case studies may result in amendments to RDM procedures throughout South Africa and mitigate river connectivity issues.

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The ecosystem service values of fish ladders in poor counties: Who should pay?

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Fish passages are often presented as a parsimonious way of assisting water infrastructure development in poorer countries whilst preserving some ecosystem values. Amongst those values is the provisioning services associated with harvesting local fish and maintaining protein in the diet of the rural poor.

However, understanding and capturing the wider benefits of fish ladders is no simple task. On the one hand, ecosystem values, like those related to existence and options values, are notoriously difficult to measure in dollar terms making their inclusion in conventional benefit-cost analyses complicated. On the other hand, the distribution of those values creates additional analytical challenge. More specifically, ecosystem services can accrue across nations and there is no compulsion for beneficiary countries

to make payment to ecosystem providers. Establishing mechanisms for voluntary payments from rich nations to afford those services shows some promise, but there are also serious concerns about free-rider effects and the impact on efficient provision.

This paper considers the ecosystem benefits of fish passages constructed in Lao. The paper uses this case to highlight the technical challenges of measuring and appropriating the wider values of fish passages. The paper develops and uses a simple model to guide the deployment of different options for securing resources to support fish passage construction.

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Gender impact: a forgotten dimension in hydropower development

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The position of women in rural livelihoods dependent on fisheries in the Mekong in Lao PDR will be set against a framework of hydropower development. Gender Analysis and Gender Impact Assessment will be used to examine the likely effects of hydropower development on rural communities and specifically the imbalance between males and females in terms of benefits and outcomes. This information will be used to assess how household decision-making is gendered to adapt to shifts in household well-being and livelihoods opportunities. Mechanisms for promoting gender inclusiveness and empowerment in hydropower development scenarios will be explored.

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Using ear bones to understand connectivity and movements of fish

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Ear bones (otoliths) of fish have been used since the late 19th century to age fish, but ear bones can also be used as innovative tools to understand past environments and biological processes such as movement patterns. Otoliths accrete new material onto the exterior surface on a daily basis; as this occurs minor and trace elements are also incorporated along with the major constituents of carbon, oxygen and calcium. Hence otoliths provide a chemical chronology over the entire life of a fish. Quantifying and interpreting the chemical composition of fish otoliths is challenging, but can be used to explore life-history information. Determining movements from otolith chemistry relies on different chemical signatures or tags being incorporated from different environments. Groups of fish with similar tags can then be linked through space and time to determine where and when fish moved. Chemical signatures across an otolith can provide natural tags for several different life-history stages, which can then be related to the different environments the fish has lived in thereby demonstrating movement patterns. Multiple different approaches can be used to determine fish movement using otolith chemistry. What is required for each approach and the assumptions made differ. The aim of this keynote will be to introduce fish passage researchers and practitioners to how otoliths, in particular their growth patterns and chemistry, can be used to address ecological and fisheries questions around movement and connectivity of fish populations, as well as understanding environmental conditions that fish have experienced.

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Possible pitfalls in fish passage research and how to avoid them

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The worldwide expansion of hydropower as well as the need for ecological improvements of riverine biological communities have prompted intensive research and monitoring of fish passage, yet many procedures and protocols have not been sufficiently validated. This presentation investigates some of the most common assumptions and pitfalls in fish passage research and provides concrete recommendations of how they can be avoided. This includes the following examples: (1) the bias introduced by various catching /monitoring techniques, (2) the transferability of findings from fish passage laboratory experiments to real situations, (3) the replacement of experiments with real fish by modeling and sensor fish experiments, (4) the optimization of fish ways for the sole purpose of increasing passage, as well as (5) the assumption that innovative hydropower techniques would always be more fish friendly than conventional ones. A systematic study on the above points comprising nine sites with innovative and conventional hydropower use revealed that (1) even advanced sonar- and camera-based monitoring tools can introduce substantial bias in terms of fish counts and sizes and that net-based catches can result in high injuries and mortalities under certain conditions. They also revealed (2) strong discrepancies in the efficiency of downstream passage fish guiding devices between laboratory and field, as well as (3) between modeling and sensor fish experiments and the damage observed in real fish populations. Moreover, it is suggested that (4) fishways can also have important functions as substitute habitats in addition to their function for fish passage, and that (5) some of the innovative hydropower techniques can result in mortalities higher than in conventional Kaplan or Francis-turbines. All of these findings suggest that the development of standards in fish passage research requires further optimization to increase comparability of data from across sites.

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The Importance of a Constructed Near-Nature-Like DanubeFish Way as a Lifecycle Habitat for Spawning, Fish Larvae, Juveniles and Adults – A Long Term View with Remarks on Management

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The importance of functioning habitats for the lifecycles of River Danube fish species becomes clearly visible in times when degraded-, impounded-, or channelized stretches prevail, and when current speed reduced sections of the river dominate the fluvial ecosystem. Major segments of today's rivers are not supporting essential requirements of riverine fish.

We investigated the near-natural fish by-pass system of Vienna/Freudenau for its function as a compensatory fish habitat. The study was conducted continuously over three years - 15 years after construction. The present data show, that the chosen natural like construction of the by-pass system provides similar functioning habitats as natural tributaries do. More than 17,000 fish and a surprisingly high number of 43 species, including several protected- and endangered species, in all life stages - eggs, larvae, juveniles and adults - were captured. Furthermore, the indicator species of the free-flowing Danube, nase and barbel, migrated into the fish pass in very large quantities and successfully spawned before returning. Therefore, the system serves as an important key ecosystem for the conservation of the remaining native fish fauna. The heterogenic habitat configuration provides conditions for all ecological guilds and consequently increases significantly the spotted biodiversity. Finally, approved management tools are discussed

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Survival of fish passing downstream at a small hydropower facility

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Hydropower dams can negatively impact upstream and downstream migratory fish populations in many ways, such as blocking access to upstream habitats and causing injuries or mortality during downstream passage. For downstream passage at projects in the USA, federal regulators and agencies responsible for oversight of hydropower facilities typically require assessment studies and mitigation to address negative impacts with a primary goal of minimizing fish impingement and turbine entrainment and mortality. In order to assess impacts of downstream passage of fish populations at a unique, small hydro project on the Mississippi River, impingement and entrainment rates, Obermeyer gate passage, spillway gate passage, turbine survival, and total downstream passage survival were estimated. It was determined that 85% of fish passing downstream at the project would be small enough to pass through the bar spacing of the trash racks and 15% would be physically excluded. When 55% of river flow enters the turbine intake channel, the total project survival rates were estimated to be 77.3% with an Obermeyer gate bypass rate of 10% to 96.6% with a gate bypass rate of 90%. Therefore, any impacts to local fish populations resulting from the operation of the project are expected to be negligible and inconsequential.

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Surface bypass as a means to protect downstream-migrating fish – lack of standardized evaluation criteria complicates evaluation of efficacy

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Surface bypasses are downstream migration structures that can help reduce hydropower-induced damage to migrating fish. However, no comprehensive design concept that facilitates good surface bypass performance for a wide range of sites and species is available. This is why even efficiencies at recently built bypass structures vary widely between 0% and up to 97%. We reviewed surface performance studies and existing guidelines for salmonids, eels, and potamodromous species if available to identify crucial design criteria for surface bypasses. Two-tailed Pearson correlation of bypass efficiency and bypass design criteria shows that bypass entrance area ($R=0.3300$, $p=0.0036$) as well as proportion of inflow to the bypass ($R=0.3741$, $p=0.0032$) are the most influential parameters on bypass efficiency. However, other parameters like guiding structures and trash rack spacing though not statistically significant (Spearman correlation, ordinary t-test) have shown to have an effect on efficiency in some studies. The use of different performance criteria and efficiency definitions for bypass evaluation hampers direct comparison of studies and therefore deduction of design criteria. To enable meta-analyses and improve bypass design considerations we suggest a list of standardized performance parameters for bypasses that should be followed in future bypass performance studies.

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Low-sloping racks and the importance of bar spacing for fish passage

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Rivers have been used as a source of energy throughout history, but the construction of dams for a secure and even availability of water can disrupt the dispersal and migration opportunity for aquatic organisms, causing a tradeoff between biological and socio-economic values. Contemporary hydropower plants are no exception, and hydropower companies strive to optimize energy utilization while minimizing deteriorating effects on environmental values. The European eel and the Atlantic salmon are threatened and iconic fish species that have life cycles that are obstructed by dams in rivers. European hydropower companies traditionally compensate this negative effect by constructing fish passage solutions to allow two-way migration, albeit such solutions have highly variable success. Downstream passage solution design is particularly poorly known and hence targetted in many recent rehabilitation and research projects.

Downstream migrating silver eels and salmon smolts tend to experience high rack- and turbine-induced mortality at hydroelectric plants (HEPs). Recent attempts using low-sloping racks guiding eels and salmon smolts to bypasses have reached passage efficiencies of >90% and median delays of 24 h at small to medium sized HEPs, but detailed knowledge on behaviour by racks and bypasses are still largely lacking. It is neither known if such solutions are applicable to large HEPs, and one major concern relates to the bar spacing of evaluated low-sloping racks (15-18 mm). A recirculating flume with two 25 m long experimental arenas, 4 m wide and 2 m deep, has now been built at the Vattenfall Ecohydraulic Centre in Sweden, where we are currently studying the importance of bar spacing for behaviour and performance of downstream migrating silver eels and salmon smolts. The flume facility, the study design and preliminary results will be presented to incite discussion.

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Comparison of sonar-, camera- and net-based methods in detecting riverine fish movement patterns

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Monitoring of fish movement is important in understanding and optimising the functionality of fishways and in restoring riverine connectivity. This study compared fish monitoring data (ARIS-sonar and GoPro-camera-based) with catches in a multi-mesh stow net following downstream passage in a small river in Bavaria, Germany. In terms of the number of individuals, the sonar-based system (detection rate=62.6% of net-based catches) outnumbered the counts of the camera-based system (45.4%). Smaller specimens of <100mm and <150mm were underrepresented with the sonar and the camera-based systems, respectively. For larger specimens, species identification based on the camera system was similar as in net-based catch, whereas no proper species identification could be performed with sonar data. In conclusion, the sonar-based system can be recommended for the counting of fish >100mm during night and turbid conditions unless species identification is necessary. During daylight and with clear water, cameras can be a cheaper and promising option to monitor species compositions of fish >150mm.

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Development of a comprehensive fish passage approach for floodplains of the lower mekong basin

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Irrigation, flood protection and road development in Lao P.D.R. has led to construction of numerous water regulation structures on the floodplains of the Lower Mekong Basin. Movements of fish (and other aquatic animals) between rivers and floodplains is subsequently restricted, or may be entirely prevented, and this has led to severe declines in fish production in many areas. Developing robust fish passage outcomes requires an integrated and long-term approach. Implementing a strategy that sought to identify the scale of riverine development, develop a widely applicable solution and also capture social and economic benefits was a sound approach that had wider support from government and investment agencies. Subsequent research in Lao P.D.R. demonstrated that fish-passage technology has the potential to enable movement of migratory fish past these low-level (less than 6 m) barriers. Consequently, fisheries agencies were interested in increasing capacity to design manage and operate fish passage facilities on new and existing low-level water control structures in order to ensure the long-term sustainability of fish resources. To raise the importance of the issue with other water users, it was important that barrier mapping had been undertaken at the same time to increase the spatial understanding of existing infrastructure development. This led to active collaboration with engineering and development agencies to include fish passage restoration in ongoing irrigation development projects. Combining this information with an inventory of planned construction would provide a powerful tool for future investment opportunities.

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WITHDRAWN: Wetland fish communities above stream regulators with and without fish passage in Lao PDR

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We have implemented a multiple lines of evidence approach to assessing the efficacy of fishways in the Houay (small stream) Peung and Houay Souy, Lao PDR. The methods include socio-economic surveys of households, direct observation of fisherman catch, trapping within the fishways, and surveys of fish assemblages in each fishway wetland, along with comparison wetlands that do not have a fishway installed. The in-wetland surveys are designed to be a long-term program and in this presentation I report on the design, monitoring and preliminary results. Whilst there are several differences in the types of fish present in each of the wetlands, there was no statistically significant difference in the CPUE, species richness or the composition of fish assemblages between fishway wetlands and comparison wetlands, regardless of season, during the first two years of our study. This is consistent with previous studies, that found only one or two species are likely to respond in the first few years and it may take 4 or more seasons of operations for major compositional changes in assemblages to be recognised. Our results are consistent with expectations from pre-fishway operations and the monitoring program is well placed to detect changes as the fishways enter full operational mode. We also discuss the implications of high fishing pressure in these wetlands and how this may affect the rate of change and detection of those changes.

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Householder catch and use of fish before and after a wetland fishway at Pak Peung, Laos PDR

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This research paper describes fish harvesting and use from Pak Peung wetland, Paksan District Bolikhamxay Province. The ongoing research surveys 10 households in 4 villages twice a year over a 4 year period and I present data from the first two years of the surveys. The villagers surveyed predominantly catch fish either above or below regulators on two nearby wetlands, Kadan and Peung. Peung wetland has a fishway installed which has been operational since 2015. We predict that the catch in the wetland above the fishway will change through time as a result of the improved fish passage. In this paper I focus on the socio-economic outcomes of improved fish passage, by studying the fate of the household fisherman catch over the first two years of surveys. I present results documenting changes in the use of fish since the fishway was installed, including comparisons of the number of fish consumed, preserved, given away or sold by villagers above and below each wetland since the fishway was installed. The results are also compared to pre fishway surveys conducted in 2011.

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A cautionary tale about the inhibitory effects of gated culverts on fish passage restoration efforts

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Connectivity between river-floodplain habitats has been heavily constrained in many large tropical river systems by the construction of regulators, levees and other physical barriers. Fishways are being constructed to ameliorate the effects of these barriers; but it is important that all aspects of fishway design cater for local target species. We investigated the lateral movement patterns of Lower Mekong Basin fish in Laos, through a fishway that incorporated a series of cones, resting pools, and a culvert with a vertical lift gate. Fish needed to negotiate all of these structures to move from the Mekong to an adjacent wetland. We tested the hypothesis that gated culverts may hamper the effectiveness of fishways, by comparing the abundance and species richness of fish at three locations along the path of the fishway and culvert: (1) the fishway entrance; (2) the fishway exit; and (3) the culvert exit (i.e. immediately upstream of the culvert). There were no marked differences in the total abundance and species richness of fish between the fishway entrance and culvert exit while the river remained at levels where the culvert was only partially inundated. Nevertheless, the abundance and species richness of fish were markedly lower at the culvert exit than at the fishway entrance and exit once the headwater levels rose to where the culvert was completely inundated. These findings indicate that fish were able to ascend the fishway but not the culvert once it became completely submerged, and thus support the hypothesis that gated culverts can hamper the effectiveness of fishways in facilitating the lateral movement of fish in large tropical systems. Fish passage at such installations can be enhanced through optimised operating regimes. Ensuring that headwater levels remain below the culvert ceiling is likely to be the best way to maximise fishway effectiveness.

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Listening to local knowledge to inform fish passage and fisheries management

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Local knowledge of people using floodplain fisheries can play an important role in informing the management of fish passages and fisheries resources. This paper describes local people's knowledge of Mekong fish species including where they are caught and perceptions of fish movements in and out of the Pak Peung wetland in Lao PDR. Semi-structured interviews were conducted in 2011 with 81 households from six villages around the wetland. The survey was repeated in 2015 to ascertain any changes in practices and observations of fish migrating up a fish passage, one year after becoming operational. Respondents mentioned 55 fish species in the wetland and showed the most likely locations where they were caught. Women caught a broader range of species than men but less quantity of fish Respondents also identified species they use for fresh consumption, processing and for sale. Prices received for fish varied according to species. The majority of respondents observed that fish numbers had declined in the last 20 years for most species. The most obvious decreases had been in populations of Pa Dook, Pa Etie, Pa Kar, Pa Kilam, Pa Kor, Pa Kot, Pa Kupkong and Pa Park. Reasons for the decline were thought to be due to more people fishing using modern methods, habitat destruction, fishing at the regulator, fishing during the breeding season, not enough water in the dry season and lack of an active management plan for the wetland. However, several households reported catching fish species not seen in the wetland for many years post fish passage including two endangered species and one vulnerable species. Local knowledge of fisheries is important as a complement to scientific measurements to inform best practice management of fish passages and floodplain resources.

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Merging biology and technology to achieve selective bi-directional fish passage

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Selective, bi-directional fish passage can ease tensions between connectivity actions fish managers take to improve production of native and desirable fishes. Dam removal and fish passage can enhance fish production by increasing connectivity between tributaries and lakes or oceans. Conversely, in-stream barriers to movement can benefit native fishes by limiting the spread and reproduction of invasive species. To address the tensions, the Great Lakes Fishery Commission is leading a team of nearly 60 fisheries biologists, managers, and engineers in developing novel and effective tools to selectively pass desirable fishes while simultaneously blocking and removing invasive species. A uniquely designed facility (FishPass) is being planned for construction at the Boardman River's Union Street Dam (Traverse City, MI) to stimulate research that integrates a suite of fish sorting, guidance, and passage technologies and techniques for selective bi-directional fish passage at conditions consistent with the scale and conditions of natural rivers. To be successful, selective fish passage solutions will require the integration and redundancy of automated technologies that both exploit and overcome sortable attributes of fish (i.e., phenology, behavior, physiology, and morphology). This presentation will discuss the status of the FishPass including conceptual designs, research agenda, and next steps.

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Developing a theoretical model to help design ecologically-friendly fishway of the endangered fish species, scale-less carp (*Gymnocypris przewalskii*) in the Qinghai Lake watershed, western China

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The scale-less carp (*Gymnocypris przewalskii*) is an endangered and a unique highland cyprinid fish has long history of ecological values in northwest China. The fish migrates annually between the alkaline water Qinghai Lake and the freshwater tributaries in the region, where it feeds, grows and spawns. However, due to climate change and human disturbances, such as construction of barrages or diversion channels, its migration pathways have been impaired severely. Massive numbers of spawning fish are found exhausted and died when trying to cross the barriers due to their heights and disruptions made on the hydraulic conditions. Efforts are being made for improved fishway designs to restore the migratory routes of this species. However, the actual effectiveness and suitability of such fishways are not assessed comprehensively. This study aims to evaluate a range of ecological demands of this species and characterize the features of its preferred natural migration routes, so that it would help design the most ecologically friendly fishways in the Qinghai plateau region imitating the natural step-pool type system. We will work closely with local conservation authority to meet their conservation efforts through field investigation, theoretical modeling, laboratory tests and field experiments. Primarily, natural conditions of the preferred migration routes are measured in the field during the migration season. For this, a model is built to study the adaptability of the species to the physical and chemical parameters of the migration route. Secondly, laboratory tests will be performed to study the migratory behavior and response to

the hydrodynamic conditions of the species. The key elements needed for the step-pool system fishways design will then be determined according to the results of field investigation and laboratory experiments.

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Adding auxiliary discharge into the entrance pool of a fishway: influence of pool design on fish passage

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The German Federal Institute of Hydrology (BfG) and the German Federal Waterways Engineering and Research Institute (BAW) are working on restoring connectivity for fish in large German rivers with focus on constructing efficient fishways. In large rivers a sufficient attraction flow is needed to guide fish into the entrance. It can be produced by adding auxiliary discharge into the lowermost (entrance) pool of the fishway. This however may distract fish from their passage. To minimize this risk we investigated different solutions for adding auxiliary discharge through a horizontal bar screen into the entrance pool. Passage times of five different fish species volitionally swimming through different set-ups in an open flume were compared to identify the influence of screen design and flow fields on fish passage and to develop recommendations for a functional pool design.

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Assessing the efficacy of flow restrictor plates in denil fishways for upstream passage of arctic grayling

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Habitat connectivity is imperative in the preservation of access to habitat, food, and refuge for fish and other aquatic species. The Arctic grayling (*Thymallus Arcticus*) is a population of fish that has seen the impact that cutting off upstream habitat has on the life cycle of a species. A species once abundant in the rivers and lakes of Michigan and Montana, the Arctic grayling is now a species of concern in Montana. To help preserve Arctic grayling, approximately 60 Denil fishways have been installed on irrigation diversion structures throughout the Big Hole River watershed. The Denil fishway requires high flow levels in the ladder to facilitate grayling passage and irrigators need this water during low flow seasons to meet their water needs. In an attempt to meet the need of Arctic grayling and irrigators, a study was conducted to test the efficacy of flow-control weirs ("flow-restrictor plates") installed at the upstream end of the Denil fishway to decrease the required flowrate needed to pass Arctic grayling. This study investigated three distinct restrictor plate designs in addition to a control (no plate installed). Each treatment received the same five depth treatments in order to best compare flow restriction, passage efficiency, and several other hydraulic and ecologic factors. Upon the completion of the data collection phase, analysis was done to assess the efficacy of these plates. The end goal was to develop a statistical model that could predict passage efficiency in a Denil fishway for a given plate based on a set of other variables. Ultimately, it was found that the sole predictor of passage efficiency was flow rate and that any addition of a device that restricts flow rate will decrease passage for Arctic grayling.

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Different roles for water speed, velocity gradient, and acceleration in reproducing juvenile Pacific salmon trajectories/passage in dammed and tidal free-flowing river environments

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Understanding how fish trajectories and passage patterns emerge in rivers is critical to improving the design of waterways infrastructure for sustaining living resources. Decades of work has not yet provided a robust and broadly applicable explanation for fish movement that can operate with such fidelity and accuracy that it can be reliably applied for designing waterways infrastructure, even in cases where consequences are severe for 'getting it wrong'. Rivers are used in many ways to meet society's needs. Humans must more rapidly develop methods and solutions to de-conflict the competing needs of society and maintaining fish resources that are valuable commercially, recreationally, and culturally. We analyze a large data set assembled over 20 years with detailed, high-resolution fish movement/passage and water flow field patterns near infrastructure. The 60+ data sets represent eight sites along the west coast of the United States where the movement and passage of juvenile Pacific salmon were measured. While non-salmon species are in increasing need of attention, the inability to develop a high-fidelity and reliable movement hypothesis (computer model) for juvenile salmon – given the tremendous resources over the past 20 years – is not an encouraging sign for reaching a similar goal with other species. Here, we describe a behavior repertoire that may provide encouragement. We explain how water speed, velocity gradient, water acceleration, and pressure may operate, differently, in guiding and repulsing salmon in rivers. We are able to reproduce 2-D/3-D trajectory and passage patterns of salmon in dammed

and undammed tidal free-flowing river environments. While more work is needed to fully develop our findings, impending work and data may allow us to demonstrate that the tools we seek for improving society's infrastructure are possible, allowing us to sustain the fish resources that communities value in their commercial and recreational activities.

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Will they stay or will they go? Movement and recruitment dynamics of an iconic Australian freshwater fish in a cold-water impacted River

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The construction of large water storages and subsequent alteration of flow regimes and thermal pollution have had devastating impacts on native freshwater fish populations globally. Native fish populations in the lower reaches of the Mitta Mitta River have declined substantially since the construction (in the 1970's) and operation of Dartmouth Dam. Self-sustaining populations of Trout cod and Murray cod were reported to have substantially declined or become locally extinct in the river by the early 1990's, attributed largely to the largely annual release of cold water during spring and summer. In more recent times, recreational fishing reports and fish surveys have detected Murray cod again occupying this reach of river. This prompted managers to reconsider the general view that the reach is unsuitable for native fish populations. Here we present outcomes of a research project aimed at improving the knowledge of the Murray cod population in the lower Mitta Mitta River with the aim of guiding improved river operations and management. We investigate patterns of recruitment dynamics, movement and hydrological records to understand the role of water operations in influencing population dynamics of Murray cod in the lower reaches of the River. We then use this information in a population modelling framework to explore long-term trajectories of the population under a variety of management scenarios.

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The role of thermal plasticity in mitigating the negative effects of cold water pollution on fish swimming performance and fitness

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Thermal stratification in dam impoundments can result in a colder, bottom hypolimnion layer and a warmer, surface epilimnion layer of water. Cold water pollution (CWP) occurs when water is released from the hypolimnion resulting in temperatures significantly lower than the natural temperature of the river downstream of the dam. The abrupt drop in water temperature can be as much as 15°C lower than the natural river temperatures and the decrease in temperature can extend hundreds of kilometres downstream from the release point. The conundrum is that water is often released to achieve environmental water flows, sometimes to trigger fish migration, yet these releases can result in decreases in water temperatures that may severely impact fish swimming performance and fitness. Here we utilised an experimental, lab-based approach to examine how rapid reductions in water temperature, of a magnitude reported from the Murray Darling Basin, affect the performance of four native Australian fish species that occur in this system. We investigated both short term (acute effects) and chronic exposure to decreases in temperature on maximum sustainable swim speed (*U*crit), routine metabolic rate, and maximum metabolic rate. A key objective was to assess whether Australian fish species have the capacity to compensate for the depressive effects of low temperatures via thermal phenotypic plasticity (thermal acclimation). Surprisingly, the species studied showed limited capacity for thermal acclimation which has substantial implications for the management of cold water releases from large dams and the passage/migratory capabilities of native fish.

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Remediation of thermal stratification in an impoundment by the use of an aeration system and its effect on downstream fish assemblages

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Physical barriers (e.g., dams and weirs) are known to be detrimental to fish movements and this has resulted in wide spread investigation and installation of fishways or removal of barriers. However, non physical barriers such as hydraulic (high velocity flows), chemical e.g., pollution, low dissolved oxygen), noise and thermal barriers (warm or cold water) are also known to influence fish movement and habitat choice. In this study we investigated warm-water riverine fish assemblages downstream of an impoundment before and after thermal stratification and the associated downstream cold-water pollution was prevented using an aeration system that was installed in the impoundment. Temperatures below the dam significantly increased after installation of the aeration system and this correlated with an increased abundance and greater number of species downstream. This included attracting a number of diadromous species to the base of the dam in the vicinity of a now constructed fishway. Overall, aeration appeared to be beneficial for both the lake (upstream) and the downstream riverine environments.

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A Framework to Evaluate Vulnerability of Upriver Migrants to Existing Hydroelectric Infrastructure and Climate Change

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River systems have been extensively modified by anthropogenic development of uplands and alterations in flow regimes. These changes reduce the capacity of river floodplains to absorb natural geophysical and environmental changes and directly affect life history adaptations that have developed over the millennia for native species. For example, in western North America changes in upslope processes (i.e. fire regimes, forest harvest and associated managements) work in concert with alterations in natural flow and thermal regimes through dams, levees, and floodplain development to change recovery trajectories of river systems. However, existing phenotypic adaptation by native fishes to environmental conditions may not be compatible with alterations to flow and thermal regimes. Climate change may compound this issue by further reducing variability in environmental conditions, both directly and indirectly, thereby inhibiting the full expression of life history diversity present in current populations. We explored expressed behavioral variability in upriver migration and passage for adult Coho Salmon (*Oncorhynchus kisutch*), an endangered salmon in Washington and Oregon, USA. We combined long-term records of river flow, water temperature, and upstream fish passage in a single visualization, providing strong empirical foundations for understanding upstream behavioral movement and tolerances of this native salmon. We compared current behavioral variability of Coho Salmon to scenarios representing possible future hydrologic conditions associated with a changing climate. We found that in some locations, the range of environmental conditions in the future is not outside the behavioral variability currently expressed by upstream migrating adult Coho Salmon. However, in some locations, predicted changes in streamflow and temperature occur during times of peak migration and may affect survival of upstream migrants. We discuss management implications and recommendations for action that may expand the capacity of riverscapes to absorb perturbations, thereby allowing for enhanced resilience of native fish populations.

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Mitigating hypoxic blackwater events in river ecosystems with irrigation infrastructure

Josh Campbell

Hypoxic blackwater events can have devastating effects on riverine ecosystems. Although arguably exacerbated by river regulation, hypoxic events can also be mitigated by regulation infrastructure. We report on a collaborative effort to reduce the severity of hypoxic blackwater in the Edward-Wakool river system, a heavily regulated anabranch of the Murray River in south-eastern Australia. In 2010, significant rainfall in the catchment caused widespread flooding of large areas of redgum forest for the first time in 10 years producing high dissolved organic carbon loads which combined with high water temperatures resulted in an extensive hypoxic blackwater event and subsequent fish kill.

In response, Murray Catchment Management Authority (now Murray Local Land Services) facilitated meetings of key stakeholders to coordinate releases of oxygenated water from irrigation channels into hypoxic affected areas to create refuges for fish. The Murray Dissolved Oxygen Group was formed and with the assistance of the community and river managers, a Hypoxic Blackwater Protocol was developed using trigger points in dissolved oxygen levels to inform agreed management actions. The community were also engaged to assist with water quality monitoring and restocking native fish into affected areas. Fish monitoring revealed system recovery particularly, in the vicinity of the refuges validating the effectiveness of the protocol and collaboration. The protocol was tested again in 2016-17, with the largest flood in 40 years inundating floodplains not wet since 2010 and in some places since the mid-1990s. A hypoxic blackwater event ensued but the effects were lessened in critical areas through the implementation of the protocol preserving much of the native fish communities in the system.

Thus, despite river regulation being linked to increasing the occurrence, duration and severity of hypoxic blackwater events in the Murray-Darling Basin, the associated infrastructure can also be an integral part of mitigation measures.

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Steep grade ahead? Optimizing fishway designs for small-bodied Great Plains fishes.

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The extensive fragmentation of riverine habitat in the United States Great Plains region can be mitigated through the use of fish passage structures designed with appropriate fish performance data. Many of the fish in this region can be characterized by their relatively small body size (adult TL < 30 cm) and their unwillingness to attempt to jump over instream obstacles. We measured the effects of slope (2, 4, 6, 8, and 10%) on the passage success of three representative species of fish from this region in a variable geometry 6.1-m long rock ramp fishway using multiple PIT tag antennas to determine how far up the fishway each fish travelled. The species selected represent a spectrum of relative swimming ability, from the strongly-swimming Flathead Chub (Cyprinidae: *Platygobio gracilis*), to the intermediate-swimming Stonecat (Ictaluridae: *Noturus flavus*), and the poor-swimming Arkansas Darter (Percidae: *Etheostoma cragini*). Passage success varied by species, with Flathead Chub negotiating steeper and longer fishways than Stonecats, who were in turn better performers than Arkansas Darters. As expected, reducing fishway length and decreasing fishway slope increased the probability of successful passage for all species. A second set of experiments quantifying the passage of the same three species in the test fishway when a 180-degree bend was included as part of a 4% slope fishway was also conducted. The addition of the bend did not materially affect overall passage success for the species tested. Our results allowed us to propose fishway design criteria based upon fishway slope and length combinations that improve the passage probability of these representative small-bodied Great Plains fishes.

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The challenge of passing small and large fish in rivers with highly variable hydrology

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Australia is characterised by rivers with highly variable hydrology and a freshwater fish fauna where potamodromy and diadromy are common. These migrations involve a wide size range of fish from 20 mm to 1500mm, with a correspondingly wide range of swimming abilities. Acknowledging that designing fishways to pass these fish is a significant challenge the Murray Darling Basin Authority invested in research over 10 years to improve designs.

Variations in the vertical-slot design were assessed with CFD and tested in the field. Roughened baffles and roughened walls provided promising hydraulics, but did not improve fish passage in the field. However, the 'control', which only reduced discharge through the fishway by changing the profile of the slot, greatly improved fish passage. The finding that turbulence within the entire fishway pool was critical, and could be easily manipulated, has led to a suite of vertical-slot baffle profiles to suit different hydrologies and fish assemblages. Site-specific slot shapes are now a standard design input for vertical-slot fishways.

Experiments were also conducted on small Denil fishways, which showed passage of small fish (20-50 mm in length) was very poor, despite earlier studies demonstrating they could effectively pass small herring (50-100 mm). Broader findings on ecology have also led to separation of ecological and hydrological function in fishway design, where small and large fish passage have been separated, and high and low flow fish passage accommodated differently. The research benefited from a multi-state interaction of scientists working on the one program, which generated ideas, ensured robust science, and distributed the findings. Importantly, the program applied the principles of adaptive management and new learnings were rapidly incorporated into new fishway designs.

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Approaches to nonsalmonid small fish passage in arid areas of the American Intermountain West and Great Plains

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The American Intermountain West and Great Plains host a myriad of native fish species, many of which are typically less than 50 mm in length and have developed in slow, low sloped, sandy stream environments. While little is known about various species passage performance, what is known is that many species are poor jumpers and swimmers, which complicate providing fish passage where slopes higher than 1% are desired. In addition, what may work for one species may not work for others due to behavioral differences. Various ramp fishways, embedded culverts and small bridges have all been used to facilitate passage, some working better than others depending on the environment with generally more success the more nature-like they are. Current design criteria and approaches will be discussed, case studies presented, data gaps and areas of needed research highlighted. As these little researched, nonsalmonid species populations diminish, understanding what we know and need to know to improve connectivity will become increasingly necessary to sustain them.

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How low do we go - Advances in fish passage technology for small fish (<100 mm long!).

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In Australia, provision of fish passage has often focused on adult and sub-adult fish of a number of iconic species such as Murray cod, golden perch, barramundi and mullet. However, there is a diversity of species whose post larvae juveniles make upstream migrations from the estuary into lowland freshwater habitats in Queensland. This includes: empire gudgeons, long-finned eels, bony bream, anchovies, mangrove jack, striped mullet and barramundi have juveniles that are very small when entering freshwater. These fish, as small as 8 mm long, encounter stream barriers and successful passage is crucial to maximising survival and productivity. In extreme cases barriers, can completely block these life stages and lead to a freshwater population collapse.

Providing passage for small fish has required a rethink of traditional fish passage options, now there is a renewed focus on very low turbulence and roughened fishways that create hydraulic micro habitats that these fish use to move upstream. We outline the design options available for passage of small fish and successful fishways in Queensland.

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Passage of Golden Perch and Murray Cod through ten vertical slot fishways.

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From 2011 – 2016, DPI Fisheries completed detailed Passive Integrated Transponder (PIT) monitoring at ten (10) vertical-slot fishways in the Murray-Darling Basin. The aim of this presentation is to detail fish passage outcomes at newly constructed vertical-slot fishways, with a focus on two native species, Golden Perch (*Macquaria ambigua*; 0.1 – 0.5 m) and Murray Cod (*Maccullochella peelii*; 0.1 – 1.0 m), both of which demonstrate a facultative potamodromous migration pattern.

Analysis of fishway performance centered on the percentage of PIT tagged fish that approached the fishway entrance, passage efficiency once inside the fishway, ascent time, and the number of failed ascents where the fish returned downstream. PIT monitoring results will be discussed against criteria established by DPI Fisheries to assess the effectiveness of vertical-slot fishways in passing facultative migrating species. Fish passage trends among sites will be discussed against vertical-slot design criteria such as fishway slope (1:20 to 1:30), pool turbulence, and slot size which are generally conservative compared to northern hemisphere design standards due to the poor swimming capacities of Australian native fish. Behavioural observations such as repetitive repeat ascents will also be discussed.

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Predicting barotrauma susceptibility for downstream passage at river infrastructure

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When fish pass downstream through river infrastructure, such as dams and weirs, barotrauma may occur due to a rapid decrease in pressure. In severe cases, barotrauma may lead to mortality. Different species are likely to respond very different to these rapid decreases in pressure. Therefore, to predict barotrauma for a specific species, surrogate species may not be a valid approach, and it may be necessary to examine each species individually. For this study, Australian bass and carp gudgeon were exposed to a range of rapid decompressions using hyper/hypobaric hydro-chambers and examined for injuries and mortality. Rapid decompression data from these two species, in addition to previously examined Murray cod and silver perch were evaluated to determine which injuries were highly associated with and likely to predict mortality. Dose-response logistic regressions models were developed for each species to predict injury and mortality over a range of rapid decompressions. These models are a valuable tool for estimating injury and mortality rates for fish passing though river infrastructure and can be applied to specific sites where pressure profiles have been developed. Applying these models to current and future infrastructure can provide important insight into what measures or design alterations may be necessary to directly reduce the negative impacts of river infrastructure on fish populations.

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Injury and Mortality of Two Mekong River Species to Turbulent Shear Forces

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Global hydropower development is one solution proposed to address an increase in energy needs. However, hydropower-related impacts on riverine ecology systems is not well understood. The Mekong River Basin (MRB) is one of the world's largest waterways and is presently experiencing significant hydropower expansion. It is also one of the most biodiverse rivers; serving as home to many species that are blocked or hindered by the development of dams. One source of injury and mortality for downstream moving fishes is passage through the turbine environment where fishes may be exposed to a number of physical stressors (e.g., shear forces, rapid decompression, blade strike and turbulence). The current study sought to understand the susceptibility of blue gourami (*Trichopodus trichopterus)* and iridescent shark (*Pangasianodon hypophthalmus*) to shear forces. Fishes were exposed to an underwater jet with velocities up to 21.3 m/s (equating to strain rates of up to 1,185 s^{-1}). Fish were assessed for behavioral effects, injuries, and mortality. Overall, it was determined that both species were susceptible to shear

forces and the effects were more pronounced at higher strain rates. Gouramis were more susceptible than sharks. To minimize impacts on these species, shear forces within turbines should not exceed critical limits.

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Sensing what fish feel about passage through three different low-head hydropower turbines

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Knowing the kinds of physical stress experienced by fish passing through hydropower turbines can help optimise technologies and improve fish passage. This paper assesses the hydraulic conditions experienced through three different low-head turbines, taken using an autonomous sensor: a VLH, Archimedes screw and horizontal Kaplan turbine. A total of 127 Sensor Fish deployments were undertaken across all three turbines, generating 82 valid datasets. Decompression was rare at the VLH and screw turbines and rarely fell more than 10 kPa below atmospheric pressure. In contrast, the Kaplan was capable of generating pressures as low as 55.5 kPa (approximately 45 kPa below atmospheric pressure), over shorter periods of time. Severer ratios of pressure changes could therefore be expected for both surface and depth acclimated fish at the Kaplan when compared to the other turbines. Strike was another possible source of fish injury (detected in 69-100% of deployments), and although strike severity was highest at the Kaplan, strike was more likely to be encountered at the screw and VLH than the Kaplan turbine. Shear only occurred near the blades of the Kaplan and not at severe levels. The results demonstrate that low-head hydropower facilities are not without their risks for downstream migrating fish.

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Determining barotrauma in the Pictus catfish, Pimelodus pictus, experimentally exposed to simulated hydropower turbine passage

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Hydropower development poses severe threats to the aquatic diversity and ecosystem services. One such threat is the exposure of fish to extreme conditions within hydropower facilities. Fish may suffer rapid decompression when passing through turbines or entering/inhabiting the draft tubes, which can lead to barotrauma and mortality. We aimed to evaluate the effects of rapid decompression on the Amazonian benthic species *Pimelodus pictus* (Pictus catfish), by simulating in hypo/hyperbaric chambers. The most frequent injuries in Pictus catfish exposed to simulated rapid decompression were swim bladder rupture, intestine rupture, internal haemorrhage and embolism. The occurrence and magnitude of internal haemorrhaging and emboli were related to the ratio of pressure change and the decompression timespan, while swim bladder rupture occurred even at relatively low ratios. Emboli was present almost entirely among fish with a ruptured swim bladder. Importantly, all fish were negatively buoyant prior to exposure to decompression, posing challenges to data analysis. Therefore, barotrauma studies with benthic fish species are deemed to be challenging and are likely to require the use of complementary approaches. Research is needed to understand the state of buoyancy of benthic fish in the wild and develop methods to accurately replicate these in a controlled testing environment.

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Warning, it's a catfish! Novel approaches are needed to study the effects of rapid decompression on benthonic species

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Barotrauma due to rapid decompression has been recorded as the most common injury among fish captured in the tailrace of hydropower dams in Brazil, with catfishes representing the majority of them. Nevertheless, studies investigating barotrauma on catfish are scarce, with the majority determining dose-response curves and thresholds of pressure changes for nektonic species as salmonids. Experiments conducted with *Pimelodus pictus* showed that the current hypo-hyperbaric chambers used to study barotrauma in nektonic species have limitations when applied to benthic groups. The negative buoyancy showed by the catfish prevent the definition of the acclimation pressure of the fish prior to exposure to decompression and, therefore, hinder calculation of the ratio of pressure change (RPC). RPC has been considered the main factor explaining the likelihood of barotrauma on fish. Since its calculation is restricted for benthic species, new approaches deemed to be needed to complement barotrauma studies with this group. We aimed to discuss the limitations observed for studies with benthonic species and present potential methods

to overcome them. The diversification of approaches for barotrauma studies with benthonic species is critical to provide information for the development of mitigation and new turbine designs that would improve protection of this group.

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Using otoliths to quantify diadromy in the Lower Mekong Basin

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Fish migrations are an important characteristic of the Mekong River. Many species need to move between freshwater and marine waters between Mekong countries as either adults or juveniles to complete their life cycle known as diadromous fishes. Unfortunately, migration behaviors of diadromous species have very limited information and unlikely pay enough attention to this group, this can lead to poor management and extinction. In addition, the persistence of these species is threatened by a series of dams planned across the Mekong Basin by blocking their migration routes. There is subsequently a pressing and urgent need to improve the understanding of fish migration so that they can be considered as part of dam development planning in the Lower Mekong Basin. A review shows that many Lower Mekong fish species reside in a wide range of salinities. At least one hundred fish species exhibit diadromous traits. But a literature review alone is insufficient to determine diadromy; hard data is required. Some of these species were subsequently selected for otolith microchemistry analysis. Trace elements are used as proxies to reconstruct their historical habitat experiences. Moreover, water is also sampled to check trace metals in different locations in the basin. Preliminary results indicate that many more Lower Mekong species are diadromous than previously thought.

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Fish passage at the Don Sahong dam site, Khone Falls, Mekong River, southern Laos

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The 260 MW Don Sahong Hydropower project is being constructed from 2015 to 2019 on one of seven Mekong anabranches (Sahong Channel) which cross Khone Falls in southern Laos. The other six channels carry most of the annual flow of the river and provide for variable degrees of upstream fish passage, depending upon discharge, the degree of obstruction by natural barriers (waterfalls, cascades and rapids) and the extent of blockage by large fishing gears. About 200 species of fish are commonly caught; all migrate for feeding, refuge or spawning, with many being long-distance migrators. Fishing, particularly of migrations, is very important for local people, so mitigating the impacts of the project is a high priority for the developer, the Don Sahong Power Company. Upstream fish passage is being enhanced by in-stream modifications to increase dry-season flow of water down channels, to reduce the height of natural barriers, or to create bypass channels, and by removal of illegal gears which block fish migrations. Downstream passage is less problematic than at typical cross-river projects, as flow will be regulated by the operation of the hydropower plant, with excess water flowing down natural channels through which migrating fish can pass safely, so there is no risk from spillway passage. The plant will utilise four 65 MW GE (formerly Alstom) bulb turbines, considered relatively fish-friendly, with an operating head of 16-18 m. The overall probability of mortality of fish from strike, barotrauma and shear stress is likely to be relatively low, and it is planned to adaptively manage any unacceptable impacts through physical or behavioural measures to divert fish upstream of the plant. This presentation will give an overview of the project and the evolution of fisheries mitigation measures.

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Monitoring fish passage and fisheries at the Don Sahong dam site, Khone Falls, Mekong River, southern Laos

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The Mekong River in southern Laos splits into seven anabranch channels which flow across Khone Falls, south-east Asia's widest waterfall complex. Fish attempt to migrate upstream through all channels, and three (Xang Pheuak, Sahong and Sadam) were considered the most important for upstream fish passage by researchers who interviewed fishers in the 1990s. However, there are no actual data which show quantities or species of fish which migrate upstream through any of the channels. Sahong Channel was closed by coffer dams and dewatered in January 2016 to allow for the construction of the Don Sahong Hydropower Plant (DSHP), scheduled for completion in mid-2019. Fish passage improvements in the other channels are being carried out to mitigate the impact of closure of Sahong Channel. Ongoing monitoring is required to evaluate the success of these measures and the status of the fishery at Khone Falls to provide a basis for adaptive management during operation of the hydropower plant. Assessing fish passage directly at Khone Falls is potentially hazardous and technically challenging, as the channels are generally inaccessible, large and steep with fast and turbulent flow over a jagged substrate of fractured bedrock. Methods used include: 1) standardised sampling upstream and downstream of barriers, 2) monitoring daily catches of 60 households, 3) direct observation and counting of migrating fish, 4) interviews of fishers, 5) monitoring of catches and prices of fish in markets, and 6) downstream drift of larvae. Each of these methods produces useful information, but all have limitations. Taken together they provide multiple lines of evidence for a balanced assessment of fish passage and changes in the status of fisheries over time.

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Dazed and confused: why behavioral constraints can impose enormous challenges to fish passage in the Neotropics

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Fish passages in South American have presented several problems, related to low attractiveness, presence of hydraulic bottlenecks, high selectiveness, lack of downstream movements of fingerlings and adults, lack of critical habitats (free flowing rivers) upstream, among others. Since the great majority of studies performed in the Neotropics have focused on the passes themselves, it seems to exist a premise that fish would behave as expected and complete their reproductive cycle if they overcome the dam and the reservoir. The behavior of "local populations" and transposed fish so far has not been evaluated. In this study, we compared the migration and behavioral patterns of *Prochilodus costatus* individuals that inhabit a lotic remnant of the São Francisco River (local population) upstream of the Três Marias reservoir, with transposed individuals captured below the dam, over two reproductive seasons. Local individuals showed a highly synchronic reproductive cycle, relying on environmental cues (changes in water temperature, photoperiod and the arrival of the rains) to perform upstream migration, spawn and return to feeding grounds. This group also showed a high degree of temporal and spatial fidelity in its migratory displacements. However, transposed individuals presented different behavior patterns, including erratic movements, and up- and downstream movements, many times in short intervals. They seem incapable of recognizing geographical and environmental cues to perform spawning migrations, and could not find the spawning grounds used by local individuals to mate. These results indicate that even if individuals were able to efficiently overcome dams and reservoirs, the may not be able to recognize environmental and geographical cues in their new location, and not complete their reproductive cycle as expected. In such cases, the conservation value of a fish pass would be impaired.

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Evaluating the placement of PIT tags in tropical river fishes: a case study involving two Mekong River species

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Fish communities are becoming increasingly threatened in many tropical river-floodplain systems due to the construction of dams and other physical barriers. Efficient tagging techniques are urgently needed to better understand the movement ecology of tropical river-floodplain species — both at a fundamental level and in response to the effects of barriers. Passive Integrated Transponder (PIT) tagging has been successfully used to quantify fish movements in many temperate riverine species, but its effectiveness on tropical riverine species remains largely untested. We investigated the potential use of PIT tags in two tropical species from the Mekong River — *Pangasianodon hypophthalmus* (Striped catfish) and *Hypsibarbus malcolmi* (Goldfin tinfoil barbs). Two separate, but concurrent, 50-day experiments were conducted on the two species to determine whether (1) the PIT tags can be retained within the fish, without affecting their mortality or growth, and (2) the outcomes for tag retention, fish mortality, and/or fish growth are influenced by the location of the tags in the fish. Results indicated that, for both species, PIT tags can be retained in the chest, gut or shoulder without affecting mortality or growth. This suggests that PIT tags could be successfully used in a range of body locations in Striped catfish and Goldfin tinfoil barbs in the Mekong River. However, the Mekong fishery is a highly important food source for the people of its neighbouring countries — thus, the most suitable tag location in large-bodied species would be the gut region, as the gut, and tag, are most likely to be removed prior to human consumption.

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Energy efficient fish attraction

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Fish migration past a hydro power plant (HPP) requires not only flow in the actual fish passage (e.g. fish ladder) but also sufficient water to attract the fish to the entrance. Such attraction water is typically created by spilling water of the order of 10 m^3/s, and there are potential savings if the amount of water can be reduced without loss of functionality.

The possibility to use ejectors (jet pumps) to pump water from the area downstream of the HPP into the fish passage has been investigated with physical model tests and numerical modelling (CFD). The ambition has been to make use of fairly simple geometries without changing the layout of the suggested fish ladder, and a solution in which the ejectors are located in a separate channel parallel to the fish ladder has been evaluated. The results show that the required spill can be reduced to 1/3 despite the low head (7 m) of the considered HPP, and the savings will be even larger in HPPs with higher head.

More energy efficient ways to attract fish can be obtained if the jets are positioned within the actual fish way, but a prerequisite for such solution is that the fish is not intimidated by the jets. Another interesting option to evaluate is the possibility to guide the fish to the fish ladder entrance by an array of individual jets positioned in the river. To investigate these ideas tests with live fish are scheduled during second half of 2018.

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Assessing multi slot versus single slot pool-type fishways suitability for potamodromous cyprinids: An experimental approach using numerical modelling and fish

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Developing new fishway designs that provide suitable hydrodynamic conditions for multiple native freshwater fish species is paramount to mitigate the negative effects of anthropogenic barriers in rivers. This poses an increased challenge in Mediterranean regions, where water availability is limited and issue of conflicting demands. Vertical slot fishways (VSF) are considered one of the best types of technical fishways for potamodromous fish species. However, they generally require a greater amount of water to operate relatively to other type of facilities. The present study used 3D numerical modelling to compare the hydrodynamics and assess the hydraulic suitability for multiple fish species, of a widely used VSF and of two multi slot fishway (MSF) configurations. The MSF configuration requires a lower discharge to operate (> 20% less discharge) than the VSF, while keeping similar flow depths. With the reduction in discharge, the velocity, turbulent kinetic energy and Reynolds shear stress values for MSF are also much lower than the values for VSF (c. 20 – 40% less). Hence, besides requiring smaller discharges than similar VSF design, the MSF seems to be less selective for fish species, particularly smaller-sized individuals, and individuals with weaker swimming capacities. Passage performance of the Iberian barbel, *Luciobarbus bocagei* (Steindachner, 1864) was subsequently assessed when negotiating a VSF and a MSF in an indoor full scale experimental model. Results showed that the Iberian barbel performed a significantly higher number of movements in the MSF when compared to the VSF. On the other hand, no differences were found in the entrance time, entry efficiency and overall fish performance between configurations. This study shows that numerical modelling complemented with laboratory fish experiments can be an important tool to develop cost-effective fishways.

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Seaham weir environmental flow control gates and integrated fishway

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Seaham Weir is located near the town of Seaham on the lower reaches of the Williams River. It is owned and operated by Hunter Water. The weir provides a separation between saline tidal water in the Hunter River Estuary and fresh water that flows down the Williams River. The existing components of Seaham Weir consist of a rock weir, two control gates and an orifice style fishway.

The requirement of the study was to develop an integrated fishway for both upstream and downstream migration of fish and flow control gates that could release environmental flows between 10 and 500ML/d.

The study involved:

- Assessing the types of fishway and gate type options;
- Identify options for the Integrated fishway and flow control gates:
    - Various site location and layouts; and
    - Various gate sizes and combinations.
- Carrying out physical modelling of the short-listed options to determine;
    - The preferred layout of the proposed gates and fishway;
    - The gate operation strategy across the design range of flows and downstream water levels; and
    - Look at improvements to the layout to optimised fish passage.

The design incorporated a fish retention weir primarily to limit fish being expelled from the fishway at low tailwater and also offer the chance for fish within the retention weir to remain near the fishway entrance at low tides.

Another innovative component of the design was to incorporate a submerged and removable weir within the stop board guides downstream of one of the gates to control turbulence within the fish retention weir pool.

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Hydraulic design of an optimised vertical-slot fishway targeted at multi-range fish-biology based design criteria for low, medium and high river flows.

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The trend towards reduced operational inputs and maintenance requirements requires fishways to be increasingly self-regulating. This emphasizes the need for a robust understanding of fish migration ecology and the establishment of biology based hydraulic design criteria targeted at low, medium and high flow ranges. Consequently, the hydraulic design of technical fishways such as the vertical-slot has increased in complexity with innovations needed to achieve optimised fish passage performance for a broad range of fish species and sizes, over a wide range of river flow conditions and with minimal compromises.

The challenges are amplified at a barrier site with a high maximum differential head across a fixed-crest rockfill weir, an associated large tailwater range and large variability in the upstream limit of fish movement making fishway entrance location difficult.

An innovative vertical-slot fishway has been designed for a large maximum differential head of 4.4m, that comprises two fishway entrances and a single fishway exit. The objective was to optimise passage for fish in the size range of 20-700mm at river flows ranging between near zero and flood flows that cause weir drown-out. The fishway is designed to be self-operating without external operational input or the need for mechanised control gates. This contrasts with a more typical approach that may use multiple gated exits or potentially have compromised fishway entrance attraction conditions for a significant period.

The work covers low and high flow fishway entrance arrangements and fishway baffles with variable slot geometry aimed at delivering hydraulic performance that meets the targeted fish passage objectives inherent in the developed multi-range design criteria.

The long-term benefits for owners of an operationally simple fishway with minimized maintenance demands comes at the expense of a more challenging design process that requires a cohesive collaboration between fish biologists, experienced design engineers, asset owners and stakeholders.

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Proposal
an engineering solutions for fish migration upstream and downstream over one dischar ge sill located on the Bistra Mărului river

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Restoring the longitudinal connectivity of watercourses must be a priority for both river managers and policy makers. The abundance of transversal hydrotechnical constructions along the watercourses including natural reserves, as is the case of the discharge sill located on the Bistra Marului River, creates existential problems for local aquatic life and the migratory species the same. **None of the** the Bistra Mărului River discharge sills have fish migration systems. The Water Framework Directive of the European Union allocates important chapters of both legislation and implementation regarding the protection of the lotic ecosystems including the restoration of the longitudinal connectivity. Structural and functional redevelopment through the technical improvement of existing fish systems and the development of new practical designs will in particular bring new hope for migratory fish species as well as ecological stability for local ones. **The River system supports a diverse fish community with many migratory species, some potamodromous and some diadromous. So there are significant challenges in attempting to design a system that passes the majority of fish from a diverse range of size classes.** The complementarity between the solutions proposed in this presentation will provide an efficient logistic support for the builders of the migration system on the Bistra Mărului River located in Caraș Severin County, România, the European Union. **There is currently no fish pass construction program in Romania and there is an urgent need to develop solutions which will benefit all species and are simple for managers to install and implement.**

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Role of fish migrations and ecosystem connectivity in PROBFLO holistic environmental flows assessments in Africa.

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Throughout the developing regions of Africa, water resource use is increasing rapidly with dam developments and other river connectivity impeding stressors. Best practice principles of Integrated Water Resource Management in Africa includes the need for robust holistic frameworks that address the risk associated with multiple stressors to social and ecological objectives on regional, trans-boundary scales. With regional regulators we have developed an Environmental flow (E-Flow) framework that gives adequate consideration to flow and non-flow stressors to describe the risk to socio-ecological endpoints in a holistic, multiple scenario context. This regional scale ecological risk assessment approach called PROBFLO incorporates Bayesian Networks to model the probable relationships between the flows and other driver variables, and socio-ecological indicators by assigning magnitudes and probabilities of adverse impacts of hazards to endpoints.

Connectivity requirements within rivers and between rivers and floodplain ecosystems, have become an important component of E-flow assessments. We demonstrate how ecosystem connectivity and fish migrations have successfully been used to evaluate the socio-ecological consequences of altered flows to multiple management endpoints in a holistic context in the Mara River (Nile Basin, Kenya), Kalungwishi River (Congo Basin, Zambia), Inner Niger Delta (IND, Niger Basin, Mali) and Senqu River (Senqu-Orange River basin, Lesotho) using PROBFLO. Fish migration information and associated river connectivity requirements provided evidence to characterise the risk of multiple stressors to numerous subsistence fisheries, fish community wellbeing and biodiversity maintenance endpoints. In these case studies, E-flow requirements were established that address; instream habitat depth and velocity requirements for migratory fishes at suitable times, suitable depths to maintain river connectivity for migrations, downstream migration habitat requirements, protection measures for migratory fishes, barrier mitigation measures and sustainable use and conservation endeavours to maintain migratory populations. These case studies demonstrate how ecosystem connectivity and fish migration evidence can contribute to holistic E-flow assessments.

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The effects of river discharge and instream barriers on the fish assemblages of the Clarence Basin, New South Wales, Australia.

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The role that natural instream barriers take in shaping riverine fish communities is frequently overlooked, with the focus most often on man-made structures such as dams and weirs. There have been few detailed studies of fish communities in the coastal rivers of south-eastern Australia. The Clarence Basin is located in northern New South Wales (NSW) and is one of the largest of these coastal drainages, encompassing an area in excess of 20,000 km^2. The system is largely unregulated and plays an important role in the recreational and commercial fisheries of NSW. The aim of this study was to better understand the relationships among river discharge, instream barriers and fish ecology across the freshwater and estuarine reaches of the Clarence Basin. Electrofishing surveys and acoustic telemetry were used to determine the effect of four potential fish passage barriers in the Clarence Basin 2006-2017. Based on bi-annual electrofishing surveys, the natural barrier created by the Clarence Gorge had the greatest effect on the fish assemblages in the system. Acoustic telemetry was used to study the movement patterns of five large-bodied fish species native to the system; three migratory and two non-migratory. Large-scale linear movements were undertaken by all three migratory species, facilitated by increases in river discharge. Longer linear movements from the freshwater reaches to the estuary aligned with individual species breeding season and were often impeded by natural and anthropogenic barriers alike. In comparison, the two non-migratory species moved relatively short distances and mainly during late-winter and spring for breeding. The current study has provided an insight into the role river discharge and barriers have in shaping the structure of fish assemblages in coastal river systems. These results highlight the challenges faced by natural resource managers as climate change and anthropogenic influences place ever increasing pressure on coastal ecosystems.

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Barriers to Fish Passage in the Queensland Murray-Darling Basin Phase II: Validation of the "Keller" method for determining discharge at weir drown-out.

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Information about the distribution and characteristics of weirs is important in modelling fish movement and connectivity. One weir characteristic that is rarely available in literature is the weir drown-out threshold. This threshold describes the stream discharge where tailwater levels exceed the height of the weir, providing a theoretical opportunity for fish to move over the weir. It therefore provides a means of relating stream discharge to opportunities for fish movement. In this project, we have used an Excel spreadsheet devised by Keller, Peterken & Berghuis (2012) to calculate weir drown-out thresholds for four gauging weirs in the Upper Condamine River catchment, and validated the results using depth loggers and gauge data.

Each gauging weir site was surveyed to populate the spreadsheet with the weir dimensions and the slope, roughness, cross-section and rating table of the downstream channel. Loggers were installed upstream and downstream of the weir to record depth over 12-18 months, thus detecting drown-out events. The discharge at drown-out was determined by cross-referencing the time at which drown-out commenced with discharge recorded by the gauge. The frequency of flows exceeding the calculated and measured drown-out thresholds (ML/day) were compared using the Wilcoxon Rank Sum Test. The results showed that the thresholds were not significantly different for three of the four sites.

The Keller, Peterken & Berghuis (2012) spreadsheet provides a method for calculating a drown-out threshold for critical barriers to fish movement. This can be achieved quickly, with minimal cost and at an accuracy suitable for modelling fish movement. The drown-out threshold provides water managers with tool to determine whether the existing or proposed infrastructure provides opportunities for fish passage, and at what frequency. At the same time, it produces values that can be used to attribute passability scores to barriers when developing connectivity models.

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Understanding the effects of flow on the movement of Yellowfish using the FISHTRAC programme as a management tool in Southern Africa: Crocodile River, Kruger National Park case study.

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The excessive use of aquatic ecosystem services in developing countries has caused a decline in ecosystem integrity processes. Alterations to flow, habitat and water quality from dams, abstractions and users are among the main drivers towards the decline in ecosystem integrity and processes. The FISHTRAC programme has been established to promote the development of, and use of fish movement variables in the evaluation of ecological consequences for altered flow, habitat and water quality in southern Africa. Numerous evidence research studies have been undertaken on the Vaal (O'brien et al. 2013, Jacobs et al. 2016, Ramesh et al. 2017) and Crocodile Rivers (Burnett et al. 2018) to evaluate the behavioural ecology, home range, daily and seasonal migratory behaviour and movement responses to changes in environmental variable. The most recent Crocodile River evidence-based research has shown the response of yellowfish towards the releases of flows from upstream. Understanding these responses can assist park and water affairs managers to reach the required environmental flows both within and outside the Kruger National Park. This behavioural study included the use of manual and remote fish tracking techniques developed for the FISHTRAC programme with a range of flow, water quality and habitat evaluation methods. Established univariate and multivariate statistical and probability modelling techniques were used to evaluate the response of fish behavioural data (+180 00 data strings) to the changes in environmental variable states. The movement responses by yellowfish resulted in the establishment of a four primary levels of fish movement response this includes the disruption of established behaviour, significant reduction in movement, prolonged residency of refuge areas and vacation of their core home range. These responses can be incorporated into water resource management in South Africa, and used to monitor the wellbeing of the variable states in real time and remotely using the FISHTRAC approach.

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A connectivity conundrum for freshwater eels in South Africa: comparative study for relative abundance and distribution of freshwater eels in a highly regulated and free flowing river in South Africa.

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Four freshwater eels species (*Anguilla spp.*) occur in South Africa. From sea to source and back, these facultative catadromous species face multiple-stressors including habitat alteration and deterioration, pollution and migration barriers. Although these eels have social and ecological importance, very little is known about their present distribution and impact of multiple stressors on the wellbeing of populations. Understanding these fishes can contribute to the better use and protection of our water resources, especially in rivers where connectivity is impaired. Existing information demonstrates that river penetration potential of species differs. The giant mottled eel *Anguilla marmorata* generally does not occur above 750 m a.s.l. while African longfin eel *Anguilla mossambica* should be distributed throughout river systems up to altitudes of 1650 m a.s.l. In this study, we evaluated the distribution and relative abundance of eels in association with environmental variables in the Sundays, Keiskamma and uMgeni Rivers in South Africa using standard night fyke net efforts. It was hypothesised that the longitudinal distribution of the species would differ between the species and between the systems. A longitudinal survey of survey of the Sundays River (n = 450 fyke net sets) and down the Keiskamma River (n = 73 fyke net sets) confirmed this hypothesis with *A. marmorata* only being sampled only from the lower reaches of the river while *A. mossambica* was ubiquitous, occurring from headwater streams to the lower reaches. The uMgeni catchement is heavily regulated and impacted by anthropic activities and it is hypothesised that they are virtually absent from the system. Recent surveys confirmed this hypotheses with only 2 individual *A. mossambca* caught upstream of the first major dams from a comparable sampling effort. This study has provided evidence that represents the effect of barriers on important river ecosystems in South Africa.

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Monitoring PIT-Tag Passage Through Steel Fish Bypass Baffle at Wells Dam, USA.

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Douglas County Public Utility District (DCPUD) owns and operates Wells Dam on the Columbia River, Washington, USA. The Wells project has ten generating units rated at a combined 840 megawatts. Eleven gated spillway openings can pass a flood of over 33,311 m^3/s. The hydrocombine structure is 355 m in length and the dam is 1,360 m long overall. The unique hydrocombine design incorporates the powerhouse, spillway, switchyard and fish facilities into one unit instead of separate structures. The Wells Dam juvenile bypass system comprises modifications to 5 of the 11 spillways to enhance bypass efficiency. Each bypass bay utilizes a baffle structure consisting of 64 approximately 1.2 m x 1.2 m openings arranged in 4 columns of 16 openings.

DCPUD installed a juvenile PIT-tag detection system at Wells Dam in 2016 and 2017 to determine compliance with FERC-license obligations. Detections at Wells Dam are used to determine travel time between Wells Dam and Rocky Reach Dam, the next dam downstream, and those data are used to calculate passage date at Wells Dam for the thousands of fish detected at Rocky Reach Dam but not at Wells Dam.

DCPUD worked with Biomark to design and install a PIT-tag array in a subset of the Spill Bay 2 bypass baffle openings. Biomark used thin-wall shielded antennas to minimize the amount of flow constriction and allow placement within the steel structure. Each antenna is connected to a Biomark IS1001 reader housed in a submersible enclosure and mounted to the downstream side of the bypass baffle. The 16-IS1001s are connected to a pair of Biomark IS1001-Master Controllers. Power to the IS1001-MCs is provided using an isolation transformer. All diagnostic and tag-detection data is transmitted to a data-collection computer through a fiber optic cable and then to Biomark's BioLogic web portal.

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Fishways and PIT reader systems: demonstrating the restoration of longitudinal connectivity in the Murray River, Australia.

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In the Murray River, Australia, longitudinal connectivity was compromised by the construction of dams, weirs and regulators, during the early-mid 1900's. To re-establish the longitudinal movements of fishes along the Murray River, 14 fishways were constructed as part of the 'Sea to Hume program'. To evaluate fishway success, a large-scale integrated passive integrated transponder (PIT) reader system was implemented across all fishways along the Murray River upstream of Lock 1. We analysed 11 years of fish movement data to document the extent of long distance migrations. A total of 4,373 fish (18% of the total PIT tagged population) were recorded by the PIT reader system, with approximately 17% of these undertaking multi-site (multiple fishway) journeys, with some fish moving through six different fishways. Mean movement distances for those fish undertaking multi-fishway journeys were 116.3, 163.9, 208.5 and 352.5 km for Murray cod, golden perch, carp and silver perch, respectively. Maximum movement distances recorded for Murray cod, golden perch, carp and silver perch were 497, 1556, 1713 and 1556 km respectively. These data demonstrate fishway construction restored long distance migrations along the Murray River, particularly during low-medium flows, when the weirs remain in place. Completion of the 'Sea to Hume' fishway program has achieved its aims of reducing the impact of instream barriers on fish movement and reinstating longitudinal connectivity. Reconnecting 2,235 km of the Murray River for native fish passage therefore, represents one of the largest successful river restoration programs in the world.

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Fish migration assessment by acoustic telemetry in the lower Ebre river (Catalonia, NE Iberian peninsula, Europe)

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This research is associated to the LIFE MIGRATOEBRE project (www.migratoebre.eu), which aims to improve fish migration in the lower Ebre river, a Mediterranean river, mostly focused on *Anguilla anguilla*, *Alosa fallax*, *Petromyzon marinus* and *Acipenser sturio* conservation and recovery.

Migrating periods, main fish movements and preferential downstream routes (if they overcome a weir above, enter to irrigation channels or go to hydroelectric turbines) of the Ebre fish population (López et al., 2012) are unknown.

Following Le Pichon et al. (2015), in spring 2017, ceded by EABX R.U. of IRSTEA-Bordeaux, 47 VEMCO VR2W-69 kHz receivers (stacked to a concrete blocks of 500 kg; 15 months of battery life) were installed in a river stretch of 115 km long, between Flix dam and the Mediterranean Sea, including 4 Ebre delta coastal lagoons. Between May and October 2017, 30 fish from 58 km upstream the river mouth were marked: 5 *A. fallax* (using V9-2H acoustic pingers; 9x29 mm, introduced by the mouth, without anesthesia; 270 days of battery life), were released at the catching point; and 11 *A. Anguilla*, 13 *M. cephalus*, and 1 *L. ramada* (using V13 acoustic pingers; 13x36 mm, placed in the peritoneal cavity, with anesthesia and suture; 513 days of battery

life), 52 km upstream (downstream Flix dam). An active tracking from a boat with a VR100 acoustic receiver and directional (VH110) hydrophone was also done.

A. fallax went soon to the sea. *M. cephalus* were detected 3 months later their release, in July and August, upstream and downstream Xerta weir. None fish did not go in or out the coastal lagoons 10 months later.

Obtained results seems indicate that the Ebre river possibly allows the recovery for those endangered species. To reinforce this information, other fish will be marked, including, if available, juveniles of *A. sturio* in 2019.

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Flow characteristics in tailrace: understanding how hydrodynamics may attract fish to hydropower plant in South America

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Management of fish movement, either to direct them to the entrance of a fish bypass or to prevent their entry into areas where they can be injured, killed, or their migration delayed, is a common goal downstream of most dams in South America. Multidimensional numerical simulation is a useful tool which can provide detailed flow pattern information to help understand observed fish abundance and distribution in the tailraces of dams and to guide the decisions on locating fishway entrances. To this end, we developed a 3-D computational model to investigate flow characteristics near Tres Marias Dam located at river 3 KM on the Sao Francisco River, Brazil. The modeled spatial domain included a portion of the powerhouse (including the draft tubes), tailrace, and a river reach extending 3 KM downstream of the dam. We simulated a common operational scenario consisting of three active turbines on the right side of the powerhouse and three inactive turbines on the left side of the powerhouse. Domain discretization was conducted using Gridgen software and numerical simulation was performed using Fluent. From the model results we identified two dominant components in the flow pattern: a relatively straight discharge plume originating from the right-most turbine that was constrained by the right-side wall of the powerhouse and the generation plume from turbines 2 and 3 and a second component featuring a complex entrained primary eddy with two secondary eddys maintained by the discharge plume of the powerhouse. The complex primary and secondary eddys could constitute a low velocity refuge area where fish could concentrate even during hydropower generation. Finally, we concluded that local velocities were not a significant challenge for neotropical species, such as Pimelodus maculatus, Leporinus Renhardti and Prochilodus lineatus, since their prolonged swimming speeds were higher than the modeled water velocities.

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Reservoir provides cool-water refuge for adult Chinook salmon in a trap-and-haul reintroduction program

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Trap-and-haul is a mitigation strategy at many hydropower dams lacking upstream fish passage facilities, and protocols are needed to maximize its effectiveness. We used biotelemetry to assess the potential benefits of releasing transported adult Chinook salmon (*Oncorhynchus tshawytscha*) into a cold-water reservoir versus a relatively warm-water tributary before spawning. Warm river temperatures in the study region have been linked to high prespawn mortality in Chinook salmon, and so reservoirs provides a potential thermal refuge where salmon can select preferred water temperatures to regulate maturation processes and reduce disease risks. Over five years, we released 160 salmon into Foster Reservoir (Oregon, USA) and another 102 into the South Santiam River near historic salmon spawning areas further upstream. In total, 70% of reservoir-released salmon entered an upriver tributary after spending a median of 3-95 d annually in the reservoir. Data recovered from 61 archival temperature loggers indicated that salmon were ~3-6 °C cooler per day in the reservoir than in the river. We estimated that cumulative exposure of reservoir-released fish was reduced by 64 degree days (DD), on average (*range* = -129 to 392 DD), relative to river-released fish. The results demonstrate that adult trap and transport to reservoirs may reduce thermal exposure for some temperature-sensitive populations, and therefore may be an effective strategy to help reduce prespawn mortality. However, reservoir releases were not risk-free: 14% of all reservoir-released fish fell back downstream past the dam versus 1% of river-released fish; the fallback may have been related to homing behaviors, but natal origins were unknown for all fish. We conclude that reduced transport distance, reduced thermal exposure, and potential survival benefits of releasing salmon into reservoirs should be weighed against fallback risks.

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Optimizing hydropower development and ecosystem services in the Kafue River, Zambia

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Fisheries is an important sector in Zambia, but are experiencing resource overexploitation and are under increasing pressure from external development activities that are compromising river ecosystem services and functioning. One such system is the Kafue Flats floodplain, which is under threat from hydropower development. This paper explores the impact of potential hydropower development on the Kafue Flats floodplain and explores mechanisms to optimise the expansion of hydropower whilst maintain the ecosystem functioning and services it delivers.

Since the construction of the Kafue Gorge and Itezhi-tezhi dams, there has been a reduction in the seasonal fluctuations in the height and extent of the floods. This situation is likely to get worse with the potential incorporation of a hydropower scheme into the Itezhi-tezhi dam, which will operate under a hydropeaking regime. This will have major ramifications for the fishing communities and ecosystem functioning and likely result in a collapse of the fishery along with destruction of the wetlands and associated wildlife. To redress the problem it is recommended that an environmental flows study is conducted to account for the ecosystem services provision and optimise the hydropower development to ensure continued delivery of the ecosystem services provided.

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WITHDRAWN: Hydropower effects on aquatic species: lessons from individual-based modeling

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Individual-based models (IBMs) have been used to predict hydropower effects on fish populations since the 1990s. Designed to overcome the limitations of “habitat suitability” models, IBMs can make testable predictions of how alternative flow and temperature regimes affect populations. We have modeled instream flow and temperature effects on trout and salmon, effects of hydropower peaking on trout and juvenile pikeminnow (a desert species that uses backwaters as habitat), effects of salmon restoration flows on a frog that breeds in rivers, and flow effects on a warmwater herbivore. Lessons from this experience include: (1) Many hydropower management questions concern variation over time, so models need to include time; and there are many reasons to doubt that observed habitat “suitability” represents habitat quality. For these and other reasons, habitat models like PHABSIM are of questionable value. (2) When fish are assumed able to adapt their feeding site, moderate levels of within-day flow peaking is predicted to have minor if any effect. (3) The assumption that natural flow regimes protect native fish is valuable but should be applied cautiously in highly modified systems. (4) Temperature management for coldwater species often focusses on effects of summer peak temperatures, but populations can be affected as much by effects of temperature on growth in other seasons. (5) The primary concerns for protecting aquatic populations should always be providing food and feeding habitat and, often, protection from predation. Building IBMs requires time and expertise, and traditional validation is not always possible; however, the modeling process provides a valuable framework for organizing knowledge, clarifying and testing beliefs and mental models, and ensuring that field studies contribute to improved decision-making. Information on our models is at www.humboldt.edu/ecomodel.

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Long-term study of reservoir cascade in Southeastern Brazil reveals spatio-temporal gradient in fish assemblages

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In reservoir cascades, effects on fish assemblages are expected to strengthen over time and transfer from one reservoir to an adjacent one. To test this, fish assemblage data from 23 years of monitoring in the Araguari reservoir cascade system, upper Paraná River basin, were analyzed. From 1993 to 2015, 72 fish species were recorded in the studied reservoirs, representing five orders and 19 families. In all, 58 species were native to the basin and 14 non-native (10 from other Brazilian basins and four from other countries). The results showed a clear reduction in richness of native and migratory fish species and an increase of non-native species, following reservoir formation. Migratory species richness was higher in reservoirs that presented habitats similar to lotic stretches or tributaries upstream of the impounded area. A clear tendency for native species’ decline and non-native fish abundance to increase, was observed in a downstream direction. Fish assemblages became increasingly dissimilar as reservoirs became more distant from each other (longitudinal gradient) and were dominated by small and medium sized species. Alongside biogeographic factors and the presence of non-piscivorous non-native species, reservoir area and age were found to be important drivers of variation in fish assemblage structure. Results from this study help to clarify the potential accumulated impacts of reservoirs cascades on fish diversity, which must be carefully considered in river basin inventories for hydropower plants, and reinforces the importance of long-term monitoring, considering longitudinal and lateral dimensions of the basin.

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Determining Migration Corridors and Lifecycle cues for Key Commercial, Subsistence and Conservation Freshwater Fish in Myanmar.

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The fisheries sector plays a vital role in the culture and socio-economic life of Myanmar. Traditionally Myanmar people prefer freshwater fish to marine fish. Fish is one of the most important sources of animal protein and micronutrients in Myanmar with average consumption levels estimated to be approximately 30 kg/person/year, second only to rice. Migratory fish make up an important component of the inland capture fisheries. Little is known about the migration patterns of any of the inland fish species. In the north there are cold water species and anecdotal evidence from fishers and fisheries catch data suggest that these fish take long distance movements to the edge of their water temperature ranges. Species like Hilsa Shad, one of the most economically important fish in the whole of the Bay of Bengal are a known to be anadromous, and have been recorded in freshwater sections of the Ayeyarwady River in Myanmar, but little is known about it from a management and infrastructure sense. In addition to anadromous and potradomous river species, there are many river/wetland species that migrate into and out of wetlands during the wet and dry seasons. These wetland migrators make up a significant proportion of the inland catch, but also act as the main source of protein and micronutirents to inland people, especially the poorer regions. Infrastructure development for rice and power generation would be affecting these species, but how is not well studied. To fill some of these knowledge gaps to improve management for these species, Myanmar Department of Fisheries is working with local and international organisations on research projects to improve our understanding of the migratory species within Myanmar and they are presented in these projects are presented in this talk.

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The importance of determining and maintaining migration corridors for the Hilsa Shad fishery in Myanmar Inland Rivers.

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The hilsa shad (*Tenualosa spp*) fisheries are one of the most important commercial fisheries in the Bay of Bengal region, being the national fish of Bangladesh, and playing an essential cultural and economic role in the lives of Myanmar people. More recently, the availability of Hilsa has declined across this region, due to a number of anthropogenic pressures, mainly intensive fishing and river obstruction by dams and barrages. Hilsa are known to be anadromous moving from the sea to the brackish or freshwater to spawn, however very little is very little is known about the lifecycle requirements of Hilsa in Myanmar waters and their migratory routes. River engineering and irrigation infrastructure is increasing in Myanmar rivers, wetlands and estuary systems and this has the potential to significantly negatively impact the Hilsa fisheries in Myanmar. With very little information on the migration patterns of Hilsa in Myanmar, it limits the ability for planning and positioning of infrastructure or remediation works such as fish passage. Leading on from other preliminary World Fish studies, Delta Flows is utilizing otolith microchemistry to determine the movements of adult Hilsa from the sea to the brackish or freshwater, where spawning might occur, and the movements of the juveniles back to the sea. Preliminary catch data has found adult Hilsa hundreds of kilometres inland including young-of-year, so it is suspected that at least a proportion of the population is spawning in freshwater. The next stage is analysis of the otolith microchemistry and this will help to better understand the lifecycle requirements of Hilsa in Myanmar waters, and improve informed decision making in relation to infrastructure planning.

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Fish ladder as connectivity in a large Neotropical river: upstream and downstream movements of *Prochilodus lineatus*

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The potamodromous species worldwide has been threatened by dams intercepting large rivers. One strategy of mitigation is providing passage through fish ladders; however, ladders in Neotropical rivers have been considered as only ascending routes. We study the possible occurrence of and upstream and downstream movements through the fish ladder of *Prochilodus lineatus* at a large dam – Porto Primavera – in the heavily impounded Upper Paraná River, Brazil. A total of 1,419 specimens of *P. lineatus* were PIT-tagged in areas downstream (n = 807) and upstream (n = 612) of the dam, and continuously monitored for 4 years with the RFID system. We documented bidirectional movements of *P. lineatus* through the fish ladder. Of the 807 fish tagged downstream, 306 (37.9%) entered the ladder and 267 (87.2%) successfully reached the upstream exit. Conversely, of the 612 fish released upstream, 86 (14.0%) entered the ladder and 78 (90.7%) successfully reached the downstream exit. The

entry proportion was significantly diferent between upstream and downstream (likelihood ratio chi-square: $\chi^2 = 104.7$, $p < 0.01$) but not different between success likelihood ratio chi-square: $\chi^2 = 0.8$, $p = 0.37$). Many individuals repeated these movements; one individual as many as six times. Besides, eight fish tagged in upstream probably moved to downstream by alternative routes (turbines, spillways or locks), because were not recorded descending the fish ladder but were recorded ascending. Thus, the 353 fish performed 452 passes through the fish ladder. This study showed the Porto Primavera fish ladder provides, bidirectional passage for *P. lineatus*. We suggest that fishways can acts as connectivity tools between upstream and downstream habitats.

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Impacted fish movement into tropical freshwater wetlands discharging water low in dissolved oxygen; the tail of two wetlands

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Coastal freshwater wetlands are important ecosystems which support myriad of plants and animals. In north-eastern Australia freshwater wetlands comprise a mixture of natural and modified habitats. Ponded pastures are a common type of modified wetland in central Queensland and were created to provide improved grazing pastures for cattle. The wetlands were formed when earthen bunds were constructed across portions of upper estuaries and lower flood plains. Despite the modified nature, ponded pastures provide the same ecological services as natural freshwater wetlands. The extensive nature of many ponded pastures often make them the largest freshwater wetlands within a catchment.

Like natural freshwater wetlands, ponded pastures are commonly impacted by poor water quality, in particular low dissolved oxygen (DO). Low DO levels have been linked to fish kills within wetlands, it has also been suggested that fish are unlikely to move up flow paths that are low in DO. Concurrent monitoring of fishways at two ponded pastures within the same catchment identified a considerable disparity in catch rates and species composition. Fishways were monitored at Tedlands and Boundary wetlands, central Queensland, between 2016 and 2018. Pooled average daily catch rates from Boundary were 770 fish/day, while Tedlands recorded 290 fish/day. A total of 21 species were captured from Boundary, while 12 species in total were recorded in captures from Tedlands. The DO (% saturation) concentrations of water exiting Boundary ranged from 13.0% - 128.2%, while at Tedlands DO levels ranged from 0.6% - 21.6%. Temperature, pH, and conductivity were relatively consistent between the two wetlands.

Our observation support suggestions that low DO concentrations in water exiting freshwater wetlands negatively impact fish movement. Given that coastal freshwater wetlands provide critical habitat for many important socio-economic species and provide primary habitat for many others, it is imperative that causes of low DO be addressed.

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Beyond headloss: do we have the right ecological and hydraulic metrics to determine successful fish passage in rock ramp fishways?

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Rock ramps are nature-like fishways that provide fish passage and aquatic habitat in rivers by simulating hydraulically diverse riffles and pools found in natural environments. The design of these ramps has typically been conducted with simple parameters (i.e. headloss) and 1-D modelling techniques common for other fishways. However, while it has been realized that 2-D and 3-D modelling more closely simulate the dynamics of a rocky ramp environment, even then they do not adequately capture the full ability of these ramps to provide fish passage, through their rocky environment and interstitial areas. The inadequacy of current design and modelling to capture actual fish passage, especially of small fish, will be discussed by comparisons to existing fish monitoring or observational data on select projects that were deemed barriers by current evaluation standards. The authors propose that monitoring live fish for fish passage success at rocky ramp projects be the primary tool for their passability, at least until sufficient data is collected that we all as a community learn what parameters are most effective in rocky ramp design.

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Restoring coastal connectivity through low cost rock ramp fishways

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In coastal catchments connectivity between freshwater and saltwater habitats is particularly important as diadromous fish often comprise a high proportion of coastal freshwater fish communities. In tropical and subtropical regions of eastern Australia many diadromous species have high socio-economic value, forming the basis of key fisheries. This is in addition to the vital ecological roles diadromous species fulfil in maintaining functional ecosystems.

Growing recognition within the state of Queensland of the migratory requirements of diadromous species, combined with recent adoption of ecosystem health reporting, has seen Local Governments, Natural Resource Managers, Catchment Management Authorities and community groups eager to remediate barriers to fish passage. However, the cost associated with fishways, particularly technical type fishways, often prohibits organisations from undertaking fish passage projects.

Rock ramp fishways present an effective, low cost fish passage option when compared to technical fishway designs such as vertical-slot or lock fishways. Rock ramps are generally based on a pool/ridge configuration and are designed to emulate natural riffles. Key features include the irregularity of rock faces, ridge spaces of 1.5 – 3.0 m, ridge drops of 50 – 75 mm and minimum pool depths of 300 mm. These features have been incorporated in full and partial width designs to good effect. Recent monitoring observation in central Queensland have recorded up to 31,000 fish/day successfully ascending this type of fishway, with the majority of the catch comprising small bodied and juvenile fish, <50 mm in length. It is thought that the surface roughness and the dissipative capacity of the deeper pools creates conditions conducive to the passage of small fish.

Here we present case studies of four rock ramp fishways constructed in tropical and subtropical coastal systems, on barriers ranging from 0.45 – 2.4 m in height. Case studies detail the design, construction and monitoring of each fishway.

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Kyogle weir a cost effective rock-ramp fishway design

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Kyogle Weir was a 3m high drop-board weir structure that limited fish migration to the upper Richmond catchment for 95% of river flows. As such, Kyogle Weir was one of the highest priority barriers to migrating fish in coastal NSW.

The innovative full width V-shaped fishway design, installed as part of this project, allows fish to ascend the now 2m high headloss drop via 23 incremental rises of 100mm over a 50m distance, opening up over 300km of waterways in the upper Richmond sub-catchments.

The use of the V-shape creates a high flow central region where large debris can pass through freely, and quiet zones on the fringe that fish can use to ascend the structure. Accordingly, this enables fish migration, whilst reducing accumulation of debris on the fishway, thereby reducing ongoing maintenance costs.

Being a solid structure made from precast concrete, rock and steel plates, headlosses between baffles were able to be accurately set, construction time in-stream was minimised and the ongoing maintenance of the fishway (as compared to other fishways) is significantly reduced. Furthermore, the durability of the fishway was able to be demonstrated shortly after construction, with the structure withstanding an extreme flood event produced by ex-tropical cyclone Debbie, resulting in limited rock movement and no effect on headloss.

Through this project, this design has now been shown to be an efficient and durable concept which is planned to be rolled out across NSW as the preferred design for low-head (<2m), 'natural-like' fishways. The specific design and construction techniques utilised for this project resulted in a fishway that only cost $0.65 million per vertical meter, almost half the cost of typically vertical slot fishway projects in Australia that generally cost over $1.0 million per vertical meter.

1. Northern Rivers Catchment Action Plan 2013-2023: http://northcoast.lls.nsw.gov.au/__data/assets/pdf_file/0011/496829/NR_CAP_2013.pdf
2. Eastern Freshwater Cod Recovery Plan May 2004: https://www.dpi.nsw.gov.au/fishing/threatened-species/conservation/what/recovery/efc

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Targeted improvement of the Dight's Falls Fishway Complex

Thomas Ewing, Penny Rogers

The Dight's Falls fishway complex, located in Melbourne, is a hybrid fishway design incorporating both rock ramp and vertical slot sections. Monitoring of the Dights Falls fishway has shown that the performance of the fishway decreases at higher flows. Based on the results of the fishway performance monitoring, the owner and operator of the fishway (Melbourne Water) has decided to pursue options to improve fishway performance at high flows.

The hydrodynamic conditions at the fishway entry were identified as a likely cause for the observed reduction in fishway performance with flow. An investigation was undertaken involving flow observations, Computational Fluid Dynamics (CFD) modelling, and one-dimensional modelling of the internal fishway hydraulics. The results of the modelling studies agreed with observations and indicated that excessive water velocities and turbulence near the fishway entry are likely to exclude fish at high flows. In addition, higher than desirable flows within the vertical slot section of the fishway may also contribute to the observed reduction in functionality at high flows.

The models developed to characterise the existing hydraulic conditions were subsequently used to evaluate potential modifications to the fishway. Following the evaluation of 8 options, a preferred option was selected. This option involves extension of the existing fishway and the addition of a third entry slot. The third slot is placed downstream of high turbulence zone and is oriented to intercept fish moving upstream along the bank and in the wake of the fishway structure.

This case study demonstrates the benefits of post-construction condition and performance monitoring as part of a fishway maintenance program, as well as the need for adaptive fishway management. The project illustrates the value of simulation tools in the evaluation of rectification options. The results of this study also demonstrate the significant role that fishway approach hydraulics play in the successful operation of fishways, and provides guidance for future designs.

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The cone fishway, a new fishway type suitable for the passage of juvenile tropical fish species in Queensland, Australia.

Tim Marsden, Ivor Stuart, Andrew Berghuis

Throughout Queensland the passage of juvenile migratory fish is critical to the ongoing maintenance of fish populations. These very small (<20mm) fish undertake extensive migrations that are the basis of fisheries productivity in these systems, therefore providing adequate passage at barriers is essential. The cone fishway is a new pool and weir style fishway developed in North Queensland to replace the rock ramp fishway design for the passage of these small fish. The rock ramp fishway has been a very successful design for juvenile fish species in North Queensland. However, in parts of this region, rock supply can be problematic due to a lack of suitable rock quarries and the vast distances required for transportation. This increases the construction cost of the rock ramp fishway design beyond acceptable limits. In addition, the installation of rock ramp fishways requires skilled engineers and operators with previous rock ramp construction experience, which is difficult to procure in remote regions. The concrete cone fishway was designed to mimic some of the best design features of the rock ramp fishway, use readily available materials (concrete) and be easy to install for non-fishway experts. Through an iterative design process, the concrete cone fishway has been refined into a suitable design for the passage of small fish past low to medium height barriers in North Queensland. With results from a number of demonstration fishways highlighting the designs potential to pass the large number of juvenile migrants that occur in these systems. Cone fishways such as the Fitzroy Barrage Cone Fishway are successful passage of up to 3.4 Million fish per year. The implementation of this design has now spread beyond this region with successful cone fishways now operating in Southern Australia and South East Asia.

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Restoring connectivity – how the Sea to Hume fishways will help achieve the environmental outcomes of the Murray-Darling Basin Plan.

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In Australia, the key reform in the management of water is the Water Act (2007). As part of the Water Act (2007), the Murray-Darling Basin Plan sets out the management framework for the waterways in Australia's most economically important river system. The Murray-Darling Basin Plan (2012), hereafter the Basin Plan, aims to restore and maintain the health of important water-dependant ecosystems within Australia's Murray-Darling Basin. To achieve these objectives, 'water for the environment' is to be managed under a Basin-wide Environmental Watering Strategy (MDBA 2014), (the Strategy) that articulates the basin-scale outcomes that will achieve the objectives of the Basin Plan. One of the key outcomes targeted by the Strategy is connectivity, both lateral and longitudinal. Longitudinal connectivity is of particular importance to Australian native fish species, many of which move hundreds of kilometres upstream and downstream at different stages of their life-cycle. The River Murray is now characterised by barrages at its estuary, and weirs and dams along its length, creating a series of barriers to upstream fish migration, and consequently impacting on the reproductive success of a number of Australian native fish species. Our understanding of the life-cycles of two large-bodied, recreational fish species (silver perch and golden perch) and two diadromous lamprey species (short-headed lamprey; pouched lamprey) demonstrates the importance of longitudinal connectivity at the river basin scale. It is these species that emphasise the importance of basin-scale management of river flows, basin-scale fish passage, and the interactions between the two. The outcomes from natural flow events and environmental watering actions targeting these species in the River Murray will be used to demonstrate the interdependencies between river flows and the Sea to Hume fishways. Demonstrating the importance of the Sea to Hume fishways, and Basin-scale fish passage more broadly, to the environmental outcomes of the Basin Plan.

1. MDBA (2014) Basin-wide Environmental Watering Strategy. Murray-Darling Basin Authority.

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Investigating larval dispersal patterns: simulating river flows in an experimental tank.

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The dispersal of young fish from spawning sites to nursery habitats is an essential component of the life cycle of many freshwater fish species. Despite this, we have a poor understanding of the processes and patterns of larval fish dispersal. Larval phases of freshwater fish are generally characterized by poorly developed swimming and sensorial abilities, and for some time, it has been assumed that the larvae of many species disperse passively. However, there is growing evidence showing that dispersal for most species is active for at least part of the early life stages. In addition, the behaviour of young fish while swimming can influence the trajectory, travel speed and destination of dispersing individuals. This study aims to improve the understanding of larval dispersal in three Australian freshwater fish species, by investigating swimming behaviour of fish larvae (swimming activity,

orientation towards the current vector and direction of movement), under a range of different experimental conditions. A racetrack flume, with a gradient of flow velocities, was used to simulate different flow conditions that are present in Australian rivers, hereafter classified as i) fast; ii) moderate; iii) slow, and iv) weir pool scenarios. Here, we will present initial results of the swimming behaviour of two consecutive developmental stages of golden perch (*Macquaria ambigua*). Preliminary results showed that during downstream movements, 76.1% of fish larvae were oriented upstream and performed active swimming movements. During the weir pool scenario, larvae actively selected low-flow zones and remained there during the entire experiment in 100% of trials. These data may significantly contribute to optimize weir operations to maximize flow that is required to maintain larval dispersal.

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Multiple lines of evidence reveal the contribution of non-diadromous recruitment and the importance or reversing lake outflows for supporting endemic fish populations within New Zealand's longest river.

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Otolith microchemistry was used to identify marine- versus freshwater-derived recruitment of three native freshwater fish species that belong to the southern hemisphere Galaxiidae, including two threatened species, in New Zealand's longest river system, the Waikato River. Water chemistry data for trace elements and $^{87}Sr/^{86}Sr$ isotope ratios collected from 5 lentic and 10 lotic water bodies throughout the lower river floodplain, representing potential spawning and rearing sites for these fish, were compared to values obtained by laser ablation inductively coupled mass spectrometry (LA-ICPMS) depth-profiling of Young of the Year fish otoliths sampled from 9 lower river catchment sites. Otolith chemical signatures from the larval rearing period indicated that catchment-scale recruitment for two of the species (*Galaxias argenteus* and *G. fasciatus*) was driven predominantly by non-diadromous recruitment from riverine lakes. Diadromous recruitment appeared to be more common for *G. maculatus*, however, non-diadromous specimens were also identified for the first time from a New Zealand river. Reversing outlet flows linked to river stage appeared be crucial for facilitating dispersal of rheotactic non diadromous larvae out of contributing lakes. This study highlights that some waterbodies can supply a disproportionately large number of recruits to maintain and supply fish populations within a wider riverscape, and that lake outflow management is likely to be crucial to sustain this ecologically-important function.

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Sins of dams over fishes in Albania

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Five years ago the WWF International Freshwater Program published 'the seven sins of dam building', and in light of this general prospective, in this paper we derive a case analyze dedicated to fish species and propose a fish based scheme for assessing the ecological integrity of rivers affected by the hydropower construction. At the European scale the ecological integrity has become a primary objective in monitoring programs of surface waters according to the European Water Framework Directive. For this reason the contribution propose a scheme for assessing the ecological integrity of a certain river (in this case surveyed Lumi i Lumes in Kukes, north east Albania under the support of GEF UNDP office Tirana) and Valbona system through analyzing the effects of hydromorphological intervention, dam construction and habitat structure conversion on fish communities. Access to clean water, food, and electricity as a basic need of Albanian citizens, is widely addressed in different political and strategic documents by Albanian Government, while yet considerable number of people face numerous lacking. In the last six decades rivers have been dammed to meet national needs, but construction of dams increased in a dramatic way in the last twenty five years. Following different source of information until November 2017, there have been identified 432 hydropwerplants in Albania, 361 of which are planned to be developed, 27 are in the constructing process and 44 currently exist. Current situation and investments has not bypassed even valuable protected areas, while the trend will bring very soon to a real collapse native and endemic "specific fish species" and give space to "generalist type of species", aliens and invasive ones. Dozens of species as European eel, Ohrid loach, Skadar loach, Ohrid nasse, Ohrid sprilint, Sturany loach, brown trout, Blalkan barbell, etc., are facing serious threat and appeals for urgent conservation measures.

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Addressing the Connectivity Conundrum—A Vision for Selective Fish Passage

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Dams and barriers interrupt aquatic connections between tributaries and their endpoints (e.g., lakes). Habitat fragmentation by barriers both hinders and facilitates the conflicting management objectives of restoring native species and controlling invasive species (i.e., connectivity conundrum). Selective connectivity, where taxa and potentially individuals can be discriminated on the basis of management or conservation objectives, presents a potential solution to the connectivity conundrum. Historically, efforts to combine fish passage and invasive species control needs have focused on designs targeting a single factor or trait (e.g., leaping ability) to pass desirable and block invasive fishes. Efficacy of these single-factor designs has been mixed, but limited, depending on species, location, and trait targeted. To achieve selective fish passage, tools that build on insights from past successes and failures involving both traditional fish passage science and invasive species management techniques must be integrated and the physical and biological attributes, including behaviours, of target fishes must drive fishway design. The problem of selective fish passage is essentially a problem of sorting an assortment of things. We seek an eco-engineering approach inspired by single-stream recycling, which evolved over the past 25yrs through advances in automation and integration of multiple technologies to separate mixed materials. Using the context of invasive sea lamprey control in the Great Lakes Basin, we outline a conceptual framework of selective connectivity for fish passage while discussing potential obstacles, realistic expectations, and implications to ecosystem restoration.

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Advances in machine vision scanning

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Observation of migrating fish provides critical data required for recovery and management actions. Considerable resource is expended to count, speciate and sort migrating fish at purpose-built viewing facilities within dams and other man-made barriers. Manual operators observe and record the data in real time or post analyze video recordings. However, the data gathered, and decisions made are inherently prone to human error, operator fatigue and fish directional behavior. Turbidity can also exacerbate accuracy - the main reason that prior automation attempts have been largely unproductive. Recent development of machine vision technology used in manufacturing and fruit harvesting operations provides the potential for dramatically improving and simplifying fisheries data collection. In this session we describe an adaptation of the current state of the art to fisheries management. Using a simple false weir configuration, the fish are dewatered, singulated and descend a short, wetted slide. Controlled lighting and high-speed imagery from radially arranged cameras provide multiple photographs of consistent quality for real time processing. Using combinations of machine learning, image recognition and triangulation, the control system computers are able to simultaneously synthesize the needed data and provide signals for sorting actions in less than 2 seconds, with an extremely high degree of accuracy. Fish counts, and individual fork length and girth measurements can already be reliably captured. Currently under development are algorithms that include fin clip detection (for separation of wild and hatchery fish), and some speciation applications – primarily focused on exclusion of invasive species. The automated nature of the system facilitates 24-hour operation with real-time decisions and remote access to image data. Volitional fish passage is not interrupted, fish are not physically handled, spend minimal time de-watered and are efficiently classified allowing for selective passage.

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Machine learning for automated sonar monitoring of outmigrating American eel behavior

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Abundance of American eel (*Anguilla rostrata*) is low compared to historical levels, which makes it a species of management concern. Adult American eel are vulnerable to hydropower turbine mortality during outmigration from inland waters to their spawning ground in the Sargasso Sea. Morphological and behavioral characteristics of the species make it particularly challenging to provide safe downstream passage at hydropower projects. Furthermore, outmigration of adult eels is episodic and protracted, typically extending over a period of several months or more each year. Consequently, design, optimization, and operation of downstream passage facilities that are economical and biologically effective requires knowledge of eel behavior during their downstream migration. Site-specific information requirements include knowledge of when eels are approaching hydropower facilities; pathways of approach and passage; and near-field behavioral responses to facility structures including intakes, guidance structures, and bypasses.

The EPRI Eel Passage Research Center investigated three sonar technologies for observing the abundance and behavior of outmigrating adult eels. Among the three sonar types tested, ARIS multibeam imaging sonar holds the most promise for correctly identifying eels at up to 16-20 meters range. While multi-beam imaging sonar can provide the needed data, the protracted nature of adult eel outmigration and the rate of sonar data production make automated data analysis essential for cost-effective monitoring.

Our ongoing project has the goal of developing machine-based detection of American eel from ARIS sonar data. The project will: (1) extract training and validation data from ARIS sonar records collected at the Iroquois Water Control Dam on the St. Lawrence River, USA/Canada; (2) utilize two-dimensional wavelet transform analysis to filter noise and increase contrast of the sonar images; (3) apply convolutional neural network analysis to classify the images into three types of objects – background, eel, and moving, non-eel target; (4) quantify the performance of the analysis system.

1. EPRI (Electric Power Research Institute). 2017. Assessment of Technologies to Study Downstream Migrating American Eel Approach and Behavior at Iroquois Dam and Beauharnois Power Canal. 3002009406. February 2017.

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Is automatic monitoring accurate enough?

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The need for monitoring fish migration has never been greater. With environmental changes and growing aquaculture production in critical areas many rivers are experiencing new and sometimes not-so welcome guests entering the habitats of local species. Some methods of monitoring fish migration such as trapping puts stress on the fish and some non-contact methods such as video surveillance are quite labour intensive.

The Riverwatcher is the most widely used fish monitoring system in the world. It was produced to minimize disturbance to the fish and to produce valuable results automatically, such as count, size, direction, PIT-Tag and log several environmental factors such as temperature, oxygen and PH and run the results against migration patterns. It creates automatic reports and sends river information to a data cloud where users can access the real-time information from any web based device. But is automatic monitoring adequate?

Only size categorization is fully automatic at the moment. The count is 98% accurate and size measurement is 95% accurate. In rivers with few different species that are in different size and shape this would be adequate. In others where species are similar in size and shape, categorization is a challenge even for the trained eye of experienced scientists. Image recognition software post processing the data can do this to some extent if the image is very good but this is far from accurate at the moment. Until it is, most users would like to identify species and the conditions of the fish themselves by going through the data. The current challenge is to make this process as easy as possible. The future is of course a solution that can identify species and remove unwanted fish in real-time. And that is the Holy Grail our R&D team is working on.

1. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. Baumgartner L, Bettanin M, McPherson J, Jones M, Zampatti B and Beyer K (2010) Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. Industry & Investment NSW - Fisheries Final Report Series No. 116. 47pp.
2. VAKI Riverwatcher Fish Counter Turbidity Trials Report – Fisheries Assessment Team - FAT/10/06 November 2010 Published by: Environment Agency Horizon House, Deanery Road Bristol BS1 5AH Email: enquiries@environmentagency.gov.uk www.environment-agency.gov.uk © Environment Agency 2011
3. Technical, Logistical, and Economic Considerations for the Development and Implementation of a Scottish Salmon Counter Network: Scottish Marine and Freshwater Science Vol 7 No 2 Tuesday, March 22, 2016 ISBN: 9781785449642

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Fish behaviour at navigation locks

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Anthropogenic hydraulic structures such as ship locks, pumping stations and hydropower plants play an important role in navigation, flood control and sustainable energy production. However, despite their obvious benefits, these structures may severely impact the aquatic ecosystem and freshwater fish in particular. More specifically, they create a barrier for upstream and downstream migration of fish species, significantly alter the physical habitat and even might wound fish during passage. In Flanders (Belgium), the Albert Canal connecting the river Scheldt to river Meuse, is an important migration route for two critically endangered species: European eel (Anguilla anguilla) and Atlantic salmon (Salmo salar). Both species have a downstream migrating phase in their lifecycle (respectively silver eels and salmon smolts), during which they are hampered by hydraulic structures. In the coming years, Archimedes screws are to be installed at the navigation lock complexes present in the canal, which can function both as pumping stations and hydropower generators. A first installation is already present at the navigation lock complex of Ham. Before fish mitigation measures can be implemented, it is important to gain understanding of the swimming behaviour of downstream migrating fish around the navigation complex. In this project, we tagged 62 silver eels and 71 salmon smolts with acoustic VPS-transmitters (Vemco Positioning System). This paper presents the resulting swimming tracks in relation to CFD (Computational Fluid Dynamic) simulations of the hydrodynamics around the sluice complex and the pumping/hydropower station.

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CFD modeling of fish passages

Brian Fox[1], john wendelbo[1], Amir Isfahani[1]

1. Flow Science, Santa Fe, New Mexico

The practice of fish passage design and construction offers engineers a truly complex, multi-faceted, and hugely diverse set of design considerations that need to be successfully integrated in order to reliably deliver operational success for fish migration, be it across natural or man-built stream obstacles. Among many other considerations remains one central component that is the detailed understanding of the spatially and temporally varying hydraulic conditions throughout the fishway. This includes locations not only within the fishway but also near the approach and exit of the passage in the context of broader scale hydraulics.

While laboratory testing is an important tool for the investigation into the hydraulic characteristics of these structures, Computational Fluid Dynamics (CFD) tools can also offer additional valuable insights. CFD offers extraordinary versatility to assess stream conditions and fishway passage configuration. Using currently available modelling tools, along with available modern computational power, users are able to obtain high accuracy and confidence in the flow solution.

Commercially available CFD tools can now resolve complex free surface flows in their full three dimensional complexity, giving designers a detailed understanding of the velocity field and other key metrics such a turbulent kinetic energy and temperature. In addition, powerful post-processing techniques allow engineers to clearly render regions of high velocity and turbulence.

This presentation will provide examples of CFD models for three common types of passage configurations: a vertical slot structure, a pool and weir with orifice configuration, and a Denil type example. Beyond the CFD modeling aspect, special emphasis will be given to presenting post-processing methods that will allow designers to readily quantify critical flow metrics and fish pathways.

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A "Fluid" perspective on fish passage design and performance

Aline Cotel[1]

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Turbulence is omnipresent in natural and man-made environments, having a range of impacts on the biota in aquatic systems, from positive to detrimental to neutral. Lessons learned from fish habitats choices and fish swimming are applied to the context of fish passage to look at the importance of turbulence on design and performance. Past studies have shown a strong correlation between fish performance and physical parameters.

While a wide range of parameters (biological and physical) with various length and time scales are important in determining success of fish passage, we will focus on determining physical parameters responsible for the challenges fish encountered in fish passage structures and the type of measurements needed to refine the design of these structures. New developments such as selective fish passage will also be explored.

A deeper understanding of the biology and physics, better numerical models and new sensor technology allow us to dream about new and exciting advances in fishways design and performance evaluation.

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Addressing connectivity constraints to freshwater fish: a European perspective

Peter Gough[1]

1. World Fish Migration Foundation, Usk, MONMOUTHSHIRE, United Kingdom

Connectivity of our rivers for fish is seriously constrained in many parts of the world and in some it is threatening to get worse. The scale of this is a serious problem if the benefits of free-flowing rivers and flourishing fish populations, and the fisheries that depend on them, are to be protected and restored towards optimum levels. The time is right to re-consider priorities and to adopt bold new thinking if we are to have free-flowing rivers in the future.

In Europe this is being addressed through ambitious and challenging statutory environmental policy: the European Union Water Framework Directive. In this presentation the opportunities, obligations and great challenges of securing defined outcomes under the WFD are considered, and are briefly compared with policies with similar ambitions for connectivity in other parts of the world.

Improving connectivity at a strategic level requires better information and better understanding of potential, but also the challenges to securing objectives. The EU funded AMBER project seeks to contribute to this partly through the compilation, for the first time, of a European atlas of barriers. This has already shown that there are many more barriers in European rivers than previously recognised.

Technical fishways have generally been the selected option to deliver connectivity for fish, however there is growing recognition that, depending on the objectives, they have their limitations. They often secure connectivity only for certain fish species and for certain times, whilst hydromorphological impacts remain. They are also expensive and probably unaffordable at the large scale required. There is also growing recognition that true connectivity and the multiple objectives of policy such as the WFD, can really only be addressed though barrier removal, but that is tempered by acknowledgement that in many cases this is not possible.

In the context of sustainability, and a new mantra of the sustainable management of natural resources, the promotion and communication of solutions to connectivity constraints are considered. Moving the whole agenda forward requires vision to tackle inherited constraints, understanding to manage new pressures, and consideration of the value to society of free-flowing rivers.

Lessons learned, for example in Europe and the USA, are valuable - but only if they are communicated well and with passion to enthuse all those with a stake in our rivers and their fish populations.

A new popular approach is required taking account of joined-up thinking across society with better communication. This can be supported though improved connectivity of managers, experts and communicators to ensure learning is maximised, and through better social engagement with initiatives such as the World Fish Migration Day and the International Year of the Salmon.

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Re-thinking the hydropower design process: reversing global trends in fisheries decline requires new approaches and techniques

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Hydropower development in large tropical rivers is rapidly expanding. Despite the efforts to mitigate impacts, fisheries have consistently declined and the question remains whether large hydropower dams can be designed to maintain viable riverine fisheries.

We consider that a fundamental shift in planning and design is needed, at both catchment and site scales. Large hydropower projects follow a similar development sequence of: i) proposal and concept design, with optimised energy estimate; ii) business case; iii) detailed concept; iv) impact identification; and v) mitigation. Fish passage is frequently identified as a mitigation and is developed in the last step. The project sequence leaves designers (engineers and biologists) to compromised solutions because: the dam site is chosen; the budget is set; the dam design has mostly been done; and fixed energy estimates limit the amount of water that can be used for fish passage.

We recommend integrating impacts and mitigation in the first step *before* the energy estimate and business case. At the catchment scale this enables a more strategic evaluation of dam sites based on ecology and habitats, especially the spatial scale of cyclic migrations and flowing water (lotic) habitats required for spawning and larval drift. At the site scale, it enables a major rethink of fish passage. Upstream passage has a record of very poor performance at large tropical dam sites, but we consider that it is potentially solvable with research, conservative designs and early cooperation of planners, biologists and engineers. Downstream passage, however, is rarely considered and major knowledge gaps remain – particularly larval drift, and design of screens and turbines. We present an alternative to mainstem thinking on dam design, and a practical way forward for developers and fisheries managers to consider.

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Avoiding fish passage impacts through basin-wide infrastructure project planning

Alison Bowden

River basins that are, or will be, influenced by hydropower support a range of important environmental and social resources, including more than half of all freshwater fish species on earth and at least 6 million tons of fish harvested annually (Opperman et al. 2017). Given the global influence of hydropower, fish passage through in-stream infrastructure is critical for access to seasonal habitats and for meta-population dynamics required to maintain riverine fish populations, and other species dependent on them. Fish passage structures, at best, provide for successful movement of a subset of fish species, and generally do not allow 100% passage of any species. Given the lack of understanding of the portion of species and of individuals of each species necessary to maintain fish populations and the ecosystem services they support, the adequacy of most fish passage structures, may be inadequate for sustainability. While the focus on better fish passage design is necessary to improve passage for existing infrastructure projects, a far better approach is to avoid critical sites for new projects through planning at a basin-wide scale and identifying alternative sites that collectively avoid impacts to fish movement while achieving energy and water resource management goals. We will present a framework called Hydropower by Design, which evaluates scenarios of potential future project sites and flow management and the expected impacts to environmental, social, and economic attributes, including those dependent on fish passage. We will show examples to illustrate how energy and water resource management goals can be achieved while minimizing or avoiding impacts to fish. While minimizing impacts does not ensure sustainability for fish species and populations, the potential outcomes can greatly exceed fish passage obtained through fish passage structures at individual project sites with high impact to fish movement, and certainly additive impacts among multiple project sites in critical areas.

1. Opperman, J., J. Hartmann, J. Raepple, et al. 2017. The Power of Rivers: A Business Case. The Nature Conservancy: Washington, D.C.

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A perspective on the need for assessing the fish transfer risk associated with pumped hydropower schemes

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3. NSW Department of Primary Industries, Nelson Bay

4. NSW Department of Primary Industries, Batemans Bay

5. Pacific Northwest National Laboratory, Richland, Washington, USA

Pumped hydropower is becoming a more popular form of power generation in many countries. A main benefit of pumped hydropower is that it can take advantage of existing impoundments and continuously cycle water between the upper and lower impoundment. However, in situations where pumped hydro leads to cross-catchment transfers of water, operation of the station can introduce the risk of unintended biotic transfers between the headwater and tailrace; especially for fish. For instance, fish that are present in tailwater reaches, and not upstream may introduce a risk to upstream populations. The degree of potential impact would be dependent on the (a) population ecology of the head and tailwater fisheries; (b) operation and design of the turbine and pumping scheme; (c) habitat and thermal regime of the two reservoirs; and (d) whether mitigation options are incorporated into the system design. Snowy 2.0 — a proposed 2000 MW pumped hydropower facility in south-eastern Australia — is a major national infrastructure project which will augment Snowy Hydro Limited's existing hydropower output. It is possible that operation of the pumped hydropower station may introduce a risk of invasive species transfer from the tailrace to the headwater reservoir. A multi-factor risk assessment was performed to assess the transfer likelihood. It was quickly evident that limited information on the ability of fish to withstand conditions that are likely through the development, and the lack of existing similar developments, made it difficult to accurately estimate the likely risk of successful fish transfer using desktop investigations alone. As a result, laboratory and field experiments were proposed to fill any remaining pertinent risk-related knowledge gaps with empirically-based evidence.

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River Connectivity: Addressing the exclusion, collection or guidance of fish, debris, algae, and water temperature at dams and power plants in order to provide enhanced river connectivity.

Andy Peters[1]

1. Pacific Netting Products, Kingston, WA, United States

Objective:

We will review the engineering, technology, and methodology, research, and lessons learned of structures and systems (usually placed in the forebay) that are used to

1. a) guild fish or debris to a particular point
2. b) exclude fish from moving through a dam or into a cooling water intake,
3. c) segregate reservoir waters to modify water temperatures or exclude water with higher blue-green algae concentrations (Microcystis aeruginosa, Aphanizomenon flosaquae, and chlorophyll-a) from moving downstream of a dam or structure.

The discussion will include a) examples research by Toby Kock (USGS) in comparison efficiency of fish passage structures at facilities including Puget Sound Energy (Baker Lake), Tacoma Power (Cushman Dam), Pacific Corp's (Swift Dam) and PGE (North Fork Clackamas and Round Butte). b) examples of downstream exclusion to prevent invasive species (Colorado Elkhead Lake) or preserve valuable species at Ameren UE (Bagnell Dam) and c) discussion of materials and methods to control water temperature and algae blooms at PacifiCorp's Iron Gate dam. ,.

Value:

This talk should lead to knowledge exchange and discussion on the advancement of materials and technology that are critical to fish passage solutions and the implications for operations, maintenance, and community affected by those decisions.

It should inform and instigate discussions between researchers, educators, practitioners, biologist, engineers, and regulators from around the world on unique approaches to develop and implement cost-effective, environmentally sound, and robust methods to collect, protect or restore migratory fishes and aquatic species; prevent impingement and entrainment of threatened or endangered species, and address migration of invasive species of fish.

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Fish friendliness of archimedes screw turbines: quantified by forced fish passage (Albert channel, Belgium)

Ine Pauwels[1], **Raf Baeyens**[1], **Ans Mouton**[1], **Jenna Vergeynst**[2], **Johan Coeck**[1]

1. Research Institute for Nature and Forest, Brussels, VLAAMS-BRABANT, Belgium

2. BIOMATH - Dept. of Mathematical Modelling, Statistics and Bioinformatics, Faculty of Bioscience Engineering, Ghent University, Ghent, Oost-Vlaanderen, Belgium

Hydro-power stations serve the essential need for power generation worldwide. However, they may seriously impact the aquatic ecosystem. Specifically fish that pass such structures may be killed or severely injured. Therefore scientists and engineers seek for high capacity pump and turbine types that minimize the physical impact on passing fish. For instance, turbines with Archimedes screws are assumed to be more fish friendly than widely used propeller type pumps and turbines. In the Albert Channel in Belgium, the first Archimedes screw hydropower plant was built, and more are to follow. The hydropower plant consists of three open Archimedes screws with a 10 m head and maximum capacity of 5 $m^3.s^{-1}$ each. In this study the impact of the Archimedes screws was assessed at three different modes of operation (3, 4 and 5 $m^3.s^{-1}$). To evaluate the impact, mortality and injury of 900 European eel (*Anguilla anguilla*), 900 roach (*Rutilus rutilus*), 900 bream (*Abramis abramis*) and 900 rainbow trout (*Oncorhynchus mykiss*) was quantified after forced passage. Injury was defined as 'heavily injured' (cuttings, bruises, bleeding, swelling or scale loss > 25%), 'slightly injured' (fin damage or scale loss < 25%) or 'not injured'. In general, around one third of the fish died and 10 % got injured due to turbine passage. Of the injured fish more than half were heavily injured. Nearly all dead or heavily injured fish showed bruises and some were decapitated. Furthermore, 10% of the individuals that survived the turbine passage, died within one week due to injuries. Although Archimedes screws are assumed to be fish friendly, this study indicates

considerable fish mortality, mainly caused by fish being squeezed between the screw and its housing as indicated by the decapitations and bruises. Adaptations to the screws might further improve the fish friendliness of Archimedes screw hydropower plants.

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Status of anadromous fish reintroduction and passage investigations at large dams and reservoirs in California

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Because major dams exist on most rivers feeding water into the California Central Valley, this ecoregion contains many projects for determining the feasibility and efficacy of re-introducing salmon and steelhead trout above rim dams that may aid in recovery of these threatened and endangered species. The California State Wildlife Action Plan 2015 update has an anadromous fish conservation strategy to conduct rim dam re-introduction pilot projects on the Yuba and Sacramento rivers and evaluate efficacy of expanding rearing and spawning habitats for recovery. In addition, the 2016 update of the California Water Action Plan states that the Department of Fish and Wildlife, in coordination with state and federal resource agencies, will develop an evaluation and feasibility process for addressing fish passage at California's rim dams and develop rim dam solution plans for the most feasible locations. This presentation includes updates for implementing these strategies by way of describing current results from a set of investigations and studies at specific projects, including the Yuba and Sacramento rivers. The presentation will focus on a very important, and a more limiting biological and engineering challenge for large dams and reservoirs in California: downstream juvenile fish passage and connectivity.

1. California Department of Fish and Wildlife (CDFW). 2015. California State Wildlife Action Plan, 2015 Update: A Conservation Legacy for Californians. Edited by Armand G. Gonzales and Junko Hoshi, PhD.
2. California Natural Resources Agency. 2016. California Water Action Plan 2016 Update http://resources.ca.gov/california_water_action_plan/

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Downstream passage of potamodromous fish at small hydropower plants in Austrian rivers

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The downstream passage of various fish species was assessed at small scale hydropower plants in Austrian rivers covering a variety of river types. Opposed to the downstream migration behavior of anadromous fish, knowledge is scarce regarding the biological, behavioral and technical requirements needed for future planning and development of management strategies for downstream migration of potamodromous species. The project tries to (1) quantify downstream fish passage at hydropower plants including turbine mortality, (2) investigate the efficiency of newly built bypass systems, (3) assess potential preferences for certain migrations routes and (4) define criteria for the minimization of harmful effects during downstream passage. Fish upstream of the hydropower facilities were tagged individually using PIT tags and fixed antenna sets at various migration corridors were set up to study the downstream passage. At a species rich potamal river, turbine mortality was quantified at <23% for fish <160 mm TL. Although about 80% of river runoff passes the hydropower turbine, only 44% of migrating fish use this corridor. The fish migration facility and a residual flow bypass both located at the beginning of the irrigation channel showed much higher efficiency for downstream migration. 54% of fish passed these corridors (using only 14% of total discharge). A downstream migration bypass next to the turbine was used by only 5% of migrating fish. The performance of the built bypass systems was generally poor for migrating fish. We conclude that efficient and harmless downstream migration may happen at any corridor with permanent discharge and that the location of the upstream entrances is crucial for the efficiency. The frequent use of migration facilities built for upstream migration indicates a high potential for future planning scenarios. Efficient protection from turbine passage seems to be the highest priority to minimize mortality related to downstream passage at hydropower plants.

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Seasonal and diurnal variation of downstream fish movement at four small-scale hydropower plants

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Hydropower plant structures and other obstacles hinder the movement and migration of fishes, impairing their life cycles. Additionally, downstream moving fish are often at risk of being injured during turbine passage. To improve hydropower production towards more fish-friendly techniques and management, knowledge on natural patterns of fish downstream movement is necessary. So far, migration behavior of long-distance migrators such as eel or salmon has been well studied, but little is known about seasonal and diurnal movement patterns of non-migratory species or medium-distance migrators. In this study, fish movement patterns in four different impounded rivers were assessed and compared with the fish community composition in the headwater of the hydropower plants. There were strong differences between the fish community composition inhabiting the headwater and the fish detected in downstream passage. In each study river, the downstream moving fish community composition differed significantly between spring and autumn. On average, significantly more fish were caught per hour during the night (2.9

fish/h) than during the day (1.3 fish/h). In all study rivers, *Pseudorasbora parva*, *Thymallus thymallus*, *Sander lucioperca* and *Cottus gobio* mostly moved downstream during the night. During the day, the most frequent downstream moving fish were *Rutilus rutilus*, *Alburnoides bipunctatus* and *Alburnus alburnus*. There was a significant positive relationship between the number of downstream moving specimens and turbidity, water temperature and the discharge of the four investigated study rivers. Following the strong differences in seasonal and diurnal fish movement patterns, fish damage can be strongly reduced with adaptive turbine and corridor management.

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Potential application of the fish-friendly Alden turbine at large projects and as a replacement unit to improve fish survival at hydropower dams

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The Alden fish-friendly turbine was originally designed for new hydro projects or powerhouse additions with heads between about 6 and 30 m and unit flow of about 15 to 70 cms. More recently, the Alden turbine has been considered for application at large dams with heads of about 30 m or greater and turbine flows of more than 200 cms. A new retrofit design of the Alden turbine has also been developed to replace a Francis runner at a small hydro project in the USA. Large dam applications were considered on a conceptual level and indicated that the Alden turbine has potential to be installed at existing and new projects on large river systems like the Columbia River in the USA and Mekong River in Southeast Asia. Efficiencies of these large units are expected to be comparable to more conventional turbine designs (e.g., Kaplan and Francis), whereas survival rates are expected to be considerably higher (greater than 99% for fish with lengths up to 425 mm). Compared to the original Alden design, the re-design was developed to increase turbine efficiency and generation while providing a safe passage route for downstream migrating fish at a low head dam. It was demonstrated that the re-design would increase average annual energy production by 4.3% based on current flow allocations for generation, downstream passage routes, and bypass reach habitat. Survival of fish exposed to blade strike and low pressures is predicted to increase dramatically, from 96.0% to 99.8% for 100-mm fish and from 83.0% to 99.8% for 300 mm fish. The results of the conceptual analysis for large dams and the re-design for a small hydro project demonstrate the ability to apply the Alden turbine at a wide range of projects to provide a safe passage route for downstream migrants without compromising generation output.

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The impact of pumping station entrainment on silver European eels and downstream passage at pumping stations with a gravity bypass channel

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The downstream passage of European eels (*Anguilla anguilla*) through pumping stations is currently a concern in Europe. The EC Eel Regulation (1100/2007) established measures for eel protection from human mediated activities and is enacted through the Eels Regulations (England and Wales) 2009 Statutory Instrument, including requirements for eel passage and states water intakes abstracting greater than 20 m^3 a day should be screened. There are 913 pumping stations in England, and yet knowledge of eel damage and mortality during pumping station operation is limited to anecdotal reports. Further, approximately a third of pumping stations in England have a gravity bypass channel but it is currently unknown whether eels pass through them during their downstream migration.

Seven pumps of varying size, design and specification were investigated and the greatest level of mortality was found for the smallest pump with the most blades on the impeller and the highest rotation speed. Eels entrained at sites with 'fish-friendly' axial flow pumps also died whereas larger mixed flow pumps that rotated at a slower speed did not kill eels. Key results will be presented, including proportion of immediate and delayed mortality, and the types of internal and external injuries observed. The catchment-wide movements and fine-scale behaviour of downstream migrating silver eels were studied upstream of two pumping stations with a gravity bypass channel using acoustic telemetry. Eels were delayed and performed extensive searching behaviour, which appeared to increase predation, although findings varied between study years with differing flow regimes. Further, tagged eels were detected passing through pumps despite attempts to alter pump operating regimes to maximise the amount of water passing through gravity bypass. Discussion of how the findings are currently being used to help identify the most effective remediation measures for the safe downstream passage of eels through pumping station will be presented.

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Honouring the past and creating a future

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The Thomson River, a 210 km river in the south east of Victoria, Australia hosts a large variety of native fish species including IUCN Red List species. It flows from the Alpine region in Victoria to the Ramsar Listed Gippsland Lakes.

In 1911 a river diversion tunnel was constructed in the rugged mountainous region of the river, to allow easy access to alluvial gold. The tunnel was dug into the bottom of a deep pool in the river, draining the river for a 1 km section between the tunnel entrance and exit. The lack of flow through this section of river and the velocity of flow through the tunnel has meant fish access to 40% of the river has been blocked for over 100 years. The site is popular with tourists visiting the local historic mining towns and provides a spectacular sight of the river gushing out the side of a hill.

Reconnecting the river is a major technical and community engagement challenge. The solution needs to provide fish passage but also protect the heritage values of the site (which includes the tunnel and the river flowing through it), the natural landscape, and recreational values. Traditional hard engineered solutions are impractical because of these factors and the site's remote location and rugged conditions.

This paper will provide an overview of the community engagement process and key learnings. It will also provide detail on the design of the highly innovative low-flow fishway that protects the natural, heritage and recreational values of the site.

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The corangamite fishway program fish passage in the coastal streams of the otway coast and barwon basins

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The Corangamite Catchment Management Authority (CCMA), has had an active fish passage reinstatement program for many years, as part of the Victorian Government's Great Ocean Road Estuaries Restoration Project.

The Corangamite Fishway Program involved detailed planning, design, and construction, as well as fishway performance monitoring.

Fish passage prioritisation, planning and works focussed providing connectivity for small bodied native fish species of the coastal streams of the Otway Coast and Barwon River Basins. Many of the fish species targeted were migratory and listed as threatened including the Australian Grayling and Yarra Pygmy Perch. Types of fishway works have included the construction of various rock ramp fishways, different forms of barrier removal and the construction of precast vertical slot and cone fishways. Construction methods used by the CCMA have resulted in low cost and effective fishways via the use of suitable local materials and contractors and minimising construction times by completing as much pre-work as possible off site.

Performance monitoring of fishways has included formal fish surveys pre and post works, videography and measuring fishway hydraulics. Recent performance monitoring of fishways has seen the return of some threatened species to river systems that had not previous been recorded since the 1980's.

Future planned works include the continued delivery of the Otway Coast and Barwon Basin Fish Passage Plans, as well as large scale works associated with restoring connectivity and improving water regulation at the Lower Barwon River Wetlands Ramsar sites.

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Fish Friendly Stream Gauging Stations

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Stream gauging data is essential for managing our water resources and for flood warning purposes. Stream gauging stations vary in function and design, but most historic stream gauges present a hydraulic and/or physical barrier to fish, adversely impacting on movement. The process of determining what should happen to a historic stream gauge from an ecological and managerial stand point is underpinned by a few key pieces of information including, species present, stream hydrology, location within the catchment, stream gauge technology present, stakeholder requirements, and presence of other instream barriers. The Fish Friendly Stream Gauging Station Program is reviewing and prioritising stream gauging sites across Victoria to assess each for their relevance, integrity, functionality, and fish friendliness. Larger structures located lower in the catchments, those most in need of repair, and those used for flood warning purposes are being prioritised for inspection and works (i.e. removal, replacement, fishway construction). A total of 12 sites have been inspected as part of an initial scoping investigation and we discuss several of the outcomes including fishway construction, stream gauge control replacement, stream gauge control removal, and the use of modern gauging technology. Outcomes for native fish and stakeholders of stream gauging stations will improve substantially if contemporary stream gauging methods and fishway designs are incorporated into Victoria's stream gauging stations.

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Gauging weir retrofit using cylindrical clusters for upstream fish passage of non-salmonids

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Gauging weirs act as barriers to longitudinal river connectivity, often preventing fish from moving between different habitats for spawning and feeding, which can lead to population decline. Although many fish passage designs exist, they are often more effective for salmonid compared to non-salmonid species. A new fish passage design has been developed, comprising of a staggered array of cylindrical clusters, which when mounted onto the downstream face of gauging weirs, improves fish passage whilst not effecting gauging or accumulating debris. Flume experiments have been undertaken to determine the influence of varying fish pass geometry (cluster diameter and spacing) which influences the wake width and length created by the clusters. Six different cluster configurations were tested (combination of 0.03, 0.05 and 0.07m diameter clusters and 0.1 and 0.15m spacings) where fish movement through the pass was monitored using video footage and their positions tracked using LoggerPro. This presentation will discuss the passage efficiency of this fish pass and space use of fish when swimming through a staggered array of cylindrical clusters, the relationship between passage and wake geometry and the implications of this design for future fish passage research.

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Use of built barriers in New Zealand streams as a conservation management tool

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New Zealand has 77 species of freshwater fish. Fifty-seven of them are native, most are endemic and 72% are threatened with, at risk of extinction or extinct; a higher proportion than almost any other country in the world. While providing fish passage is advantageous for most fish, some of New Zealand's native freshwater fish, other instream species and habitats cannot cope and/or compete with some invasive species. In these situations, physical barriers, which impede or prevent upstream and/or downstream movement of unwanted fish species, can help protect key locations by keeping invasive species out and providing safe refuge areas. Prior to retaining or installing a new fish passage barrier, consideration should be given to what species and habitats are present, their distribution and extent, their conservation status, habitat preferences, timing of migration and spawning, life history and possible impacts of providing or impeding fish passage. Natural waterfalls do protect a few of these key native locations, however under changing climates and flows these key native fish hotspots are also being compromised and invasive species are impacting on a number of these populations. Fish removal and barrier installation has been successfully undertaken in a number of key locations in New Zealand to remove invasive species and prevent reinvasion and has resulted in good recovery of native fish species. An overview of the use of physical built barriers in small streams as a conservation management tool; focusing on lessons learnt from invasive species removal, important design criteria for structures to exclude invasive species, and monitoring and maintenance considerations will be presented.

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Ecological perspectives on developing methods for selective passage of fish species across anthropogenic barriers

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Disruption of movement patterns is a pervasive effect of humans on animal populations. In many terrestrial and aquatic circumstances there is increasingly tension between the need to simultaneously allow passage of some species while blocking the passage of other species. We explore the ecological basis for developing selective passage methods with a focus on riverine fishes, where the need to restrict movements of invasive species conflicts with the need to allow passage of species of commercial, recreational, or conservation concern. We develop a trait-based framework for selective fish passage based on understanding of the types of movements displayed by fishes and the role of filters in determining the spatial distributions of fishes. We then synthesize information on trait-based mechanisms to create a multi-dimensional niche space based on attributes such as physical capabilities, body morphology, sensory capabilities, behavior, and movement phenology. Following this, we review how these mechanisms have been applied to achieve selective fish passage. To date, trap-and-sort or capture-translocation efforts provide the best options for movement filters that are completely species selective, but these methods are hampered by the continual and high cost of manual sorting. Other less effective methods of selective passage risk collateral damage in the form of lower or higher than desired levels of passage. Fruitful areas for future work include using combinations of ecological and behavioral traits to passively segregate species; using taxon-specific chemical cues in a push-pull arrangement to direct unwanted species away from passageways and into physical or ecological traps; and developing automated sorting mechanisms based on fish recognition systems. The trait-based approach proposed for fishes could serve as a template for selective passage in other ecological circumstances.

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Control of globally invasive common carp: a 10 year commercial trial of the Williams' carp separation cage in a Murray River fishway.

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Common carp *Cyprinus carpio*, are a highly migratory pest fish in Australia, North America, New Zealand and parts of Europe. Fishways built to facilitate native fish passage also benefit invasive carp. The Williams' cage was developed to separate carp from native fish as they pass through fishways by exploiting their unique jumping behaviour. We report on a 10-year commercial application in a fishway on the lower Murray River (SE Australia) where a high biomass of carp resides.

Between November 2007 and April 2017, the automated Williams' cage was installed and operated at Lock 1 by a collaborative team of river managers, weir keepers, commercial fishers and researchers. To date, over 700 tonnes of adult carp, (approx. 350,000 fish) have been removed at a maximum rate of 5 tonnes per day. The income generated from the sale of the fish has far exceeded set up costs. Catches and separation efficiencies were highest in spring (Austral) when fish were migrating to spawn. During the cage design phase, refinements helped reduce bycatch of non-target native fish to practically zero (0.03%) and informed future designs, application and operation.

The Williams' cage has now successfully moved from an experimental idea to full commercial viability and could play a key role in controlling the dispersal and abundance of carp where high abundances preside and collaborative management alliances can be formed.

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Weir going to build a wall

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Barriers to Protect Threatened Fishes

Whilst improving fish passage is valuable and often essential tool to rehabilitating native fish populations, there can also be the unintended consequence of facilitating the passage and spread of undesirable alien fish that are known to have devastating impacts on certain threatened fish species. Similarly the blockage of fish passage to limit or stop the spread of alien fish into new habitats can be a useful tool in the protection of remnant populations of vulnerable threatened native fish species.

We provide three separate case studies of where barriers, both constructed and natural have been used to protect remnant populations of two threatened fish species in NSW, from recent invasions of alien fish species, a fourth case study will be included, where we have designed and propose to construct a significant fish passage barrier, then remove alien fish upstream of that barrier with the aim of reinstating and expanding a population of threatened native fish.

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NSW Fish Passage Strategy – a 20 year vision to restore waterway connectivity.

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NSW legislation recognises the environmental importance of fish passage, and by association its social and economic significance. However, the legislation is not underpinned by a strategic framework and strategy that ensures that the intent of the legislation is met. Rather than being driven by ecological priorities, the legislation is instead linked to asset refurbishment schedules to trigger fish passage remediation. In recognition of this 'disconnect', the NSW Ministerial Taskforce on Fish Passage was established in 2017 to develop a strategic, coordinated approach to fish passage remediation. The Taskforce has subsequently developed the NSW Fish Passage Strategy, which focuses upon improving waterway connectivity at priority weirs and regulators across NSW over a 20 year timeframe.

The key elements of the proposed Strategy are (1) improved arrangements for the delivery and oversight of fish passage in NSW, (2) the identification of 160 high priority fish barrier sites and their targeted remediation in order to re-establish catchment-scale fish migration along key waterways, and (3) a strategic approach to widening the funding base for fish passage related works through market-based instruments at both the state and federal level.

The aim of this presentation is to detail how the Strategy addresses current limitations to deliver a prudent, cost-effective approach to restoring waterway connectivity. This includes updating policy and guidelines that clarify minimum fishway design requirements, as well as the responsibilities of asset owners to operate and maintain fishways. Moreover, directed research into fishway optimisation and novel technologies will underpin Strategy implementation, along with post-construction monitoring to validate the success of completed projects. A revised funding model will also be developed, underpinned by a Business Case Assessment, to optimise funding opportunities throughout the 20 year Strategy implementation period.

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Connectivity for future freshwater conservation – biophysical and institutional issues

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The demise of freshwater ecosystems globally has been widely documented and represented in global assessments and intergovernmental processes, yet it still occurs. The most recent evidence comes from global assessments by the

Intergovernmental Panel for Biodiversity and Ecosystem Services and the Ramsar Convention on Wetlands. The issues of connectivity across scales, including within streams and between streams and floodplains and across catchments and further across landscapes and continents has been well exposed through such processes. At the same time the responses have often covered the need to reconnect these systems, to manage across landscapes, and to do this through multiple sectors. In considering the protection of freshwater ecosystems a number of principles have also been identified and relate to:

- the intimate links that exist between freshwater ecosystems and surrounding catchments
- the importance of the water regime for managing freshwater ecosystems
- the hydrological, biogeochemical and ecological connectivity that occurs within and between freshwater ecosystems
- the protection of hot spots of native freshwater biodiversity, endemism and endangered species, and
- the maintenance of ecological resilience in freshwater ecosystems of the present and in the future.

These issues are not new, and given the continuing declines, we can conclude that our institutional arrangements have been insufficient to stem the problems which underpin the abovementioned principles. Given this situation and adding a further layer associated with global change and the stretching of planetary boundaries it is proposed that a new paradigm is needed and one that may not be met by current institutional connections. It may also break the connection between the ecosystems that we had and those we will have. Thus, our future freshwater ecosystems may be disconnected from those of the past. And our institutions definitely should be, after all haven't they failed?

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Region-wide expansion of the Salmon Superhighway, USDA Forest Service prioritization of fish passage barriers in the Pacific Northwest Region of the US

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The USDA Forest Service is a member of the Salmon Superhighway partnership, restoring fish passage in the Tillamook and Nestucca drainages on the Pacific Coast of Oregon. Over the last 5 years, the partnership used the Anadromous Fish Passage Optimization Tool (APASS) (O'Hanley 2011) to develop a portfolio of prioritized passage projects, restoring access to 90% of historical fish habitat in those drainages at a fraction of the cost of restoring all access. With 3,690 anthropogenic fish migration barriers remaining to be treated on National Forest System Lands in Oregon and Washington and newly completed fish migration barrier and fish distribution databases, the agency is applying the Salmon Superhighway prioritization approach region-wide. This presentation updates the progress of the Salmon Superhighway partnership, recounts the creation of the regional fish migration barrier and fish distribution databases, and describes how all three were used to prioritize treatment of the remaining fish migration barriers throughout the Pacific Northwest Region of the USDA Forest Service.

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Improving practical fishway design through a multi-disciplinary approach

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The selection of an effective fishway arrangement is dictated by any number of influences at any one site. This includes (but is not limited to) the existing fish passage barrier characteristics and function, vehicle and plant (construction) access, cultural heritage, environmental assets, geomorphology (e.g. stability), fish passage requirements (e.g. target fish species hydraulic requirements), surrounding land uses, construction costs and stakeholder objectives. On this basis, a number of key technical specialists are generally required to contribute to the selection of a preferred fishway design arrangement and detailed design.

This paper presents several case studies of fishway design projects in North-East Victoria undertaken in partnership with North East Catchment Management Authority (NECMA) and Arthur Rylah Institute (ARI). Four fishways have been designed over the past 18 months and are now in varying stages of design and construction. Three of the case studies involved the design of rock ramps/chutes while one involved the design of a vertical slot fishway. Each location posed specific design challenges which were able to be overcome through the use of innovative fishway design, detailed modelling and stakeholder engagement. Key outcomes of these projects are that fish passage will be markedly improved across a large range of flow conditions in the Ovens River and Snowy Creeks through the use of innovative multi-disciplinary approach. The collaborative approach has also ensured that the existing values and functions of the fishway site and surrounds are maintained.

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Sea to hume fish passage task force

Jim M Barrett[1]

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In 2001, the Murray-Darling Basin Commission (MDBC) initiated a program to improve fish passage along 2225km of the River Murray, from the sea to Hume Dam, including the construction of 15 new fishways. The three disciplines of biology, hydraulics and engineering are inherently linked in fishway design. As such, a Fish Passage Taskforce (FPTF) was established to recommend fishway design criteria and comprised a team of scientists, engineers, managers and river operators. In order to complement the FPTF, a team of freshwater fish scientists from three states of the Basin (NSW, Victoria, South Australia) was also created to quantitatively assess fishway performance and any associated longer-term benefits from improved fish passage.

The rigour instilled in the design process by the integration of the three disciplines was crucial to the overall success of the program. The FPTF has provided a good model for interdisciplinary cooperation and integration of ideas in relation to the conceptual design, construction and monitoring of fishways, setting objectives according to the characteristics of native fish species. An adaptive management approach to fishway design was taken, thus leading to constant design improvements, optimisation, and improved cost-effectiveness as the construction program progressed. The program had a strategic, holistic view and a strong ecological basis, recognising that fish migration can occur over hundreds, and occasionally thousands, of kilometres.

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Fish injury and mortality in pumping stations – a comparison of conventional and fish-friendly pumps

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Pumping of water during floods from hinterland's drainage systems into the main river poses a health risk to fishes. Herein, we investigated the effects of pump passages on fish health of four conventional and one ´fish-friendly´ pump at the Danube River in Germany. Conventional and 'fish-friendly' pump types caused external fish injuries leading to direct and delayed mortality. Immediate mortality and injury intensity increased with revolution per minute (rpm) and differed significantly between pump types. At the ´fish-friendly' Pentair pump, higher numbers of injuries resulting from blind force (e.g. haemorrhages, scale loss and fin tears) were detected than at the conventional pumps potentially due to the differences in blade design. The Köster pump at low rpm proved to be similar 'fish-friendly' as the special-developed 'fish-friendly' Pentair pump due to the low amount of sucked-in fishes. As measures to reduce the damaging potential for fishes, the pumps should run on low rpm as often as possible. This lowers the collision risks with machinery parts and hence the mortality rate as well as suction effects, which can be caused by high rpm. After long periods of anergic state, pumps should generally run on low rpm before adapting to higher rates.

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Evaluation of external and internal fish injury caused by hydropower plants using field-based methods and x-ray technology

Melanie Mueller, Joachim Pander, Juergen Geist

Knowledge on the extent and mechanisms of fish damage caused by hydropower facilities, resulting in direct mortality and delayed effects, is important for their ecological improvement. Herein, we propose a novel field-based method to asses externally visible fish injury combined with a rapid screening of internal injuries using x-ray technology. External injury assessment includes vitality and 4 general health criteria, as well as 9 lethal and sub-lethal injury types across 18 body parts. Additionally, fish are screened for 36 internal injuries using the x-ray protocol. The method was validated using 3.087 specimens from four species of hatchery-reared fish as well as 2.262 specimens from 32 species of wild fish. The external injury protocol allowed a detailed and systematic evaluation of different fish injury types in the field. Injuries related to handling and to contact with different parts of the hydropower structure could be clearly distinguished applying multivariate statistics. The rapid x-ray screening for internal injuries successfully detected injuries of the bony structures, the swim bladder, emboli and haemorrhages and the data could be used to explain delayed mortality within 96h after turbine passage. This approach allows quantifying and comparing external and internal fish injuries across sites, and can help to identify the technologies and operational procedures which minimize harm to fish.

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Understanding migration behaviour to guide the development of downstream passage options for shortfinned eels

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There is a significant body of evidence that global stocks of freshwater eel (family Anguillidae) are in decline. Of the 19 known species or subspecies of freshwater eel, four are listed as threatened on the IUCN Redlist. It is likely that the often arduous catadromous migration requirement of anguillid eels contributes to the vulnerability of this family to anthropogenic disturbances.

Short finned eels (*Anguilla australis*) are an important component of south eastern Australia's native freshwater fish fauna. While they are adept at negotiating a wide range of natural instream barriers, large dams and weirs impact upon both upstream and downstream migration. Trevallyn dam is located in the downstream reaches of Tasmania's largest water catchment, and blocks the migratory path of short finned eels between the Tamar estuary and the South Esk River. Upstream migration of juvenile eels

past the dam is facilitated via an elver ladder and a trap and transfer program. However, the dam spills infrequently and downstream migrating eels have little option but to pass through Trevallyn power station to reach the estuary.

Hydro Tasmania deployed an adaptive resolution imaging sonar (ARIS) on the intake of Trevallyn power station and implanted downstream migrating eels with Juvenile Salmon Acoustic Telemetry system (JSATS) tags to obtain information on migrating eel behaviour around the dam, power station intake, and tailrace.

The study showed that there is significant potential to explore the development of downstream passage facilitation at Trevallyn, as eels showed aversion to entering the power station intake, and did not necessarily enter it upon their initial encounter. Hydro Tasmania is currently designing a downstream bypass system that aims to safely pass eels downstream by capitalising on the results of the migration behaviour study.

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Improving fish ladder efficiency by accurately predicting and observing fish movements: results, challenges and opportunities of the case near the hydropower plant of Altusried (Germany)

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Despite technical innovations in hydropower being limited, the potential for hydropower development in the EU is maintains a prominent position amongst renewables. However, it affects the essential characteristics of aquatic habitats supporting fishes' biological functions, such as reproduction by blocking or delaying fish spawning migration. Hence, hydropower industry address fish migration issues by fish passage facilities, amongst others. To ensure great effectiveness of these measures, ecological knowledge and decision support tools are essential. In this study we customize a modelling tool to enhance the efficiency of fish passes by assessing and modelling the attraction flow and upstream fish migration. Specifically, the agent-based model is developed based on detailed fish tracks observed in the turbulent outflow area around 200 m downstream of a fish ladder bypassing one of 5 hydropower plants on the river Iller. The 2-dimensional fish tracks were collected using the VEMCO positioning system with HR2 180 kHz receivers and fish tags transmitting an unique acoustic signal every second. Beside detailed fish movements in the head stream, fish presence and the catch efficiency of the temporary catch construction in the fish ladder was assessed. Specifically, movements of 25 grayling (*Thymallus thymallus*) and 25 barbel (*Barbus barbus*) were accurately observed. Tagging of fish caught in the head stream, as well as fish caught in the fish ladder allowed to assess potential effects of learning behaviour on the efficiency of finding the fish ladder entrance. The study is rare in its kind, because high frequency acoustic telemetry allowed positioning tagged fish every 1 to 3 meters in a turbulent area direct downstream of a hydropower plant. This presentation will not only focus on the observed fish movements, and fish ladder efficiency, but also on the experiences and challenges of 2-dimensional fish tracking in this environment and the link with ecohydraulic modelling.

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Fish ladders at small hydropower plants and potential contribution to downstream passage of eggs and larvae

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Fish passage can potentially enhance downstream fish passage of larvae and eggs at small hydropower plants (SHP's). To evaluate this hypothesis, two SHP's located in the Sapucaí-Mirim River, Southeastern Brazil, both with weir-and-orifice type fish ladders were studied. Eggs and larvae were collected fortnightly between November 2016 and February 2017 (seasonal reproductive period) from set locations upstream of the dams, including the lotic, transition and reservoir. Additional downstream drifting samples were collected from within the fish ladders. Higher densities of eggs and larvae were collected, from all sampling sites, in December, January and early February. Larvae and eggs were only collected from the fish ladders during these periods and only during intense pluviosity events after river flow peaks. The low egg and larval abundance registered with the fish ladders, when compared with lotic, transition and reservoir sites, indicates that few eggs and larvae successfully move downstream through the fishway. They likely travel through turbines and/or the spillway, get eaten by predators or even simply drop out of drift. Increases in river flow has significantly influenced the passage through the fish ladders.

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The impact of a high-head hydropower station on downstream migrating shortfin silver eels *(Anguilla australis)*

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In New Zealand, barriers to the migration of shortfin eels *(Anguilla australis*), including those associated with hydropower, are of increasing concern to water resource managers. Understanding eel migratory behaviour around such infrastructure is essential to quantify the impact and develop passage solutions. Downstream migrating adult silver eel were caught, surgically implanted with an acoustic transmitter and released in the Wairua River, New Zealand, at two sites (33-km upstream of the Wairua Power Station diversion weir (n = 12) and in the power station canal 2.2-km upstream of the intake (n = 13)). Tagged eels were detected on 19 acoustic receivers strategically located around the catchment, including arrays of multiple receivers in the forebay of both the diversion weir and the power station to quantify escapement, route choice, delays experienced and areas occupied at structures. Three of 11 eels that reached the weir from the upper release site passed through a gate at the diversion weir, hence avoiding the power station, with the remaining eight and all 13 released in the power station canal (n = 21) entering the power station forebay. Ten eels that entered the power station forebay (48%) passed over the spillway after experiencing delays of between 12 to 46 days. The other 11 tagged eels were either impinged on the intake screen or entrained in hydropower turbines. The influence of power station operation and spill prior to and during impingement and passage will be presented, including conditions experienced when eels passed the diversion weir, speed of eels migrating through an unobstructed reach, behaviour upstream of the intake and onward migration. Recommendations for maximising escapement from the Wairua River will be discussed based on knowledge of tracked eels; information that is transferable to rivers with similar hydropower schemes.

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Evaluation of a fish friendly pump for increasing the survival of downstream migrating shortfin eels (*Anguilla australis*) in the Waikato, New Zealand

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Large areas of high-value agricultural land in New Zealand are serviced by flood and drainage pumps. While critical to maintaining the viability of this farmland, these pumps are also known to be a migration barrier to fish, and cause mortality and injury to fish entrained by them. The risk to New Zealand's native freshwater eels is particularly high due to their long body shape and catadromous life-history. In 2017 the first purpose-built "fish friendly pumps" used in New Zealand were imported from the United Kingdom and installed at the Orchard Road Pump Station in the Waikato Region. While these type of pumps had been tested on European eels it was unclear how safe they would be for New Zealand species which tend to grow to a larger size. A monitoring programme was implemented to test the efficacy of the new pumps so that their role in future pump station remediation could be evaluated.The movement of downstream migrant eels passing through the new pump station was carried out using Passive Integrated Transponders technology and the attachment of large sock nets over the pump outlets. To increase sample size 98 adult migrant-phase eels were translocated above the pump station. The condition of eels that had passed through the pump was made using visual assessments, post-mortem examinations and x-ray imagery.The results have shown a significant increase in the survival of downstream migrants compared with the pre-existing pumps at the site. However, a high rate of sub-lethal injuries were detected, and it is unknown how these injuries may affect the ability of migrant eels to successfully complete their life cycles. The potential implications of these findings on future pump station remediation in New Zealand is discussed.

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The use of a novel acoustic methods for detecting pump impellor strike on downstream migrating eels in New Zealand

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The effects of agricultural drainage on aquatic ecosystems have been well documented. One of the primary impacts, particularly in floodplain habitats, is loss of river connectivity and associated fish passage. In the Lower Waikato River Basin in New Zealand, the loss of natural gravity fed flows caused by subsidence of peat has resulted in many 'one way' flood pumps. These pumps now operate against gravity to keep this lower elevation agricultural land free from flooding. Although fish mortality through pump-stations is known to occur, few studies have documented the degree of mortality and or trauma that occurs during typical operating scenarios. Nevertheless, it has been noted that when fish, particularly eels, are migrating through pumps that a distinctive sound is made by the pump as the blades strike them. In this investigation, and for the first time to our knowledge, we explore the potential to use hydrophones as a potentially cost effective remote monitoring ('listening') tool to assess eel mortality at a relatively common type of axial pumping station. We evaluated the range of sound and trauma experienced by both resident and released migrant eels passing through pumps during a typical autumn migration period. We also attempted to catalogue the 'type' range of sounds made by freshly euthanized eels and compared them to those of goldfish to illustrate differences. These type sounds are currently being used in the Waikato to develop pump and anguillid specific algorithms to evaluate the degree of mortality that may be occurring at other sites. It is envisioned that this approach will result in a range of information that has substantial potential to improve future management options and approaches at these and possibly other structures.

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Atlantic salmon smolt migration in a regulated river: anthropogenic vs natural influences

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Dams and barriers to migration are commonly cited causes of mortality among downstream migrating salmonid smolt due to the delays and physical damage that passing such barriers can cause. But the environmental and ecological influences of impoundments are not limited to their immediate environment. Changes to the morphology and hydrodynamics of a river can occur over extended stretches of a regulated river, both upstream and downstream from a hydroelectric dam. For this reason, it is important to understand how smolt movement and mortality is affected by the entire range of environmental and ecological conditions that they experience along their migratory route. As part of a multi-year dam removal study, radio-telemetry was used to monitor the downstream migration of Atlantic salmon smolt in the Mörrumsån, a regulated river in Sweden. Using time-to-event analyses, the impacts of natural and anthropogenic factors on migratory dynamics were assessed for altered and unaltered sections of the river, including sections expected to be most strongly affected by the future dam removal. With Sweden being among the countries with the highest number of regulated rivers in the world, and new governmental regulations making the future of many dams uncertain, furthering our understanding of which factors affect the riverine portion of a fish's migration is crucial to help industry and government make sound, informed decisions.

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The behaviour of downstream migrating silver European eels immediately upstream of a pumping station with a traditional trash rack

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Many lowland rivers around the world are regulated by pumping stations to protect land and property from flooding. Critically endangered European eels (*Anguilla anguilla*) that inhabit catchments regulated by pumping stations will inevitably encounter such structures during their downstream spawning migration to the Sargasso Sea. However, the response of eels when encountering pumping stations and the effect on their natural migratory behaviour remains largely unknown. During this investigation, a multi-beam sonars (ARIS) imaged 362 eels approaching a pumping station trash rack (55-mm bar spacing) during pump operation. Of these eels, 278 (76.7%) retreated back upstream, 65 (17.8%) passed through the screen and the route out the ARIS beam could not be determined for 19 eels (5.2%). Of the eels that retreated back upstream, 126 (45.3%) performed a startle or avoidance response when approaching the screen, 141 (50.7%) touched the screen and 11 (4.0%) both avoided the screen and touched it before retreating. Eels approached the pumping station almost exclusively at night, and thus it is unlikely the eels were able to visually identify the screen. Findings relating to the part of the trash rack the eels approached, distance from the trash rack when they performed a startle or avoidance response, factors influencing the type and strength of the response and the extent of searching behaviour before retreating upstream will be presented. This knowledge about eel behaviour at pumping stations is essential for us to determine how to increase downstream passage for this critically endangered species, especially given current European legislation (EC Eel Regulation (1100/2007)) currently states water intakes abstracting greater than 20 m^3 a day should have fine-mesh screens.

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Optimisation of Fishway Entrance and Exit Conditions Using Physical Modelling: SARFIIP Pike Floodplain Regulator and Fishway Designs

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As part of SARFIIP, Jacobs and Kingfisher Research prepared designs for two integrated regulator and fishway structures at the Pike floodplain for SA Water, DEW and the MDBA. These structures will enable the future managed inundation watering of Pike during regulated river flows to restore floodplain health and fish passage connectivity through the floodplain.

A successful floodplain flow regulator and fishway design requires that fish are able to readily locate and enter the downstream entrance. The entrance must be located at the 'limit of fish migration', represented by either a wall or a line of turbulence below the regulator gate that fish cannot pass. The upstream fishway exit must be located where fish are not drawn back downstream over the gates.

To confirm the optimal fishway entrance and exit arrangements, a 1:15 scale physical model was constructed and tested at the UniSA AFMG facilities. The model was designed to enable the performance of critical elements to be identified and if necessary, quickly adjusted.

The sheet-metal model incorporated six lay-flat regulator gates and an adjustable downstream fishway entrance. The model was tested for variable scaled passing flows up to 3,000 ML/d.

The modelling revealed the existence of complex hydraulics and the need to maintain the integrity of attraction flows to the fishway entrance. A 'flow straightening wall' was incorporated to ensure positive velocity vectors downstream of the entrance. A nib wall was provided across the regulator below the overshot gates to form the 'limit of fish migration', aligning with the fishway entrance. The location of the fishway upstream exit was also confirmed and the optimised arrangements demonstrated to the client.

In summary, low-cost physical modelling was undertaken to optimise the fishway designs and provide certainty to the biological functionality of the structures and this helped maximise ecological value for investment.

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Hydraulic Approach for Dimensioning Fish Way Attraction Flow

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The German Federal Institute of Hydrology (BfG) and the German Federal Waterways Engineering and Research Institute (BAW) are working to restore upstream connectivity for fish on German Federal Waterways by means of fish ways. In order for fish to find the entrance of a fish way, sufficient attraction flow is necessary. However, to this day, there is no generally accepted definition of sufficient attraction flow and how to evaluate it. Furthermore, according to the European Water Framework Directive fish of all species and sizes have to be considered for upstream migration. Thus, requirements for attraction flow are diverse.

Theoretically, attraction flow should be designed as large as possible. Practically, space for fish ways is often limited and large supply structures may lead to other restrictions, especially distract fish from their passage. In addition, in terms of operational discharge, fish ways often compete with hydropower and other interests. Thus attraction flow should be designed as large as necessary and as small as possible. It is common to design attraction flow rate as a proportion of competing flow, e.g. mean annual discharge or hydro power plant design discharge. However, these approaches do not consider site specific parameters such as geometric and hydraulic boundary conditions.

The framework presented characterizes requirements for attraction flow by a simple set of variables. Hydraulic jet theory is used in order to estimate attraction flow diffusion and to take into account tailrace characteristics. In doing so, site specifics such as water depths, river bed boundaries and influence of competing flow are considered. The straight forward approach aims at applicable dimensioning recommendations for attraction flow rates and fish way entrance design.

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A practitioner's approach to monitoring hydraulic performance of aquatic organism passage on constructed roughened channels

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Channel reprofiling using roughened channels is a commonly employed technique to remove barriers to aquatic organism passage. Roughened channels often are designed to simulate natural stream beds under self-formed conditions. These structures often use a mix of large boulders that project into the flow field to create complex flow conditions. Complexities in the flow field are intended to provide a range of conditions that facilitate volitional aquatic organism passage through the structure. We measured water depths and velocities on several roughened channels and identified and characterized complex flow conditions within these channels. We obtained bed and bank morphologic data using a robotic total station and point velocities and velocity profiles using a Sontek Flowtracker with a 3-d probe. These flow conditions were reviewed and evaluated using empirical data from published research and compared with hydraulic models commonly used in the United States to design roughened channels for fish passage projects. Results summarize uncertainties in data collection and evaluation of fish passage projects and limits in the application of 1- and 2-dimensional models for project design. Our efforts are intended to foster discussions on monitoring of roughened channels.

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Cost Effective Modelling to Improve the Functionality of the Broken Creek Rice's Weir and Kennedy's Weir Vertical Slot Fishways

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Acknowledgement Goulburn-Murray Water

Broken Creek in north-central Victoria flows into the River Murray upstream of Barmah. There are 10 low-head (<2 m high) weirs on Broken Creek which all have vertical slot fishways however these have high turbulence (i.e. 75 W/m3) and thus limited functionality for several species of native small and medium sized fish (i.e. <300 mm long).

In late 2017, the Victorian government (DELWP) engaged Jacobs and Kingfisher Research to hydraulically model the Rices and Kennedy's Weir fishways to prepare conceptual designs for retro-fitted 'key-hole' slots to reduce pool turbulence and demonstrate potential for improvement in functionality to pass much smaller fish (i.e. >50 mm long).

Jacobs applied a Microsoft Excel based fishway model which takes fishway geometry, calibrated slot discharge coefficient data, and headwater/tailwater ranges, and uses these data to predict individual pool turbulence, depth and slot velocity. These hydraulic outputs were combined with fish swimming ability, maximum allowable turbulence, and minimum water depth to graphically demonstrate water level ranges for which each fishway could pass small, medium and large-sized native fish. Conceptual level 'key-hole' slot designs were then developed, reducing slot areas and flow rates and enabling passage of all fish sizes.

The modelling showed that The theoretical implementation of 'key-hole' slots effectively halved the fishway discharge and reduced the pool turbulence to 35 W/m3, the known threshold suitable for passage of small-sized native fish.

This project demonstrated the efficiency of Microsoft Excel based modelling to bring together both fishway hydraulics and fish biology, with novel design options rapidly evaluated for a low cost. Graphical fishway operation tables were automatically produced for the full range of site operational conditions without the need for costly post-processing of model results.

GBCMA propose to retrofit key-hole slots to Rice's and Kennedy's weir fishways to improve their performance during 2018.

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A comprehensive approach to vertical slot fishway hydraulic analysis

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Vertical slot type fishway structures operate by carefully controlling internal hydraulic conditions, allowing fish to move upstream. While the design of small vertical slot fishways can be straight forward, the hydraulics of larger fishways is more complex, especially when combined with variable headwater and tailwater levels. Other design elements, like non-uniform slot geometry, use of supplementary fishway flow sources, multiple fishway exits and entries, non-uniform cell sizes, and non-uniform bed slope can further complicate fishway hydraulics.

The interplay of complex hydraulics behaviour and multiple (and at times contradictory) design criteria criteria can result in unexpected fishway performance at particular headwater and tailwater combinations, and can significantly complicate the fishway design and analysis process.

This presentation describes an approach to vertical slot fishway hydraulic modelling designed to address these inherent complexities. This system utilises an exhaustive modelling approach, where each fishway configuration is simulated under hundreds of thousands of individual hydraulic conditions, the results of which form a database that is used to map fishway functionality according to the design criteria. This approach to fishway analysis has been implemented in a computer program called the Vertical Slot Fishway Functional Envelope Model (VS2FEM).

Use of this modelling approach allows for the efficient development of more highly optimised fishway designs and allows optimum fishway function to be aligned with the most frequent occurring hydraulic conditions. It can also be used to evaluate existing fishway structures, investigate the implications of modelling uncertainty, or used to develop operational guides for management of configurable fishways.

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Restoring fish passage and estuarine ecosystems at tidal barriers: current practice and future directions

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Worldwide, barriers are constructed in the tidal zones of rivers and estuaries to control water exchange, primarily to prevent saltwater incursion and flooding, and maintain upstream freshwater reserves. Barrier designs and terminology vary (e.g. barrages, dikes, weirs, tidal gates), but ultimately, all influence fishes by: 1) obstructing movement; and 2) altering estuarine hydrodynamics (i.e. tidal water movement and/or freshwater discharge), and coincident salinity regimes and habitat. These primary impacts may be exacerbated by climate change driven sea-level rise and reduced riverine discharge.

Remediation of tidal barriers to promote fish passage and the rehabilitation of estuaries (e.g. restoring tidal flow, delivering environmental flows) is increasingly common in developed countries. Research evaluating fish behaviour and passage success through various fishway and barrier designs has informed remediation; nonetheless, such approaches remain complex from ecological, economic and engineering perspectives. We present case studies from Australia, the Netherlands and the United States to examine and characterise fish passage issues in a variety of systems, and document contemporary approaches to improving fish passage and restoring ecosystem function in systems with tidal barriers. This includes the application of technical fishways, ecologically sensitive operation of water control structures and provision of environmental flows. We integrate insights and lessons learned from these case studies to guide remediation strategies at other tidal barriers and provide direction for future research.

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Effects of tide gate upgrade or removal on fish passage and habitat quality: a literature review and knowledge synthesis

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The ecological effects of tide gates are thought to be sufficiently understood to justify estuary restoration involving removal or upgrades of aging structures with the goals of improving fish passage and estuarine habitat conditions. However, whether tide gate upgrade or removal affect salmonid passage, growth and survival, and habitat quality, lacks clear answers in the primary literature. To address this paucity of information, we conducted a systematic review of the primary literature and of tide gate related project reports. We used a multi-faceted approach to knowledge synthesis, including review of relevant scientific literature, agency and non-agency reports on tide gate projects, and inquiries to state and federal agency staff working on estuary restoration in the Pacific Northwest region. Some of our findings indicate that: a) tide gates limit connectivity in a way that negatively affects fish passage, community composition and water quality, b) all tide gates have some impact on fish, even those

labelled “fish friendly”; c) tide gate removal or upgrade projects produce very variable outcomes because not only the design of the gates may affect results but also their location and installation in the channel network; d) fish passage improvement is only one of the four main objectives of tide gate projects, the others are fish nursery habitat improvement and expansion, flood damage reduction and infrastructure protection; e) tide gate projects are only the first step in improving ecological conditions in fish migration corridors. The data and reports we summarized provide ample sources of the raw materials needed towards the development of guidelines, based on ecological and econometric principles, to determine the costs and benefits of various types of tide gate removal or replacement and estuarine restoration projects.

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Development and application of an agent based model for glass eel selective tidal stream transport

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Temperate eel populations have been in severe decline due to anthropogenic influences. In Europe, acts of regulation are in place for the sustainable management of the European eel (*A. anguilla*) population, through annual assessment of commercial landings and recruitment trends. Recruitment of juvenile eels into estuaries and subsequent rivers is thought to occur through usage of the flood, ebb and slack tides (Selective Tidal Stream Transport, STST) and other environmental variables. However, instalment of estuarine barriers is known to affect upstream migration with adverse consequences for the population.

To evaluate anthropogenic impact (e.g. estuarine barriers) on recruitment and aid in the improvement of population assessment, we present an Agent-Based Model (ABM) for the upstream migration of glass eels/ elvers through estuaries. A systematic review of the impacts of environmental factors based on a meta-analysis of the literature provided the behavioural parameters of the agents. The ABM is coupled to a hydrodynamic model of the Thames Estuary (UK) and simulations are validated with catchment data from different sampling sites along this waterway.

Results from the meta-analysis show that the predominant mechanisms for upstream migration include drifting with the flood tide and remaining in the substratum during ebb tide, whereas exploitation of the slack tide is debatable. Water temperature, the salinity gradient, and the moon phase are the most reported environmental variables affecting STST/ migration. Based on this, the ABM proved to be successful in predicting upstream migration along the Thames while explaining the efficiency of STST. Finally, the ABM is applied The Milford Haven Waterway (UK), which is heavily exploited by human activities, to provide information on possible recruitment success here and illustrate its functionality in the context of estuarine barrier management.

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Estuarine fish passes in the northern Netherlands provide contrasting windows of opportunity for migrating fish species

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The Wadden Sea in north-western Europe is the largest system of connected intertidal sand and mud flats in the world and is included in the UNESCO World Heritage list. Notwithstanding its ecological value, almost all rivers flowing towards the Wadden Sea are heavily modified with inter-tidal barriers, hampering the migration of diadromous fishes. To mitigate the negative effects of such barriers, fish passes were constructed, but their effectiveness is poorly understood. Since most fish passes are only functional during part of the tidal cycle, migration activity should match this operation window to secure effective migration. In this study we focused on the upstream-migrating behaviour of glass eel (the juvenile stage of catadromous eel, *Anguilla anguilla*) and three-spined stickleback (anadromous *Gasterosteus aculeatus*) at nine fish passes along the Dutch Wadden Sea coast. We investigated the presence of sticklebacks and glass eel at the downstream side of intertidal barriers in relation to fluctuations in their environment. Fish were collected with 1x1-m lift nets, with a 2-mm mesh size. In 168 sample days between February and May 2014, 4558 samples were taken and a total of 107,349 sticklebacks and 23,082 glass eel were caught. At all locations, glass eel were most abundant in the hour before high tide, while sticklebacks did not show a significant pattern with environmental variables at all locations, but when they did catches were highest at the start of flood tide. This means that the window of opportunity for migration is different for both fish species and that optimisation of the operation window of a fish pass for glass eel could mean a mismatch for stickleback and *vice versa*. Knowledge of temporal migration dynamics of fish species is therefore essential for the design of effective fish passes.

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Fish passage at tidal barrier Nieuwe Statenzijl in The Netherlands, a regional perspective.

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Regional Water Authority Hunze en Aa’s is one of the 21 regional water management organisations in The Netherlands and is positioned in the NE corner of the country. The main responsibilities are water level management, flood defence and water quality management in the regional lakes, canals and river systems. As part of these water management tasks, RWA Hunze en Aa’s

operates several sluices and pumping stations that discharge water from the regional rivers and polders into the estuary of the River Ems. These locations play an important role as access point to the hinterland for diadromous species like smelt, Atlantic eel, three spined stickleback, flounder and river lamprey. In the past these tidal discharge locations showed to be an almost impassable barrier for diadromous fish. Since 2001 several projects have been carried out to restore fish passage possibilities. A combination of a more “fish friendly” management of the sluices and the construction of technical fishways is used to allow diadromous fish to get passed these tidal barriers. The presentation will focus on the practical discussions (salinity, sediment, safety) and monitoring results for one of the main tidal discharge sluices at Nieuwe Statenzijl in the River Westerwoldsche Aa. This location has been fitted with a combination of adapted management of the sluice doors, an eel pass and additional “cat flaps” allowing millions of diadromous fish to pass.

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Maintaining fish passage for Queensland's native fish species tools to facilitate fish passage across waterway barriers

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In Queensland, fish passage is recognised for its importance in maintaining the life cycles of many native fish species. All waterways providing for fish passage within Queensland are protected through provisions of the *Fisheries Act 1994*. However, the *Planning Act 2016* allows approval to be granted for waterway barrier works that can demonstrate adequate fish passage. Operational work that involves constructing or raising waterway barrier works must either comply with Fisheries Queensland’s Accepted Development Requirements (ADR), or require assessment under the *Planning Act 2016*.

What constitutes a barrier to fish movement depends on the species involved, their movement patterns, life stage and swimming ability. Unlike fish species from the northern hemisphere, such as salmon, Australian native fish do not have the ability to scale large drops in a single leap or swim against high flow velocities over long distances. Fisheries Queensland have developed tools based on the swimming abilities of Australian native fish. These tools aim to provide guidance on design elements of commonly built waterway barriers, such as culvert crossings, to help facilitate fish passage across these structures.

The spatial data layer, *Queensland waterways for waterway barrier works,* categorises waterways into colours based on the potential risk of instream barrier works to fish passage. This informs the specific design requirements for certain types of instream structures proposed on these waterways, depending on their location. It can then be determined if the proposed works are likely to be Accepted or Assessable development. Design features to provide fish passage, are incorporated within the ADR and similar provisions are required for assessable development within the State Development Assessment Provisions. With approximately 80% of development categorised as Accepted Development, this facilitates an affordable and time-effective process for certain waterway barrier work developments and ensures adequate fish passage for native Australian fish species.

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Building a fish passage assessment protocol for New Zealand: implementation of Bayesian network models for evaluating the likelihood of fish passage success at instream structures

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Migratory fish species are dependent on connected habitats to complete their life cycles. Instream structures such as culverts, weirs and dams can impede the movement of migratory species. Disruptions to migratory pathways impact ecosystem health by reducing the abundance and diversity of species present.

A number of metrics are available for quantifying habitat fragmentation within river networks, but they are dependent on sufficient information being available on the location and severity of migration barriers. Characterising the likelihood of fish passage success at instream structures requires information on the characteristics of the structure and the capabilities of fishes. Biotelemetry and mark-recapture studies are the most effective approaches for quantifying passage success, but are impractical for broad-scale evaluation of multiple instream structures.

Bayesian networks offer a flexible approach for deriving probabilistic models suitable for broad-scale rapid assessment of instream structures for barrier severity. We present a Bayesian network derived for evaluating the probability of fish passage success at culverts in New Zealand. A formal expert elicitation process was utilised to populate the prior probability distributions in the model. We present the results from over 350 culverts where the model has been applied. By taking advantage of expert knowledge, the model offers a practical and objective approach for rapidly quantifying the likelihood of fish passage success at multiple instream structures without the need for resource intensive tagging studies. The results are also consistent with requirements for developing environmental reporting metrics for stream connectivity and the model has been used in a new fish passage assessment protocol for New Zealand.

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How and where do fish cross the road? – A strategic approach to fish-friendly waterway crossings

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There is 5575 known waterway crossing across NSW, of which 1770 represent a barrier to fish passage. NSW Department of Primary Industries - Fisheries (DPI Fisheries) has developed, implemented and modified guidelines for fish-friendly road crossings since 1999. The most recent version developed in 2003 - *why do fish need to cross the Road? Fish passage Requirements for waterway Crossings*. Much of the information that underpins the guidelines is based on fish-way research and anecdotal observations of fish swimming performance and behaviour. It is important to note that the guidelines recognise that other factors should also be considered such catchment or river specific requirements and cost constraints. Accepted knowledge gaps for the design of fish-friendly waterway crossings include specific swimming performance information on a range of fish species, and how these interact with culvert hydrodynamics.

To address this and improve the current culvert design guidelines, DPI Fisheries, NSW Roads and Maritime Service and the University of Queensland developed a collaborative partnership in 2011 to conduct research into how to develop fish-friendly culverts that integrate fish swimming performance and culvert hydrodynamics into the design.

An issue facing many natural resource and asset managers in NSW is finding a balance between infrastructure costs and the ongoing protection of aquatic biodiversity. In order to achieve that outcome, the delineation and spatial recognition of aquatic biodiversity is paramount in providing a greater understanding and appreciation of species distributions across the state.

By combining this information with evidenced based research on swimming performance DPI Fisheries is endeavoring to provide a robust information baseline on fish communities and their swimming performance, which when combined with specifically developed culvert design guidelines will provide for river specific, cost effective, fish-friendly waterway crossings.

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Finding assessing and fixing fish passage problems in Ireland

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The EU Habitats and Water Framework Directives (WFD) have highlighted migration barrier issues for diadromous fish in Europe. The Irish National Barriers Programme is developing desk-and field protocols to create a GIS layer of river barriers, for use in infrastructural development and conservation management, particularly for Atlantic salmon and sea lamprey. Desk-based analysis of aerial imagery and map sources generated 2928 potential barriers in the Barrow catchment (3,025km²). Of all potential barriers, 300 fish obstructions were surveyed, ranging across 1st to 6th order channels. The field survey collected geo-location, photo imagery and structure dimensions at identified barriers. The majority were bridge issues (n=132), weirs (n=82) or culverts (n=62). There was a significant relationship between mean stream gradient and barriers per river km. Individual sub catchment assessment within the Barrow highlighted both geographical and historical influences on barrier distribution. The 19 Barrow sub catchments displayed a range of fragmentation ranging from 0.28- 0.8 barriers per river km. Of 792 potential barriers, the field assessment identified low discharge or no fishery habitat, requiring development of rules to streamline desk-based surveys in order to eliminate such locations from further field campaigns. Where barrier mitigations are proposed, the SNIFFER and ICE protocols provide a detailed assessment of the structure and its fish passage issues. In the longer term, the national GIS layer will be used to prioritise passage easement requirements as WFD Programmes of Measures. Currently, easements are undertaken more opportunistically, where public authorities are already committed to secure or replace bridge structures, re-align roads or carry out flood relief works in channels. There is a strong preference for barrier removal, where feasible, and for more nature-like solutions, such as bypass channels and rock ramps of appropriate gradient to facilitate all fish species, as opposed to conventional engineered solutions.

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Goldie Perch and the 128 Fishways: Key Findings and Recommendations from the Assessment of the Modern Fishways of New South Wales

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Since European Settlement, Australia has been rapidly regulating the flows of rivers and streams, much to the peril of our native fish. Internationally, the need for fish to migrate within and between rivers has been recognised for over a century through the construction of fishways. In New South Wales (NSW), the first fishways were constructed in the early 1900's with little success owing to poor designs, which were modelled for Northern Hemisphere Salmonids with advanced swimming and jumping capabilities. Unfortunately, it took until 1985 to realise just how poorly these early fishways were performing for Australian native fish and for suitable alternate designs to be developed.

By 2017, 135 "modern" fishways had been constructed in NSW including rock ramp, vertical slot, denil, and fish lock designs. However, no comprehensive review had been completed on the design, management, and maintenance of these fishways since they were constructed, with the last significant review of design principles in NSW occurring in 2000. Subsequently, the NSW Department of Primary Industries (Fisheries) undertook site inspections of these fishways to assess the relevance of the current designs guidelines with the aim to develop new, updated guidelines to assist the construction and operation of current and future fishways in NSW.

The aim of this presentation will be to detail the main findings of the fishway site inspections for rock-ramp, vertical slot, denil, and fish lock designs, with common faults and issues identified, and recommended solutions and guidelines being proposed. These findings will be used to develop a revised NSW Fish Passage Guidelines document that will aim to provide clarity and certainty to asset owners regarding operational and maintenance requirements, while also aiming to ensure that fishways are operating effectively to pass native Australian fish.

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How different cyprinids perform in an experimental multi slot fishway? Testing its effectiveness in distinct seasons

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New engineering solutions are required to minimize the impacts raised by the increasing number of anthropogenic barriers on the watercourses. The longitudinal connectivity must be provided through fishways to allow free passage for the whole fish community. Recently, a multi slot fishway (MSF) was developed, with two consecutive vertical slots that divide the overall head drop, thus, reducing the discharge, velocity and turbulence. The present study assessed the effectiveness of a MSF design for two cyprinid species with different ecological traits: the Iberian barbel (*Luciobarbus bocagei*), a large-bodied potamodromous benthic fish, and the Southern Iberian chub (*Squalius pyrenaicus*) a small-bodied water-column fish. Experiments were conducted in spring and autumn. Results show differences in the passage performance between seasons and species. During spring, S. I. chub achieved a higher entry efficiency and shorter transit time to fully negotiate the fishway, while for the I. barbel no differences were found. Overall, the MSF offers low operational costs compared to a standard vertical slot fishway (VSF), however, concerns about the entrance and attraction conditions should be addressed. Additionally, due to the lower operational discharge, the propensity for obstruction with woody debris and sediments should not be disregarded.

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Action plan for the optimization of the fish lift built at the Touvedo hydropower plan, NW Portugal

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The "Action Plan for the Optimization of the Fish Lift built at the Touvedo Hydropower Plant" took place between September 2011 and February 2014, and consisted of three stages: stage 1 – evaluation of fish lift use and assessment of its efficacy; stage 2 - hydraulic characterization of the lift entrances and implementation of mitigation measures to improve fish lift operation; stage 3 – re-assessment of the efficacy of the fish lift after implantation of measures. Overall, the lift was used by 10011 fish, being the European eel (50.7%) and the northern Iberian nase (37.5%), the most abundant species. After the implementation of measures, a significant increase was observed in the number of fish that used in the lift, from 3389 (stage 1) to 6272 (stage 3), being the European eel the species which most contributed to this increase. Fish lift selectivity was low, being all species recorded with the exception of the ruivaco, a small resident cyprinid. The hydraulic characterization of fish lift entrances revealed that entry conditions are attractive for all the species, particularly for the larger size-classes, when the powerhouse is off or at full load. Contrarily, when the dam is operating at half-load, conditions are unattractive due to the presence of recirculation areas and negative velocities that may hinder fish entrance. Ten measures of different nature and priority were proposed, most of which were implemented. The comparison of the results between stage 1 and 3, indicated that 4 of the measures contributed to the increase of the fish lift efficacy, including the reduction of the gap width. The results obtained, allow us to conclude that the Touvedo fish lift contributes positively to the maintenance of the cyprinid, trout and eel populations, though the true efficacy of downstream movements is still inconclusive for this latter species.

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Advances in Biological Performance Assessment of Turbines within the Industry Context

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Turbine manufacturers are increasingly considering engineering strategies to enhance the survival of migratory fish that are exposed to turbine flows. This presentation will show the ongoing research activities at Andritz Hydro to enhance evaluations of biological performance of hydroturbines and to demonstrate how such evaluations drive design features within the industry practices. These biological evaluations typically take place in the context of rehabilitation projects of low-head Kaplan turbines but are not necessarily restricted to such scenarios. In the R&D section, we have identified two technical aspects that industry can contribute to the field of fish passage. First, we will summarize the wide variety of projects that have included fish survival assessments, with particular focus on a pump-turbine project with the challenging task of preventing the Redfin perch (*Perca fluviatilis*) from being transported between the water reservoirs. Unlike usual project provisions, this entails maximizing mortality rates ─and not fish survival─ of the target species. Second, we are presenting the latest advancements in fish trajectory modeling with the use of Lagrangian particles and the results from implementing such method in our projects. After a brief introduction of the particle-based method, we will discuss its advantage as well as cost-benefits. Our goal is to seek opportunities for collaboration with research institutions in order to advance the field of fish passage with an active participation from industry players.

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Dorrigo Plateau Run-of-River proposed hydroelectric development

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In 2015 the NSW Government funded the Dorrigo Chamber of Commerce to investigate the Run-of-River (RoR) hydroelectric potential & opportunities of the Dorrigo Plateau. Dorrigo is unique in a number of ways: mean annual rainfall is almost 2000mm, all surface water that leaves the Plateau is via waterfalls, drier months result in significant irrigation extraction from streams, and there is a history of hydroelectric generation with the town being the first in Australia to be supplied electricity from a hydro in 1922. The 2015-16 study determined that the hydroelectric capacity of the Plateau exceeded the Plateau's current demand for electricity. In addition it was determined that significant RoR hydro resources exist in NSW on the wetter, eastern watershed of the Great Dividing Range. It was determined that 99.4% of NSW's current hydroelectric systems operate from water storage dams and that only 8% of hydroelectric generation is on the wetter, eastern watershed of NSW. The Dorrigo community is working with businesses and agencies to develop methodologies to assess various hydroelectric technologies so that Dorrigo will be a leading hydro-hub resource centre for healthy-river hydro development. There are presently limited pathways in NSW for such development approvals; something this program aims to change. This presentation will summarise activities to date and next stage plans for demonstration installations and studies.

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Re-defining upstream fish passage

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In efforts to re-establish populations of migratory fish in areas previously blocked by man-made barriers, upstream migration of adults needs to be facilitated past those barriers. Passage solutions need to meet the standards of being safe, timely, efficient and effective. While traditional upstream adult passage solutions may meet these agency standards, the upfront planning and implementation costs associated with these solutions severely impacts the timing and financial viability of these programs. In an environment of increasing pressures on fish populations caused by climate change and habitat degradation, solutions that are cheaper and quicker to deploy are needed. In this talk we describe a pilot adult volitional passage system that took less than 3 months to install in 2017 at a high head dam in Washington State, USA, and the results from that system. This pilot was made possible by collaboration of private industry, tribal interests and the federal government. We will look at the technology used and additional testing that has been performed to make sure that the solution meets the acceptable standards. Biologists and engineers may be able to use this project as an example to accelerate other passage implementations with industry and government participation.

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Proof of concept for an innovative pump fishway design to move fish upstream over dams

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Abstract

Reversing worldwide declines in freshwater fish while making sustainable use of water resources will require effective and economical fishways to restore fish migrations. Mitigation of barrier effects at dams and weirs is too often impeded by poor fishway performance and high costs, so that many fish migrations continue to be obstructed. Improved and less-costly designs are urgently needed. Our innovative pump fishway concept combines fish-behaviour insights, proved fishways techniques and aquaculture's pumping methods for safe upstream transport of living fish. We ran a series of experimental trials using several scale-model fishway designs with young, hatchery-bred fish. Our horizontal-cylinder design successfully combined volitional-passage functions of existing fishways with non-volitional transport in a conduit carrying pumped water. Several key principles of fish behaviour in fishways led to design improvements: disturbed fish often seek refuge at depth; fishes' escape reactions strongly motivate swimming into flows; and curved structures aid passage by reducing delays. Replicated trials finally produced an average of 98% successful passage, within brief cycling periods. The pump fishway concept offers potential for effective upstream fish passage at new and existing sites >~2m high, with low construction and maintenance costs and highly adaptable operation in variable flow regimes. Development beyond the concept-trial phase is now a priority.

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Hydraulic optimisation of a system for transporting fish in water vertically at near-atmospheric pressure.

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Reversing worldwide declines in freshwater fish while making sustainable use of water resources will require effective and economical fishways to restore fish migrations. We have developed a proof-of-concept for our innovative pump fishway approach (Harris *et al*., 2018). This aims to safely lift live fish over vertical distances exceeding 100m without injury. Our horizontal-cylinder design successfully combined the volitional-passage functions of existing fishways with non-volitional transport in a conduit carrying pumped water for young, hatchery-bred, non-salmonid fish. Here, we describe the large-scale transport system designed with minimal moving parts and capable of transporting fish in water vertically over distances exceeding 100 metres. The fish and transported water are contained in a conduit with the transported volume kept at near-atmospheric pressure to minimise barotrauma risks. The system has been optimised to minimise the use of large mechanical pump systems. Under certain conditions, all mechanical pumping is eliminated. The entire system has been demonstrated at a physical model 1 metre vertical scale. A numerical model has been developed, verified against the physical model. Further, the numerical model shows that the system is reliable and can be applied at vertical scales exceeding 100 metres.

This contribution will describe the key principles of the system operation and larger scale (4m lift) experiments with summary hydraulic characterisations of the entire system. This will includes hydraulic approaches which retain the key biological constraints required for successful attraction but also minimise the hydraulic losses during the non-volitional transport phase. We also describe a novel method to determine the hydraulic energy losses of conduits to transport fish in water.

Reference

Harris *et al.* (2018) Proof of concept for an innovative pump fishway design to move fish upstream over dams. *Submitted to* Fish Passage 2018

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Australia's first trap-and-haul fishway: Nerang River, Queensland

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Abstract

Australia's first trap-and-haul fishway was built on the Nerang River in southeast Queensland during enlargement of the Hinze Dam. In gaining government approval for the project, the constructing alliance (HDA) concluded that providing upstream fish passage would have significant environmental benefits by conserving upstream native fish communities and encouraging recruitment into the reservoir's recreational fishery. But downstream passage, other than modifications to protect fish emigrating during spill events, could not be justified. Severely constrained outflows from the dam and the impacts of downstream urban development contrast starkly with upstream habitat conditions.

North American design approaches were adapted to suit the river's fishes and streamflows. Challenges for fish passage at the site included the marked restriction of downstream river flows and the location of the flow-release point 300m from the spillway. A barrier weir was built to prevent upstream migrants bypassing the fishway entrance during spillway flows. HDA developed a trap-and-haul system to collect migrating fish at the weir and transport them by tanker to multiple upstream release areas. This system provides flexibility to accommodate varying fish biomass; ability to operate over a range of flows up to 20-year ARI events; facilities for sorting, data collection and removal of pest species; and capacity to limit predation mortalities. Fishway performance studies led to redesign of the entrance vee-trap and other modifications. To 2017, 55,590 fish from 27 large and small-bodied species used the fishway, together with 8 turtles. Fish of three pest species were identified in the sorting facility and removed to prevent their entry to the reservoir.

This paper covers the project life cycle for Australia's first trap-and-haul fishway including the basis for selecting the fishway type, design and construction. Fishway performance studies and results from ongoing operation, including the lessons learned and the improvements made, are also discussed.

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Mud Mountain Upstream Migrant Trap & Haul Facility Design

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Mud Mountain Dam, located on the White River in Washington State USA, is owned and operated by the US Army Corps of Engineers (USACE). The project includes a high-head dam operated for flood control and a small diversion barrier downstream for directing upstream migrating fish into a trap facility designed to transfer fish into transport trucks for release upstream of the dam. Migrating fish species in the White River include Chinook, Coho, and Pink salmon; steelhead and Bull Trout. The presence of Pink Salmon in the river is relatively recent, and populations have increased dramatically in the last few years. The existing trap & haul facility is antiquated and in need of replacement to handle the increasing number of fish in the river, and the complex fish sorting requirements associated with a local fish hatchery and regional fish monitoring programs. A new facility including a new barrier in the river, a short fish ladder, and a sorting facility with a research station has been designed to accommodate an unprecedented number of returning adults. This presentation will focus on the sorting facilities, designed to sort up to 60,000 fish per day by species and tag presence. The sorting facilities include two large holding ponds, two 16-meter-long Archimedes screw lifts, visual sorting flumes, automatic tag detection equipment with fish diversion to a related Chinook Salmon hatchery adjacent

to the site, and a fish handling & research station with a water-to-water truck transfer station. Some features of the project are unprecedented in scale and operational arrangement, and the entire facility needed to be fit into a small limited property boundary. The design was completed in 2017 and contractor bidding is underway. The project should be in construction by the time of the conference in December.

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Evaluating the performance of a Larinier Super-Active Baffle Fishway to facilitate the upstream movement of three brown trout (*Salmo trutta*) phenotypes: Anadromous, Potamodromous, and Parr-marked.

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The removal of barriers to animal movement has become a priority to improve the ecological status of rivers. However, complete removal of barriers is not always an option. Fishways, such as the Larinier Super-Active Baffle (LSAB), are commonly employed to mitigate the effects of barriers to upstream fish movement. We monitored the upstream passage behaviour and performance of three wild brown trout phenotypes, encompassing a range of sizes, at a LSAB fishway adjacent to a flow-gauging weir, using PIT and Radio telemetry. Fish were captured and tagged 0.4-1.5 km downstream of the weir in the pre-spawning period. Of those that attempted passage of the weir-fishway complex, potamodromous ($n_{attempt}$ =8; $n_{successful}$ =2; χ^2_1 =8.8, p <0.005) and parr-marked ($n_{attempt}$ =22; $n_{successful}$ =8; χ^2_1 =4.5, p <0.05) individuals were less successful than expected, but anadromous trout were as successful as expected ($n_{attempt}$ =27; $n_{successful}$ =21; χ^2_1 =1.3, p >0.05). A significantly greater proportion of anadromous trout traversed the weir than used the fishway (n_{weir} =16; $n_{fishway}$ =5; χ^2_1 =5.8, p =0.02), with no preference for specific flows for route of passage (fishway =Q3-Q74; weir =Q3-83; t-test: $t_{6.1}$ =-1.0, p > 0.05). Equal numbers of potamodromous (n=1) and parr-marked (n=4) phenotypes traversed the weir and used the fishway. In each phenotype, one fish failed to ascend the fishway. Although the fishway may facilitate upstream passage, it appears the fishway fails to attract fish. The good passage of anadromous trout is likely due to their greater relative size and swimming performance compared to other phenotypes.

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Cooling water temperature gradients in a fishway are associated with poor passage and increased potential for interactions between hatchery and wild salmon

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Effective passage is critical for fish collection facilities. Trapping facilities with fishways are used to capture adult salmonids in the Willamette Valley, Oregon, USA below high-head dams during collection of mitigation hatchery broodstock and, more recently, the establishment of 'wild fish sanctuaries' above dams for ESA-listed Chinook salmon and steelhead. However, observations of holding adults and hatchery-origin salmon spawning below Foster Dam on the South Santiam River raised concerns about the efficacy of the fishway and trap before and after a major 2014 facility upgrade. In 2015-2016, optical video and DIDSON observations revealed substantial adult holding outside and within the fishway, and considerable milling in the upper ladder near the trap entrance. Experimental manipulation of velocities at the powerhouse entrance increased salmon entry rate into the fishway, but not trapping rate. In 2017, we radio-tagged 16 hatchery-origin Chinook Salmon ~30 km downstream. All were detected in the Foster tailrace, but trap collection efficiency was low (43.7%). Optical video monitoring at the trap entrance revealed 9.2 entrance attempts/trap entrance and that entrance rates were related to trap operations and potentially social cues from previously trapped adults. Salmon body temperature declined from ~16°C at tagging to ~12°C in the tailrace to ~10°C at collection because fishway temperatures were strongly influenced by hypolimnetic water from Foster Reservoir. Current hypotheses to explain observed behaviors include overall effects of cool water temperatures, temperature gradients between the Foster tailrace and adult trap, and/or a lack of natal olfactory cues in fishway waters. The ineffective collection of adults raises concern about hatchery-wild fish interactions below the dam and reduced ability to efficiently provide passage via trap-and-haul to adults with natal origin from the wild fish sanctuary above the dam. Results highlight the importance of effective fish passage in implementing mitigation and conservation strategies.

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Designing fishway traps for vertical-slot fishway assessments

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Vertical-slot fishways are one of the most common fishway designs used in Victoria, Australia. Fisheries researchers use several different active and passive sampling techniques to assess the effectiveness of fishways, however fishway traps are typically used for vertical-slot fishways. Fishway traps are customised mesh traps that are positioned in a vertical-slot fishway over a set

time-period to collect fish moving upstream. Fishway trapping provides information about fish species, their abundances and size-classes that are attracted and or can successfully pass through the fishway. Fishway trapping can also be used as a biological control.

The focus of the presentation is about the design and operation of a fishway trap. Trap design is essential and influences their functionality. Several factors to consider include:

- Trapping location (i.e. entrance, exit or baffles)
- Trap shape, size and weight
- Funnel design, width and orientation
- Materials and mesh size
- Fishway hydrology
- Fish handling and minimising stress
- Manual handling
- Transportation

The operation of fishway traps can have many impacts, including to water movement and velocity, and fish behaviour. Such impacts must be minimised to obtain a true assessment of the fishway's effectiveness.

Most importantly, the design and operation of the fishway trap must be completed in a safe and managed way.

By sharing our experiences in building and using fishway traps, we hope to foster continuous learning and improvement about trap design and operation for fishway assessments.

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Build it and they will come. Or will they? Golden Perch in Koondrook Perricoota Forest.

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The Gunbower and Koondrook-Perricoota Forest (KPF) includes a natural floodplain wetland system that has suffered for many years from a lack of water as a result of water extraction practices in the Murray River. The site was targeted with a combination of environmental water allocations and environmental works programs to manage the distribution and retention of water and ultimately improve its ecological health. A major ecological objective for the Gunbower Koondrook-Perricoota Forest is 'healthy populations of resident native fish in wetlands'. Golden perch, a large-bodied native species utilise similar habitat on the floodplain proper and floodplain channels between nearby Cobram and Yarrawonga and were documented utilising drying waterholes in the vicinity of the nearby Murrumbidgee River as far back as 1917. We report on an acoustic monitoring survey in 2016 when during a natural flood, none of 14 tagged Golden Perch tagged in the adjacent main river channel entered the forest. Yet at the same time, 34 of 44 tagged Common carp moved into the forest when passage became available from rising waters. Further, seven years of consecutive autumn condition monitoring on the KPF floodplain has failed to sample a single golden perch young-of-year in KPF, and only two adults have been sampled within KPF during that time. In addition, intensive electrofishing and fyke netting of the inlet channel during the first managed event in 2014 failed to collect any golden perch, and none were trapped in the fishways. We suggest that it is important that golden perch and other native large-bodied fish continue to be considered when operating the regulators during future events, including monitoring of fish accumulations at the outlet regulator and fishway trapping.

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Fish on the run: facilitating fish passage from drying floodplains

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In the Murray-Darling Basin, river managers are implementing site-scale managed floodplain inundations for vegetation outcomes but there is a risk of native fish stranding during floodplain recession due to the absence of natural cues. In 2014, at the 5,000 ha Gunbower floodplain, central Murray River, we devised a fish exit strategy which included: (i) a fish 'exit hydrograph', a designed recession to cue fish to leave the floodplain, (ii) evaluation of a new fishlock to facilitate fish passage from the floodplain to the permanent Gunbower Creek. During our evaluation of the exit strategy we collected 113,099 fish exiting the fishlock at up to 20,000 fish/hr, with juvenile non-native carp, native Australian smelt and native carp gudgeons dominating the catch. Fish were 15-500 mm long. Native fish exited the floodplain during the initial drop where carp exited during the later half of the recession. In addition, 30 golden perch were acoustic tagged to identify their floodplain exit pathways. The implications of our results are discussed in the context of maximizing safe exit of fish from other temporary floodplain habitats.

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Floodplain reconnection and habitat variability act as mitigation measures for sensitive rheophilic fish species in the lower rhine river, the Netherlands

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The extensive modifications in the River Rhine resulted in the severe decline or even loss of migratory fish species, typical for European lowland river systems, such as Atlantic salmon (*Salmo salar*) and European sturgeon (*Acipenser sturio*). In addition, the numbers of other potamodromous, rheophilic species, such as European barbel (*Barbus barbus*) and Nase (*Chondrostoma nasus*) have significantly reduced. Since the 1990s, authorities in the Netherlands have reconstructed numerous floodplains to improve the ecological quality of the river systems. This resulted in positive changes to water quality and habitat variability, but not to the expected recovery of rheophilic fish species, an indicator for good ecological quality. We expect that the slow recovery of rheophilic fish populations is mainly caused by insufficient presence and accessibility of those floodplain habitats that function as nursery areas for young fish. To assess the relation between the quantity and quality of these floodplain nursery areas with rheophilic fish recruitment, a large-scale, 4-year (2017-2020) comparative study was initiated. In 2017 450 juvenile fish communities in 59 floodplain water systems along four main branches of the Rhine, covering 351 river km were sampled in a wide-range of floodplain and river habitats. In addition, 39 abiotic and biotic environmental variables were measured. In the first year of this study we caught ca. 135,0000 fish, belonging to 37 species. The eurytopic species *Perca fluviatilis*, *Rutilus rutilus* and *Abramis brama* were most common, accounting for 56% of the total catch. Rheophilic species *Leucistus idus*, *Aspius aspius*, *Alburnoides bipunctatus* and *Chondrostoma nasus* made up only 29% of the catch. Our main preliminary conclusion is that water conductivity, river-floodplain connectivity and especially habitat variability were the main positive drivers of juvenile rheophilic fish abundance in the floodplains, suggesting that in future floodplain reconstructions specific attention should be paid to these aspects.

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Connecting fish, flows and habitats on lowland river floodplains

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Connectivity between river and floodplain habitats is important to many lowland river fishes enabling them to complete their life cycle, maximise growth potential and minimise early life-history mortality. There is increasing recognition of this need and in regulated systems, increasing sophistication of management processes and infrastructure around environmental water allocations to facilitate this connectivity.

Providing connecting flows with limited water resources often means prioritising watering one area over another; so comparative evaluation of fish movement, growth and productivity can be important to demonstrate success.

In the Great Darling Anabranch, we used directional-netting, measures of whole stream productivity and fish otolith growth and body condition analysis to investigate benefits of connecting flows in 500km of restored ephemeral river channel alongside the same factors in an alternative flow-path, the Darling River.

The Hattah Lakes, a complex of regulated, lowland-river floodplain lakes can be filled using large, purpose built environmental pumps; transferring water and fish recruits from the Murray River to productive floodplain habitats. We investigated the lateral movement of resident fish during filling and draw-down of the lakes, using acoustic tags in a native fish species, Golden perch (*Macquaria ambigua*) and an invasive fish, Carp (*Cyprinus carpio*). We generated regular movement-trajectories for tagged fish using interpolation, then tested observations against null models to evaluate individual and group movements against a one-dimensional behavioural hypothesis; “do fish move towards or away from the river in response to draw-down or filling?”

Results are assisting natural resource managers develop designs for environmental watering hydrographs for connecting flows in large anabranch channels and floodplain lakes.

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Barrier Tracker - Using citizen science to build the most comprehensive atlas of barriers in Europe

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There is already a substantial amount of data in existence on the barriers within European rivers. However, even for the most comprehensively audited countries, data is patchy and often of poor quality. Proper assessment and prioritisation of remedial action cannot be undertaken until the full picture is known. Barrier Tracker, part of the Adaptive Management of Barriers in European Rivers (AMBER) project, seeks to address this issue by using a smartphone app to crowd-source data from across Europe. Initially available in 9 languages the app allows anyone to record the barriers they encounter. The app has been designed

to allow a low-level of minimum information to be provided in order to reduce complexity for inexperienced recorders. However, a certain sub-set of data is always required to ensure the data is still useful.

The app also features an interactive map which displays both the app generated data and all of the currently known barrier data from Europe. This means that a recorder can easily check their local area to see if the barriers they encounter have already been recorded. It also provides motivation for recorders to tackle under-recorded areas.

A specially designed citizen science web portal has also been designed to work alongside the app. Owing the fact that many thousands of records are anticipated, the portal contains a section to allow members of the public to classify the barrier data. Classification ultimately leads to verification and/or re-determination of records. Each record has to be classified a minimum number of times and with a set percentage of agreement before verification occurs. Citizen scientists can, therefore, assist with the entire life-cycle of the data.

Having only just gone live at the time of writing, in its first two weeks the app generated over 600 records of barriers from across Europe.

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Working with recreational fishers to restore native fish populations in the murray darling basin australia

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Changes to flow, habitat and connectivity are key threatening processes for native fish in Australia's Murray-Darling Basin. Whist flow management can partially address connectivity and habitat impacts, considerable effort and investment is required to implement complementary measures that address other threats including barriers to fish movement, degraded water quality, invasive species, and habitat loss or fragmentation.

The Murray-Darling Basin Plan is the largest water reform process ever undertaken in Australia. The Basin Plan provides significant opportunities for improving native fish populations, with flow-on benefits for recreational fishing, regional communities, and local economies.

Recreational fishers as a group share a ubiquitous ambition – they want more fish in our rivers. The 430,000 fishers in the Murray-Darling Basin (and many more that visit it to fish) create an industry worth $1.35 billion annually, with substantial contribution to tourism and regional economies. Recreational fishers have an intricate knowledge of their regional waterways and fisheries, and collectively they can provide a great resource for improved management and action.

Managers from the NSW Office of Environment and Heritage and NSW DPI Fisheries (with support from State and Commonwealth agencies) have been working with recreational fishers to share and improve each other's understanding of native fish distribution, the ecological needs of waterways, and the management challenges requiring attention at a Basin scale. Continued collaboration with recreational fishers may help deliver cost-effective complementary measures that address native fish needs such as fixing fish passage, improving aquatic habitat, and managing better water quality. This will in turn contribute to the social and economic outcomes that communities expect from the Murray-Darling Basin Plan.

We will discuss opportunities that effective partnerships with environmental water managers, fish ecologists and recreational fishers can provide to achieve better outcomes for native fish populations across the Murray-Darling Basin.

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Fish Passage Remediation through the NSW Recreational Fishing Trust Habitat Action Grants.

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The NSW Recreational Fishing Licence was introduced on 23rd March 2001. The funds generated by the licence are held in a Trust and used to improve recreational fishing in the state via a number of targeted programs including fish habitat restoration. One of the success stories of the NSW Recreational Fishing Trust has been the Habitat Action Grant (HAG) Program that directs funds to onground works via a devolved grant process. Since the HAG Program began in 2003, over $850,000 has been used to leverage 40 road crossing and weir fish passage remediation projects valued at $7.1M. Importantly, native fish access was improved to over 2,000 km of waterway.

Despite the success of the program, Trust funding for individual HAG projects is capped at $40,000 per year and is primarily directed towards smaller projects involving on-ground works. Such funding is often not enough to tackle larger, more complex projects. Recently, the Trust approved a larger scale version of the HAGs called the Flagship Fish Habitat Rehabilitation Grant for which projects are able to apply for up to $400,000. The Flagship program has allowed for higher priority fish passage programs to be discussed and initiated that otherwise would have been delayed indefinitely. The Flagship program also value-adds to the existing HAG program, achieving a more holistic outcome for fish passage as will be discussed in one northern NSW catchment.

This talk will detail the outcomes achieved by the HAG program and lessons learned along the way. The NSW Recreational Fishing Trust's Habitat Action Grant Program and Flagship Fish Habitat Rehabilitation Grants are an excellent example of the NSW licence fee being directed back into the fishery to provide long term, permanent improvements to the waterways of NSW.

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Twenty years of fish passage policies establishment in Brazil: a review of the current status of fish passage science

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TBA

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Diverse options for monitoring fishway effectiveness using PIT tag technology

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Fishway designs are as varied as the species that use them. After almost two decades of designing PIT tag detections systems to monitor fish passage, Biomark has developed an offering of antennas that range in size, shape and construction technique, to provide an optimal solution for each location and budget. Biomark uses it's IS1001 Multiplexing Transceiver System (IS1001 MTS) as the backbone for monitoring systems and selects power and remote monitoring solutions depending on the specific location and unique customer requirements.

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Barriers to migration: impacts of barotrauma on fish physiology

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Brazil is home to some of the largest dams in the world, relying on renewable energy sources for electricity generation, and with aims to further expand. It also boasts the greatest continental species richness on the globe, housing approximately 2300 freshwater fish species including a number of commercially viable migratory species. Migratory *Prochilodus lineatus* ("Curimbatá" or "Curimba" in Portuguese; "Sábalo" in Spanish) are considered to be a keystone species due to their importance within the food chain, and internal consumption and exportation value. Accounting for 50 – 90 % of the biomass in its primarily native Paraná river basin, populations are on the decline, with breeding programmes in place in an attempt to restock waterways.

Large scale hydropower dams act as inaccessible barriers to migration, causing blockades, physiological damage, and mortality across life-stages including sexually mature adults, juveniles, and drifting fertilised eggs. Mortality rates of fish at hydropower sites are measured by the tonnage. Instant death or injury is well understood as a result of blade strike, however less well understood are the indirect physiological effects of rapid pressure fluctuations.

Using a custom built, manually controlled barotrauma chamber, *Prochilodus lineatus* were exposed to simulations of rapid decompression, similar to those occurring in a turbine, to assess the injurious effects on fish physiology. Tested scenarios using different rates of pressures changes (RPC), only represented a fraction of what may be experienced whilst traversing hydropower structures. Results of internal and external damage assessment (*i.e.* heart emboli; gill emboli; stomach emboli; expanded swimbladder; ruptured swimbladder chamber; or external haemorrhaging) however collectively indicate that even slight increases in RPC can cause irreparable damage to physotomous fish physiology.

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Real-time remote water quality, flow and ecological response monitoring of waste water treatment works and dams in the uMgeni catchment (FISHTRAC programme): design, implementation and preliminary results

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The Mgeni River is a high use and economically important river with various dams established to supply the city of Durban with water resources. Further the catchment has two major cities within the province of KwaZulu-Natal, South Africa, affecting the uMngeni River's water quantity and quality. Using radio-telemetry (FISHTRAC) to characterise the behaviour of Yellowfish (*Labeobarbus natalensis*) within the uMngeni River, can provide a means to measuring an ecological response of the ecosystem to water quantity and quality changes. To do this, water quantity and quality are measured alongside the behaviour of *L. natelensis* with the use of water quality probes. These water quality probes are linked to the FISHTRAC system through a Data Management System (DMS) and record pressure (converted to discharge), temperature and conductivity. These water probes are placed in the same reach as tracked *L. natelensis* where the activity, temperature and location of tagged *L. natalensis* are recorded on the same DMS. The project is still in its developmental phase and aims to bring these components and variable together to create an early warning system for water resource managers. Currently the remote networks (wireless wildlife) has been established and are strategically placed to detect the water probes and tagged fish. The water quantity and quality coming

from the water quality probes placed strategically downstream of waste water treatment works and dams currently detect changes to these variables. The use of fish movement in combinations with the water quality data can be set at various limits to alert manages to potential water quality issues prior to becoming disastrous. This is being done remotely and in real time through a DMS allowing a rapid response. This presentation aims to show the concept and some preliminary results in setting up the water probes and *L. Natalensis* movements.

1. O'Brien GC, Jacobs FJ, Burnett MJ. Kruger P, Botha IF, Cordier JA. 2013a. Remote and manual radio telemetry methods to monitor and use fish behaviour in South Africa's inland waters. Report No. 2111/1/13. Pretoria: ISBN: Water Research Commission, Pretoria.

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A novel mechanical test to better understand the impact of repeated invasive parasite infection *(Anguillicoloides crassus)* on the critically endangered European eel *(Anguilla anguilla)*

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European eel (*Anguilla anguilla*, L.) populations have drastically declined over the last 40 years. Arguably, the artificial introduction of invasive parasite, *Anguillicoloides crassus*, now widespread across Europe, may be one of the most detrimental contributing factors to rapid reductions in numbers. This swimbladder residing nematode causes structural and inflammatory pathological damage within a naïve organism, with immune responses inducing physical changes which include a reduced swimbladder volume and thickened biotissue wall. Capable of reinfection across a range of life stages and with a relatively short lifecycle in comparison to its host, absence of nematodes does not necessarily provide insight into epidemiological life history.

Previous studies have utilised gross pathology indices to evaluate impacts of the parasite on eel swimbladder degeneration. These studies however have their limitations due to degrees of subjectivity, and high reliance on information taken from measurements of infection at a single point in time, rather than assessing an entire infection history. Literature alludes to mechanical and structural damage, however other than one study to date, mechanical properties of the damaged swimbladder wall have yet to be directly characterised.

This study uses a simple novel interdisciplinary approach to mechanically test European eel swimbladder biomaterial, conducted utilising specialist tensile strength machinery. Use of thickness and strength measurements are arguably a more robust and direct characterisation of the repeated infection history of an individual.

Better understanding degenerative impacts on the swimbladder and subsequent completion of reproductive migrations is essential to prevent further reduction in species recruitment and escapement. Furthermore provisioning of such information could assist in the implementation of better mitigation and monitoring strategies.

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Fish migrations in the Volga River, Russia: Considerations for management of longitudinal connectivity

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The Volga is the longest river in Europe and 16th longest in the world and it is of exceptional cultural and economic importance. A cascade of large, shallow reservoirs affects most of the hydrological regime of the Volga, from Tver (near Moscow) to Volgograd. The dams and their backwaters changed the appearance of the river and caused significant obstruction for migratory fish. Once iconic long distance anadromous migrants spawning in Upper Volga up to 3500 km from the delta e.g., Beluga, Starry Sturgeon or Caspian Trout practically disappeared from the river system and are on the verge of extinction. Nowadays, the three fish-passing structures that exist along the main river (two fish-sluice locks at the water divider in the delta, a hydraulic fish lift in the dam of the Volgograd Hydroelectric Power Station and a mechanical fish lift at the Saratov hydroelectric complex) are shut down and passage is only possible through ship locks. Overall multiple anthropogenic stressors impact migratory fish populations in the Volga basin e.g., hydromorphological alterations, pollution, invasive species as well as fisheries and poaching. Currently there is an extremely low level of control and management in the field of conservation of natural reproduction of fish and provision of migration. To restore longitudinal connectivity, it would be necessary to build and operate new fish-passing structures as well as ensure suitable habitats for spawning. A fish lift might be feasible to support migration if spawning habitats or lateral connectivity upstream are available. Natural bypass channels solutions may support migration as well as spawning grounds at the same time. Furthermore, it is also important to consider the descent of anadromous fish towards their feeding grounds in the Caspian Sea. Thus strategies also need to consider turbine passage as well as suitable downstream bypass structures.

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Re-establishing connectivity and habitats: Considerations for fish passage in large rivers

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In order to achieve the targets of the European Water Framework Directive, it is important to think on a catchment scale, as the re-connection of river stretches might not improve ecological integrity in case suitable habitats are missing. Concerning large rivers, in some cases, re-establishment of connectivity might be only feasible using technical solutions due to limited space availability or huge reservoir water level fluctuations. We show example of fish lift in the case study Runserau. In this case suitable riverine habitats are available in the main channel or tributaries, thus re-connection is a suitable stand-alone measure by connecting free-flowing sections. On the other hand, within a chain of impoundments along a large river there is often a deficit of spawning and larvae nursery habitats for fish. Thus bypass channels that orientate on a natural side arm concerning slope, morphology and hydrology successfully feature passage, but also provide new additional type-specific habitats, that contribute to the ecological potential of the river system, as exemplified by the nature like bypass channel Ottensheim-Wilhering. These two examples show the necessity of systematic analyses to find reasonable and sustainable measures in order to manage and re-establish connectivity in rivers with multiple anthropogenic uses.

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Does a large catch of fish behind a fish passage automatically mean a successful fish passage

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Flood control is an important issue for the Dutch coast, as about two thirds of the country is vulnerable to flooding. However, migratory fish are hampered by tidal barriers when they want to reach for freshwater habitat. Therefore, several tidal barriers are equipped with fish passages for relevant migratory species. Often, these fish passages are tested by a monitoring program using a net behind the fish pass. A large catch in these netting programs are automatically used to mark a successful designed fish passage. However, the majority of these fish passes are not tested for effectiveness in terms of local abundance, migratory delay and successful migration (%). In spring 2017, a mark recapture experiment was carried out by tagging 2187 glass eel (*Anguilla anguilla)* to estimate abundance and to evaluate a fish passage in a pumping station located in Scheveningen. Before fish can reach freshwater habitat they first have to pass two separated harbours, a floodgate and a pumping station. Previous netting programs behind the fish passage showed thousands of successful migrants.

Two methods were used two evaluate the effectiveness of the fish passage in the pumping station: group dyeing (0.05gr/L Bismarck Brown Y) and Visible Implant Elastomer tags. Glass eel were caught, marked and released in a harbour in two consecutive periods. In total nine eel successfully passed the fish pass showing a low migration efficiency (<1%). Based on mark-recapture assessment at least 34.000 glass eel had accumulated in front of the floodgates with a residence time of at least 20-43 days in the system. Data analysis showed that the complex is hampered by the flood gates and limited attraction flow. However, data also showed that glass eel need limited migration opportunities to migrate to the pumping station. Therefore, limited adjustments will probably improve migration efficiency of the complex.

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CFD modeling and validation of the flow over a gabion weir structure

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The flow over gabion weirs presents distinctly different characteristics compared to regular non-porous weir structures. Because of the permeability of the gabion weir, a portion of the flow moves through the structure which results in a lower upstream hydraulic head for a given discharge as compared to the solid concrete weir. Mohamed (2009) experimentally determined the discharge and free surface profile characteristics for a gabion broad crested weir over a range of flow and gabion wall porosity configurations. It was demonstrated that standard weir equations and discharge coefficients for solid weirs cannot be used for gabion structures.

It is known that computational fluid dynamics tools (CFD) can offer excellent representations of complex free surface flows over weirs, what is less known is that CFD tools can also model porous structures and their effect on free surface hydraulics. Drawing on Mohamed's experimental results, a CFD model which incorporates the weir's porosity and upstream conditions was run to replicate the experiment. Excellent validation was obtained, indicating that CFD methods may be a valuable consideration in the design of fishway passages that include gabion weirs in their design.

1. Mohamed, H. I. (2009). Flow over gabion weirs. Journal of Irrigation and Drainage Engineering, 136(8), 573-577.

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Providing refuges for adult Pacific lamprey inside fishways

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Fishways are unnatural environments that typically present fish with uniform depth and lack of cover. Rest and sheltering areas inside fishways may improve retention and overall fish passage. We examined adult Pacific lamprey *Entophenus tridentatus* use of two specially-designed fishway refuges at Bonneville Dam on the Columbia River (northwestern USA). The 1.1 × 0.4 × 0.2 m boxes provided low-velocity, dimly lit refuges from predation for Pacific lamprey, a largely nocturnal species. The boxes were equipped with antennas to detect lamprey tagged with passive integrated transponder (PIT) tags (*n* = 3,248 released). In each year of study (2012-2014), 13 – 49% of the PIT-tagged lamprey detected at the fishway exit had used a refuge box. In addition, 63 of 217 (29%) of lampreys double-tagged with PIT tags and radio transmitters detected in the study area used a refuge box. The average residence time of lamprey in the boxes in each year was 49.7 h, 57.2 h, and 52.8 h. There was evidence that lamprey entrance into the boxes peaked at 0300 – 0500 hr and that they typically left the boxes in evening at around 2000 hr. Hence, the boxes probably functioned mostly as a refuge from daylight. Analysis of radiotelemetery data indicated that refuge box users were equally likely to pass over Bonneville Dam as non-users. However, refuge box users were detected less frequently than non-users at sites upstream from the dam, perhaps owing to their longer passage times through our study area (2.0 d versus 0.6 d). While refuge boxes show promise for improving lamprey collection or retention in fishways, further study is needed to ensure that this does not occur at the expense of lamprey fitness.

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Coanda Intake Efficiency Test on the downstream of trout in a french river.

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Coanda Intake Efficiency Test on the downstream of trout in a french river.

To ensure sediment transit and restore fish continuity, two Coanda-type water intakes with a 15mm inter-bar spacing were installed in Escouloubre and Aiguette in October 2015 on hydropower plants operated by EDF.

The objective of the monitoring presented here is to evaluate, by RFID technique, the efficiency of the system on the trout downstream.

The site of Aiguette (photo above) was equipped with 3 antennas :

- A first upstream of the sampling grid: recording of fish crossing the structure by the grid plan.
- A 2d at the outflowing outlet: detection of fish having taken this downstream path.
- A 3rd downstream of the water intake: detection of all fish leaving the system (photo below antenna and recorder)
- Sensitivity of detection is between 10 and 40 cm

The 279 trout were caught on 22/09/17 upstream of the site by electric fishing (see distribution chart below) and then anesthetized with eugenol, before Pit Tag operations.

The Trout between 50 mm and 90 mm (36%) were marked with 12 mm PitTag, those greater than 90 mm (64%) with 23 mm PitTag. (see photo). Emitters are placed in the abdominal cavity by surgical technique

No mortality was observed, the fish were then released upstream of the catch.
The other site of Escouloubre has been equipped in a similar system with 3 antennas and 302 trout.

Measurement studies were carried out at the beginning of 2017 and in the spring of 2018.
The poster will present the results of these studies.

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Assessing the effects and varied release mechanisms and operations and storage volume on thermal regimes downstream of a large reservoir

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Cold water pollution occurs below large dams when hypolimnetic water is released during periods of thermal stratification, with water temperatures being up to 16°C below predicted natural temperatures. Hypolimnetic releases can impact thermal regimes of downstream river systems for up to 300 km. These temperature changes can affect the health of aquatic biota such as algae, macroinvertebrates and fish. An innovative thermal curtain, being a large polymer structure suspended within the water column, was installed on a large dam on the Macquarie River, Australia in 2014 as an economical solution to mitigate cold water pollution by drawing epilimnetic water to the low-level fixed valve. Following implementation of the curtain, temperature improvements of 2.5°C were observed during summer whilst the dam was at low capacity. In 2016, the dam filled to full capacity, leading to a mixture of curtain, spillway and bottom releases. The effect of storage volume and varied release mechanisms from the dam will be discussed in terms of their impact on cold water pollution and downstream thermal regimes.

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The invention of fish escalator

Manuel Enrique Posada González

THE FISH LADDER / FISH ESCALATOR

A new system is developed that respects the water creatures, taking advantage of hydroelectric energy and without causing damage to the environment. This invention is based on the screw without end of Archimedes and assumes the real possibility of postage of obstacles in rivers, facilitating the rise and descent of fish without problems or damage to their physical ability. The travel along the endless screw does not entail any effort for them. Likewise, the device generates electrical energy during the descent of the fish, in this way its operation will be self-financing without any charge for the administration or the owners of the concession, since it produces an economic return through the sale of the generated electric power. The idea was patented in Spain and PCT international treaty. The fish lift is achieved by the mechanical drive by electric motor, an endless screw or Archimedes, located in an adapted channel, with the axis inclined with respect to the horizontal, which rotates on its axis clockwise, allows raise the water of the rivers, including the fish existing in it. The operation of raising the fish is done to fulfill their desires of upward migration. It is set in motion by operators who constantly monitor this need. The descent of the fish is achieved through the passage of water with the fish through the endless screw, which inducing a levorotatory turn in the screw, is used to produce electrical energy by the same electric motor operating as a generator. The compliance with the legal ecological flows, the electricity generation allows financing the investments and maintenance costs of the system, without additional costs for the concessionaire of the use of water, and for the Administration.

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Pontic shads at the Iron Gates

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The Pontic shad (*Alosa immaculata* Bennett 1835) is an anadromous clupeid that grows to reproductive age in the Black Sea and migrates into the Danube via principal delta branches to spawn upstream. Spawning takes place at different times and different river kilometers, with most individuals spawning only once during their lifetime. The Pontic shad's maximum migratory route, hence its range, was shortened to rkm 863 by the construction of the Iron Gates 2 dam (IG2) in 1984. Another dam is located farther upstream at rkm 943. Adults that migrate for spawning to IG2 traverse territorial waters of four different countries. Despite the species' high commercial and cultural value, its population decline (listed as Vulnerable by IUCN) and disparate national fishing regulations, current knowledge of its life history, population structure and migratory behavior up the Danube remains surprisingly poor. To develop species-specific molecular tools and obtain a more detailed image of meta-population structure and the migratory behavior of sub-populations, from 2016 to 2018 we sampled in a variety of locations throughout spawning migration season. Preliminary population genetic analyses indicate that individuals reaching the IG2 dam are more closely related to those migrating up the northern branch of the delta, shared by Romania and Ukraine, than those migrating up the southern branch which is in Romania. Knowing more about the migration timing and routes of fish arriving at the IG2 dam can help guide decisions about the need for their passage at the dams and possible technical solutions. Currently, any effort to construct fish passes at the Iron Gates would require international collaboration and immense financial investment. Using existing navigation locks may be a solution, but more knowledge is needed about fish behavior at the dams. Environmental DNA sampling, to be developed on the basis of this research, is a promising tool.

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Fragmentation of Europe's rivers: a pan-European atlas of river barriers

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Rivers are some of the most threatened ecosystems in the world and a major focus of restoration programmes in Europe and elsewhere. A major challenge to achieving good ecological status, as required under the EU Water Framework Directive, is the reduction of fragmentation of river habitats caused by many thousands of barriers. Strikingly, the real number and location of barriers in Europe is, currently, unknown. In that context the H2020 AMBER project addresses the issue of river fragmentation in European rivers and seeks to apply adaptive management of barriers at multiple scales to achieve more efficient restoration of river connectivity. AMBER is building the first pan-European database of stream barriers across Europe, collating and harmonising existing databases at national and regional scales.

We present here the most up-to-date database on the distribution, typology and drivers of river fragmentation at the pan-European scale. From the 48 national and regional barrier databases collated, >260,000 barriers were identified. Of these, 60% of barriers could be attributed to one of six common barrier types whilst the remaining 40% were of unknown type; 62% were without height attributes; c. 30% lacked river or basin name and only 7% included information about fish passage. We integrate this new information with pan-European datasets on climate, geography and socio-economic data to derive meaningful drivers of barrier density, from which barrier distribution can be inferred in countries and regions where data are scarce.

This approach allows the generation of a more realistic picture of river fragmentation at the national and European scale with regards to impacts on sediment, water and biota connectivity that can inform future barrier monitoring and management.

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Rehabilitating and Restoring Unique Landscapes within Five Nova Scotia Watersheds along the Bay of Fundy, Nova Scotia, Canada.

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The watersheds of the inner Bay of Fundy are important both ecologically and culturally. They are critical habitat for the endangered inner Bay of Fundy (iBoF) Atlantic Salmon (*Salmo salar*) and were significant cultural and harvesting sites for our land's first inhabitants, the Mi'kmaq People. Unfortunately, the watersheds have become degraded over time due to anthropogenic activities, leaving watercourses inaccessible or unsuitable for fish and consequently impacting the food, social, and ceremonial fishing activities of the Mi'kmaq.

Our five year study will investigate and address areas of fish habitat concern in the Chiganois, Debert, Folly, Great Village, and Portapique Watersheds. Through reconnaissance and surveys, planning, engineering, physical labour, and community support, we will help to restore fish habitat by enhancing coastal entry points and removing obstructions from migration routes for iBoF Atlantic Salmon and other migratory fish. Additionally, our study will collect local community knowledge and Aboriginal Traditional Knowledge about watercourses in each watershed to determine changes in the anthropogenic and fish use of the watercourses over time. This information will be used to set restoration goals and inform the restoration planning process. We will also assess and propose innovative solutions for modification or replacement of the aboiteau on the Chiganois River to improve fish passage in collaboration with engineers, project partners and community members.

The outcomes from this project will be: 1) increased knowledge of the five watersheds and their use by both fish and humans presently and in the past; 2) a scientifically supported management plan for each watershed that prioritizes fish habitat restoration actions; 3) increased capacity of local communities to protect, monitor, and restore fish habitat.

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Fish friendly turbine and power plant layouts

Manuela Winbeck, Christian Winkler

DIVE Turbinen GmbH & Co. KG is developing and manufacturing the DIVE-Turbine, a fish friendly hydro power turbine. Moreover DIVE Turbinen GmbH & Co. KG is also developing complete ecological hydro power plant layouts for worldwide application. In 2016 the first field tests on fish friendliness of a DIVE-Turbine were conducted at a hydro power plant in France. DIVE Turbinen GmbH & Co. KG would like to present their turbine concept, fish friendly hydro power plants as well as the results of the firs field tests.

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A variable-geometry flume for optimizing small-scale fishway designs

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Fishways are frequently expensive to construct and the designs of proposed structures are commonly based on knowledge gained from existing structures, assuming that structures that allow passage of the species of interest exist. Developing an apparatus that allows rigorous testing of fishway structure designs prior to the construction of structures in the field could reduce the reliance on a "build it, monitor it, does it work?" approach, thus saving limited resources. Such an apparatus would also allow testing of the response of target fish species to design parameters (e.g., slope, roughness elements, water depth, etc.). As part of a larger project evaluating the performance of rock ramp fishway designs for fish native to the U.S. Great Plains, we designed and built a 9.1-m long x 1.4-m wide indoor research flume at the Colorado State University Foothills Fisheries Laboratory and installed a 6-m long experimental rock-ramp fishway within the flume. The flume can be adjusted from 0 to 10% slope, and incorporate curved sections from 45° to 180° in 45°-increments to allow testing various fishway configurations. Fish movements within the flume are tracked by an array of four dual-mode (full duplex/half duplex) PIT tag antennas. Flows up to 0.10 m^3/s (3 cfs) are recirculated through the flume with a 15-hp pump; water temperature is controlled by a heater and chiller and can range from 10°C to over 25°C. Lessons learned during the design, construction, and operation of the flume are discussed in the poster.

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Exploring Chinook salmon passage through the world's longest wooden fishway in the Upper Yukon River

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Upper Yukon River Chinook Salmon populations (*Oncorhynchus tshawytscha*) maintain some of the longest salmonid spawning migrations on earth (~3200 km) despite experiencing severe declines over the past century. To access the majority of spawning habitat, Upper Yukon River Chinook Salmon must pass the Whitehorse Hydro Plant (WHP) via the world's longest wooden fishway (366 m). More than five decades of successful passage and subsequent spawning upstream provide clear evidence of individual passage success, although sub-lethal and population-level consequences of passage are unclear. Stakeholders have identified the movement of Chinook Salmon through the Whitehorse Rapids Fishladder as a priority research initiative in the recovery of Upper Yukon River Chinook Salmon populations. We evaluated the effectiveness of this fish ladder at facilitating fish passage including the attraction efficiency of the ladder and the ultimate fate of fish following successful passage. To address these objectives, acoustic transmitters were gastrically implanted into approximately 150 fish of wild and hatchery origin that were released either within or below the fish ladder in 2017 and 2018. An array consisting of twenty acoustic receivers was deployed providing coverage at the WHP and all major tributaries both up and downstream of the WHP. Behaviour below the fish ladder, proportion of fish entering the ladder, and the ultimate fate of each fish were quantified. This research will provide insight on the potential implications of fish ladder design and operations on the productivity of Upper Yukon River Chinook Salmon populations which may inform future management of ladder operations.