Institution: University of Southampton

Unit of Assessment: 15 General Engineering

Title of case study: 15-36 Protecting Fish at River Dams and Barrages: New Approaches for Endangered Species

1. Summary of the impact

Research at the University of Southampton into the behaviour of fish at dams has led to the improved design and positioning of screens to prevent economically important and endangered fish from being killed in turbines, as well as enabling them to pass barriers more successfully through improved fish passes. The research has informed practical changes to river infrastructure in the UK, Sweden, the USA, and China. It also led to development of methodologies for river restoration and planning which have aided the implementation of new conservation legislation, and quantification of the environmental impacts of beaver dams on fisheries.

2. Underpinning research

Dams and barrages are a feature of over 60% of the world's largest rivers (International Union for Conservation of Nature). Whilst essential to the quality of human life, they negatively impact ecosystems and fisheries worth US$ 70 billion per year by blocking fish migration or damaging them during passage through turbines. In England and Wales alone, the cost of mitigation by installing screens and fish passes to meet international environmental legislation will be £532 million (Environment Agency (EA)). Unfortunately, many fish passes and screens are inefficient because their design is biased towards iconic fish like salmon, ignoring the swimming ability and behaviour of other protected species.

Since 2005, Dr Paul Kemp (Reader in Ecological Engineering) and colleagues, at the Faculty of Engineering and Environment, have developed new approaches to address these issues. In 2007-2009, Kemp et al. experimentally quantified the swimming performance and behaviour of European eels. Since the 1980s, eel populations have collapsed by over 90%. River features like hydroelectric dams are among the main causes, as up to 100% of eels passing through turbines can die. The research, using large flumes in Southampton [3.1] and field-based methods with radio-tagged eels in Sweden [3.2], was funded by the EA and Swedish hydropower companies (e.g. E-ON) in collaboration with the University of Karlstad (Sweden). Traditional screens designed for salmon were less effective for eels [3.1] that either suffocated when impinged against the screen, or pass through to perish in the turbines. Further, providing alternative routes is ineffective if their design is wrong. Many fish resist entering small, dark pipes, so cover can be used to discourage them from approaching screens and turbines [3.3].

On-going research at Southampton since 2005 (e.g. funded by European Commission 7th Framework Programme FP7) led Kemp to develop and lead a Leverhulme Trust International Network to review and agree on challenges faced in fisheries engineering and provide future research recommendations [3.4].

Since 2007, Kemp et al. have also focused on optimised river restoration planning, as developed countries have a legacy of redundant river engineering structures which might be removed. Legislation (e.g. EU Water Framework Directive, WFD) requires that new development be environmentally sustainable. The methodology developed assesses the impact of structural barriers on fish movement, using results to prioritise planning and restoration efforts. The resulting model [3.5] recognises the interconnectedness of river networks. Initially commissioned by the Scottish Environment Protection Agency (SEPA) the research is currently funded by the EA and the State of California.

Work in China and South America, carried out from 2010-2011, helped rapidly developing countries that maintain the worlds' largest freshwater fisheries to avoid repeating past mistakes made by the developed nations.

In response to concerns raised by the Scottish Salmon Fisheries lobby, the Scottish Executive commissioned in 2008-2010 Kemp et al. to assess the impact of dam building by reintroduced beaver on fish populations. Results of interdisciplinary research indicated beaver dam building activity would likely have positive influences on fish populations [3.6].

3. References to the research (the best 3 are starred*)

3.1 Russon, I. J., Kemp, P.S. and Calles, O. 2010. Response of downstream migrating adult European eels (*Anguilla anguilla*) to bar racks under experimental conditions. *Ecology of Freshwater Fish* **19**, 197-205.

3.2* Calles, O., Olsson, I.C., Comoglio, C., Kemp, P. S., Blunden, L.S, Schmitz, M. and Greenberg, L.A. 2010. Size-dependent mortality of migratory silver eels at a hydropower plant and implications for escapement to the sea. *Freshwater Biology* **55,** 2167-2180.

3.3 Russon I. J. and Kemp P. S. 2011. Advancing provision of multi-species fish passage: behavior of adult European eel (*Anguilla anguilla*) and brown trout (*Salmo trutta*) in response to accelerating flow. *Ecological Engineering* **37**, 2018-2024.

3.4 Kemp, P.S. 2012. Editorial – Bridging the gap between fish behaviour, performance and hydrodynamics: an ecohydraulics approach to fish passage research. *River Research and Applications* – Special Edition DOI. 10.1002/rra.1599, and related articles therein.

3.5* Kemp P.S. and O'Hanley, J. 2010. Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. *Fisheries Management and Ecology* **17,** 297-322. In 2010 this article was the most accessed from the journal website and was selected by the editors as the most outstanding publication of the year.

3.6* Kemp, P.S., Worthington, T.A. and Langford, T.E.L. 2011. Qualitative and quantitative effects of reintroduced beavers on stream fish. *Fish and Fisheries* **13**, 158-181.

Grants

EUFP7 Hylow. Co-ordinator - Dr Gerald Muller (University of Southampton). Development of Hydropower Converters for very low head difference. 4 years, 2008 – 2012. Total value = €3.7 million. Value of fisheries component - £350,000.

Leverhulme Trust International Network Grant. Bridging the gap between fish behaviour and hydraulics. 3 years, 2008-2011. Total value of the grant = £69,000.

4. Details of the impact

The outputs produced by Kemp et al. have had international impact in fisheries engineering, and river restoration and planning. Kemp advises the EA and DEFRA on fish passage, and the Parliamentary Office of Science and Technology on the Hafren proposal for a Severn Estuary barrage. Research on eel swimming ability and behaviour has been incorporated in the EU eel regulations, which require measures that allow 40% of adult eels to escape from inland waters to the sea. Until Kemp's research, information needed to provide effective screens for eels had been lacking. In 2010 the research findings were used by the principal Swedish hydropower company, E-ON, who installed and evaluated new screen designs and fish collection facilities at the Ätrafors Hydroelectric Power plant, testifying that Kemp's advice had strongly contributed to the success of the project: "*As a result of the research on developing screens for eels led by Dr Calles at the University of Karlstad and Dr Kemp and colleagues at the University of Southampton, new screen designs and fish collection facilities have been implemented and evaluated at the Ätrafors HEP. This is the first of its kind in Scandinavia*." [5.1].

In the UK, the research findings on eels were incorporated into the EA's guidelines for hydropower and other abstraction points in 2011 [5.2]. In 2011, the guidelines were launched and disseminated at the Institute of Fisheries Management's International Fish Screening conference in which Kemp gave an invited keynote presentation, and Russon (Kemp's PhD student) was

employed by APEM (the UK's leading fisheries Environmental Consultancy) as a direct result of his expertise in fish passage for eels and lamprey.

Kemp has applied his research to assess fish response to fluid dynamics to several real life challenges. In 2008 the climbing ability of Pacific lamprey (funded by the US Army Corp of Engineers – USACE) was quantified to aid conservation efforts in collaboration with the US National Oceanic and Atmospheric Administration (NOAA) and the Confederated Tribes of the Umatilla Indian Reservation. Lamprey harvest is ceremonially important to the Tribes, but numbers have been declining rapidly, partly due to dams impeding their return to river systems to spawn. There were no previous detailed studies of their behaviour. Kemp's description of climbing behaviour and performance was fundamental in the design, installation, and full field testing by USACE of novel lamprey-specific fish passes at dams on the Columbia River (Washington State) costing several million US dollars. A testimonial from NOAA National Marine Fisheries Service stated: "*This research was applied directly in the design and modification of lamprey passes installed at lower Columbia River hydropower dams, and is now being applied to the development of lamprey passes at the ubiquitous low-elevation irrigation diversions in the Columbia River Basin. Moreover, the work has been instrumental in development of methods to assess the efficacy of these structures. Thus, this research collaboration is a prime example of the extension of research to a direct application developed to aid in recovery of an imperiled fish species*." [5.3]. There are now plans to construct further lamprey passes in the Pacific Northwest based on Kemp's work.

In China, where dams are being constructed more rapidly than anywhere else in the World, Kemp et al.'s research has aided the development of fish passage criteria for economically important species of carp on the Yangtze River since 2009. Kemp et al. provided data on swimming capability and behaviour of Chinese carp to the Ministry of Water Resources, who incorporated them into the design of fish passes. Kemp (representing the European Union) also presented data on the environmental impact of hydropower development on fisheries and potential for mitigation at the 4th Yangtze River Forum (Nanjing 2011) [5.4]. This influenced Chinese policy makers to develop a research programme on fish passage and screening. A testimonial from the Ministry of Water Resources, China, stated: "*With the advice of Dr Kemp, the Institute has designed about 20 fish passage facilities for hydropower projects all over China; among which the trap and haul system at Pengshui Dam (the first of this kind in China). Dr Kemps' presentation at the Yangtze Forum and the Training Courses convinced Chinese policy-makers that some research needs to be done before design of fish passage facilities; it is a regulation now that the swimming capability of fish must be tested before designing fish passes. With the assistance of Dr Kemp, our research team has been formed, from a couple of persons at the beginning to more than 15 fellows at the present, which is playing a leading role in China*" [5.5].

In Sweden, full scale field trials were conducted in 2007 based on Kemp et al.'s experimental research finding that overhead cover can discourage downstream migrating trout from entering turbine intakes [5.6]. Structures creating overhead cover were subsequently strategically installed at hydropower stations to deter fish from approaching turbine intakes.

Kemp's modelling tool for assessing the impact of barriers and prioritising their removal or mitigation (e.g. construction of a bypass) was adopted in Scotland by SEPA and continues to facilitate the on-going implementation of the EU Water Framework Directive (WFD) there [5.7]; Scottish fisheries officers are trained in the use of Kemp's methodology. Kemp's research article and report [3.5] have been widely accessed worldwide; the methodology is being adopted in several states. Kemp and co-author O'Hanley (Senior Lecturer University of Kent) were commissioned by the State of California in 2011 to help develop a similar optimisation tool. A testimonial from the Fisheries and Wildlife Service in California stated: "*The California Fish Passage Forum commissioned Drs. Kemp and O'Hanley to complete this project based on examples of their past and current related work, published history of international excellence in this field, and an outstanding proposal for this project…….. After an extensive literature search related*

to this type of assistance, we were very pleased to speak with Drs. Kemp and O'Hanley and learn about their highly innovative work and published research related to prioritizing aquatic habitat restoration projects using optimization methodologies. ……, the Forum was extremely impressed by Dr. Kemp's and Dr. O'Hanley's unique and proven ability to combine academic excellence and real world applicability to complex social and natural resource issues" [5.8]. In the UK, results have been shared with DEFRA, and Kemp was commissioned by the EA in 2012 to develop the methodology in the South East region, providing proof of concept for development nationally [5.9]. In 2012 Kemp was invited to Brazil to give keynote presentations to CEMIG (one of Brazil's largest power generators) and at the Sympass II international conference on fish passage on adapting the methodology to help develop hydropower while minimizing environmental impacts.

The research commissioned by the Scottish Executive was used to form a response to objections raised against the reintroduction of beaver by the powerful Scottish salmon fisheries lobby. The research has been disseminated as a public report [5.10] and has gained considerable media attention in the UK, EU and the US where beaver reintroduction continues to gain interest. Kemp currently holds a position on the Beaver-Salmonid Working Group preparing a position statement for the Minister in 2014.

5. Sources to corroborate the impact

5.1 Testimonial from Johan Tielman - E.ON Vattenkraft (Swedish Hydropower Company).

5.2 *Use of information gained from experimental eel screen study as part of EA official guidelines:* Environment Agency 2011. Screening at intakes and outfalls: measures to protect eel. The eel manual – GEHO0411BTQD-E-E. Published by Environment Agency, Horizon House, Deanery Road, Bristol BS1 5AH.

5.3 Testimonial from Dr Mary Moser - NOAA National Marine Fisheries Service.

5.4 Kemp, P.S., Eakins, L., Han, D., Chang, J. and Shi, X. 2011. Environmental impacts of hydropower development on sustainable fisheries of the Yangtze River and potential mitigation options. Proceedings of the 4th Yangtze River Forum – Ecological Protection and Restoration of Waters. Nanjing, China, April 2011.

5.5 Testimonial from Prof. Deju Han, IHE, Ministry of Water Resources, China.

5.6 Greenberg, L., Calles, O., Andersson, J. and Engqvist, T. 2012. Effects of trash diverters and overhead cover on downstream migrating brown trout. *Ecol. Eng.* **48**, 25-29.

5.7 Commissioned guidelines on rapid assessment methodology for barriers to fish migration – Scotland and Northern Ireland Forum for Environmental Research (SNIFFER). Kemp, P.S., Russon, I.J., Waterson, B., O'Hanley, J.R., and Pess, G.R. 2008. Recommendations for a "coarse-resolution rapid-assessment" methodology to assess barriers to fish migration, and associated prioritization tools. Final Report. http://www.sniffer.org.uk/Webcontrol/Secure/ClientSpecific/ResourceManagement/UploadedFiles/SEPA_WFD111_Phase1_FishBarrierPorosity_FinalReport.pdf

5.8 Testimonial from Dr Donnie Radcliffe - US Fisheries and Wildlife Service in California.

5.9 A testimonial from the Environment Agency on the importance of the methodology for developing a national tool can be made available on request.

5.10 Commissioned report on impact of beavers on fish populations – Scottish Natural Heritage http://www.snh.org.uk/pdfs/publications/commissioned_reports/349.pdf which generated considerable media interest e.g. http://www.scotsman.com/the-scotsman/environment/beleaguered-beavers-are-fishermen-s-friend-claim-scientists-1-2460418.