Section A

Institution: Durham University

Unit of Assessment: UoA 5 Biological Sciences

Title of case study: Reducing impacts of river engineering infrastructure on fish migration and dispersal

Period when the underpinning research was undertaken: 2000 to 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dr. Martyn Lucas	Associate Professor (Reader)	1992-present

Period when the claimed impact occurred: 1st August 2013 to 31st July 2020

Is this case study continued from a case study submitted in 2014? No

Section B

1. Summary of the impact

The global value of inland fisheries exceeds GBP83 billion and supports 0.25 billion people (Food and Agriculture Organisation, 2018). The ecological services value of river fish diversity likely far exceeds the fishery value, through processes such as nutrient transport and ecosystem engineering. Dr Lucas' team demonstrated that various river fish species rely on free movement much more than previously recognised and that even small, engineered, river structures can act as barriers, including for economically important and conservation-listed species (Figure). In this regard the research has promoted the conservation of fish diversity, including exploited species, in rivers impacted by humans in 73 countries. The Durham team demonstrated that conventional fish passes can be ineffective for a variety of species. Accordingly, a wide variety of stakeholders (including the European Union, Environment Agency, and Natural England) have altered their policies to improve river connectivity for a wider range of fish species, emphasising natural connectivity restoration methods, such as barrier removal, wherever possible.

Figure. Hundreds of conservation-listed river lamprey attempting to pass a small, engineered river structure during their upriver migration towards spawning habitat.

2. Underpinning research

Dr Lucas' research on spatial ecology of freshwater fishes (including those that move between the sea and freshwater) has revealed the importance of migration, dispersal and seasonal

movement (including short-distance movement among habitats and for recolonization) in many species beyond those traditionally regarded as migratory species (R1). He has developed new methods (field telemetry techniques, especially passive transponders) for the study of fish movement and has examined impacts of engineered river infrastructure (dams, weirs, culverts, hydropower etc.) on these species (R1, R2). His results challenged the conventional view of a very limited number of fish species, such as salmon and eel, being migratory and requiring free movement for ensuring healthy populations and contributing to diverse river ecosystems. Consequently, river connectivity restoration, using methods that support free movement of all native fish species, is now being communicated and instituted globally (R1, R2).

The international significance of Dr Lucas' team's work is underlined by the research of the EU Horizon 2020 research project (20 partners, 2016-2020) "Adaptive Management of Barriers in European Rivers" (AMBER) of which Durham is a major partner. Dr Lucas' AMBER research has contributed towards the first European River Barrier Atlas (Belletti…..Lucas *et al.*, 2020. "More than one million barriers fragment Europe's rivers". *Nature* **588**, 436-441). That research has also shown that 97% of the British river network is fragmented by man-made barriers. The US National Oceanic and Atmospheric Administration estimates there are over 2 million barriers to fish movement in the United States. In the context of this extensive fragmentation worldwide, Dr Lucas' team's research has better evaluated the impacts of barriers to fish migration and dispersal (R3-R6), especially for those structures of small height, that comprise the great majority of river barriers (Belletti *et al*., 2020), but that had previously been assumed not to markedly impact fish movement (R3).

Fish passes (= fishways) are commonly built to facilitate free passage past river barriers and Durham research has been at the forefront of developing methods to measure the efficacy of such approaches (R1-R6). Lucas' methods employ telemetry of tagged fish approaching obstacles, to establish what routes they use to pass the barriers, and the fate of the fish (R2-R6).

Dr Lucas' research has demonstrated that existing, often costly, conventional 'concrete and steel' fish passes can be ineffective, including for species of conservation importance (R5, R6). The team has shown and emphasized how connectivity restoration by barrier removal and use of "nature-like" fish passes can be much more effective for restoration of native fish communities than use of conventional fish passes (R6). They have helped develop better methods of connectivity restoration for practitioners, including government agencies and Non-Governmental Organisations (NGOs; R2-R6). Durham research has also shown how low-flow conditions can exacerbate the impacts of engineered-river infrastructure, resulting in delayed migration and reduced survival in migrating salmonids (R4). This is crucial because in many rivers periods of low flow are becoming more frequent during sensitive life-cycle stages, as a result of climate change. During low flow, downstream-migrating fish such as salmon smolts are unable or unwilling to pass over weirs and are exposed to predators for much longer, impacting wild populations (R4).

Evidence of research quality in terms of originality, significance and rigour

The underpinning research has been reported in international, influential peer-reviewed journals (R2-R6), except R1, a 420-page co-authored book combining research experience and critical review which, since its publication in 2001, has been cited in 1194 articles (Google Scholar, July 2020). R1 was reviewed after publication by Prof. G. Rose for the journal "*Fish & Fisheries*" (2002, vol 3, pp. 360-361) and he concluded *"The inclusion of applied aspects of migration, and how these are impacted by human use of freshwater systems, makes a fitting end and raison d'être for the book. Many know about salmon, but few know as much about freshwater fish movements as is contained in this volume. Therein lies its value."*

3. References to the research – Durham researchers underlined.

R1 **Lucas, M.C.** & Baras, E. (2001). *Migration of Freshwater Fishes*. Blackwell Science, Oxford, 420 pp.

R2 Silva, A.T., **Lucas, M.C.**, Castro-Santos, T., Katopodis, C., Baumgartner, L.J., Thiem, J.D., Aarestrup, K., Pompeu, P.S., O'Brien, G.C., Braun, D., Burnett, N.J., Zhu, D.Z., Fjeldstad, H-P., Forseth, T., Rajaratnam, N., Williams, J.G & Cooke, S.J. (2018). The future of fish passage science, engineering, and practice. *Fish and Fisheries* **19**, 340-363. DOI: 10.1111/faf.1258

R3 **Lucas, M.C.**, Bubb, D.H., Jang, M-H., Ha, K. & Masters, J.E.G. (2009) Availability of and access to critical habitats in regulated rivers: Impacts of low-head barriers on threatened lampreys. *Freshwater Biology* **54**, 621-634. DOI:10.1111/j.1365-2427.2008.02136.x

R4 Gauld, N.R., Campbell, R. & **Lucas, M.C.** (2013) Reduced flows impact salmonid smolt emigration in a river with low-head weirs. *Science of the Total Environment* **458-460**, 435-443. DOI: 10.1016/j.scitotenv.2013.04.063.x

R5 Foulds, W.L. & **Lucas, M.C.** (2013) Extreme inefficiency of two conventional technical fishways used by European river lamprey (*Lampetra fluviatilis*). *Ecological Engineering* **58**, 423-433. DOI: 10.1016/j.ecoleng.2013.06.038

R6 Tummers, J.S., Hudson, S. & **Lucas, M.C.** (2016) Evaluating the effectiveness of restoring longitudinal connectivity for stream fish communities: towards a more holistic approach. *Science of the Total Environment* **569-570**, 850-860. DOI: 10.1016/j.scitotenv.2016.06.207

4. Details of the impact

Dr Lucas' team's research on fish migration, river barriers, river restoration and fish passage has had a global impact on policy, management measures, river restoration and fish conservation actions as outlined below.

Global shift in recognition of the need for free movement of native freshwater fishes

Dr Lucas' research has demonstrated that many more river fish exhibit migration than previously realised, contributing to a paradigm shift in recognition of the need for enabling free movement of a wider range of native species (E1-E4; E1-E3 cite Lucas) and mobilization of action to solve the problem (E4, E5 cite Lucas). Between August 2013 and July 2020 ecological practitioners from 73 countries and 6 continents, cited R1 nearly 700 times, reflecting the depth and breadth of this translational impact (E1) – of these citations, 52% included authors from government (non-academic) environmental / fisheries / conservation agencies or NGOs / consultants directly involved in implementing policy change and conservation / river restoration / fisheries actions.

Contribution to methods and solutions for implementation of Water Framework Directive

The EU Water Framework Directive (WFD) aims to achieve Good Ecological Status (GES) in freshwaters through river basin management cycles (Cycle 1, 2009-2015; Cycle 2, 2015-2021). The WFD requires free movement of migratory fish, necessitating effective fish passage measures and robust assessment methodology, which Dr Lucas' research (R1-R6) has promoted, shaping ongoing policy and best practice by environmental and nature regulatory agencies and NGOs (see E2, E4, E6 with citations to Durham research). However, in 2012 and 2018 (monitoring reports for 2009-2015 and 2015-2021 WFD cycles), over 50% and 60% respectively of European surface waters failed to reach GES (E7a,b). "Hydromorphological modification" which includes dams, weirs, culverts and channelization, was the most common reason for failure to reach GES under the WFD (E7a,b). Therefore Dr Lucas' work on the impact of these structures has been, and remains, important for progress by EU states (including the UK in this regard) to meet GES (E2, E4, E5, E6 and citations to Durham work therein). For example, the objective quantification of barrier impacts and fish pass efficacy by Durham has been used as evidence, and for good practice in adaptive barrier management (E4, E5, E6). Since AMBER estimates over a million river barriers in Europe, this is going to be a long and expensive process to reduce the number of rivers failing to meet GES for that reason.

Conventional fish passes can be failures cf. barrier removals and 'nature-like' solutions
Durham's research has directly led to altered policies by UK environmental and conservation agencies in recognising the need to enable river movements by all native fish species, and that some conventional fish pass designs do not work for non-salmonid fishes (E4, E8, E9a). For a 2-m high weir, a conventional fish pass from design inception to completion costs GBP200,000-400,000, while fish passes on large dams cost >GBP1 million, and informal "easements" on streams may cost GBP30,000-100,000. Thus, it matters that they work. In 2009, the Environment Agency estimated it would cost over GBP500 million to reduce the worst barrier impacts in England and Wales. Lucas' research has directly shaped UK statutory Agency policy on fish passage by providing evidence on the efficacy of fishway designs and on stream-connectivity restoration, driving innovation on possible solutions (E4, E8). As a result of Durham's work some conventional fish pass designs are no longer recommended for several species (E4, E8), and increasingly, barrier removals or "nature-like" fish pass designs are adopted (E4). The Environment Agency / Natural England have explicitly stated in their WISER (2017) policy document (E9a) that *"when considering fish pass solutions you should conduct a feasibility study into removing the barrier to fish migration…. we consider barrier removal as best practice"*. The Department for Environment Food and Rural Affairs funded GBP24.5 million of 'Catchment Restoration Fund' projects in England to help meet WFD obligations; over the period 2013-2015, out of 400 fish passage actions, over 160 barriers (40%) were removed, 152 nature-like solutions (38%) were applied, 71 eel passes (18%) and just 17 conventional fish passes (4%) added (E9b,c), reflecting the influence of Lucas' team's research on river connectivity restoration (E4).

Climate change and fish migration bottlenecks due to low flows at barriers
Durham research showing that inhibition of fish passage at small barriers can be compounded by low river flows, which may become more common with climate change, has been adopted by stakeholders and NGOs internationally (E2, E4, E5, E6 and their citations to Durham work) and led to changes in UK management plans by environmental and conservation agencies (E4, E9d). Impacts of small barriers on downstream passage by salmonid smolts and the attendant delays and lower survival, concomitant with increased predation exposure as detailed in Durham research (R4), have received widespread consideration internationally, leading to policies emphasizing barrier removal and better designed downstream-movement bypasses (E2, E4, E5, E6, E9a, E9d).

Conservation measures to assist protected fish species
Durham research on impacts of river barriers on European river lamprey, and the efficacy of fish passes for them, has been referenced extensively in the 2019 UK Conservation Assessment of this species under Article 17 of the EU Habitats Directive (E8). This statutory document identifies the status, major pressures on, and conservation strategy for this species in the UK and contributes to its international conservation. Our research has been used similarly to support best practice for conservation of Atlantic salmon and bullhead in the UK (E4).

Community stakeholder engagement
Over seven million viewers, including key stakeholders such as naturalists and anglers, were reached through terrestrial television broadcasts in the UK alone (E10a, b). These and related media have achieved impact to natural environment stakeholders by illustrating the importance of river connectivity for fish species of conservation concern and why enabling dispersal and movement of the whole fish community at small obstacles is important for the restoration of normal ecological function and food webs in streams.

5. Sources to corroborate the impact

E1a (screenshot) and **E1b** (spreadsheet) Google Scholar output of Lucas & Baras (2001) [R1]. Over 1 Aug 2013 - 31 July 2020, practitioners from 73 countries & 6 continents, cited Dr Lucas' book 'Migration of Freshwater Fishes' nearly 700 times. Of these, 52% had at least one author who was a government or NGO environment / fisheries / conservation officer or consultant.

E2 Brink et al. From Sea to Source 2.0 Protection and Restoration of Fish Migration in Rivers Worldwide. 2018.
E3 Deinet et al. The Living Planet Index for Migratory Fish. Technical Report. 2020.
E4 Testimonial letter from Natural England's National Freshwater Fish & Fisheries Specialist.
E5 Dam Removal Europe Policy Report 2018.
E6 Obstructions and wild brown trout - Wild Trout Trust briefing paper 2014.
E7a European Waters: Assessment of status and pressures. 2012. European Environment Agency Report No. 8/2012 (report on 2009-2015 management cycle).
E7b European Waters: Assessment of status and pressures. 2018. European Environment Agency Report No.7/2018 (report on 2015-2021 management cycle).
E8 UK Conservation Assessment for river lamprey 2019. Joint Nature Conservation Committee.
E9a Water industry strategic environmental requirements (WISER) Env. Agency 2017.
E9b Catchment Restoration Fund Environment Agency summary report 2013-14.
E9c Catchment Restoration Fund Environment Agency summary report 2014-15.
E9d Climate change adaptation manual 2nd edition - rivers and streams 2020. Natural England.
E10a 29 March 2014 BBC1 Countryfile (6.38 million viewers) TV feature - Lucas interview on river restoration and barrier removal, featuring collaboration between Wear Rivers Trust and Durham Uni., emphasising the importance of mini species of fish to streams.
E10b 23 Dec 2015 BBC1 Look North Regional News TV feature (1.3 million viewers) - Lucas interview on return of lampreys to post-industrial rivers in England and collaboration (Durham Uni., EA); contextualising interface between biodiversity conservation and water control.