Institution: Queen's University Belfast

Unit of Assessment: 6 - Agriculture, Veterinary and Food Science

Title of case study: Evidence for the Harmful Effect of Stock Enhancement and Commercial Farming on Native Gene Pools of Atlantic Salmon and Brown Trout

1. Summary of the impact (indicative maximum 100 words)

The effects of accidental salmon farm escapes, intentional releases of non-native salmon and trout, and stocking of fertile farm-reared trout, on the genetic makeup, fitness and long-term viability of wild populations has been a matter of increasing concern over the past two decades. Ferguson and Prodöhl's group demonstrated that offspring of farmed, first and second generation hybrid and backcrossed salmon and trout showed reduced survival compared with wild native fish, and that repeated escape/introduction events can cause a reduction in the biological fitness of vulnerable wild populations leading to reductions in numbers and potentially to their extinction. These findings led directly to changes in regulations and guidelines by relevant major stakeholders including the Environment Agency (England & Wales), Wild Trout Trust, North Atlantic Salmon Conservation Organisation, World Wildlife Fund, and governments in Europe and North America.

2. Underpinning research (indicative maximum 500 words)

Context: Angling for wild brown trout and Atlantic salmon, as well as farming for direct table consumption, is worth over £1.5 billion (c. £900 million and c. £650 million for angling and farming respectively) annually in Britain and Ireland. The salmon farming industry world-wide is worth £4.2 billion. Due to anthropogenic factors (e.g. habitat degradation, introduced diseases and parasites, overfishing) wild stocks of both species have declined throughout Britain and Ireland and elsewhere within their ranges. Both socio-economic and environmental considerations are, therefore, very important when considering management of these species in respect to fisheries and biodiversity. Atlantic salmon and brown trout farming, and stocking with farm-reared and non-native salmon and trout, have been the most prevalent methods of attempting both to meet the consumer demand for these fish and to mitigate real or perceived wild population declines. However, the impacts of salmon farm escapes, intentional releases of non-native salmon and trout and stocking of fertile farm-reared trout on the genetic integrity, fitness and long-term viability of wild populations have been a matter of considerable debate over many years, with little empirical evidence prior to the QUB studies.

Research at QUB: For the last 40 years researchers at QUB, under the leadership of Professors Andrew Ferguson (retired 30/11/04, Professor Emeritus until 30/06/14) and Paulo Prodöhl, have researched molecular population genetics with a particular focus on the conservation and management of salmonid fishes, especially brown trout and Atlantic salmon. Farm-reared Atlantic salmon and brown trout differ from their wild counterparts genetically (primarily due to domestication in culture), phenotypically, and behaviourally. Individual wild populations differ substantially in their genetic make-up as a result of colonisation history and local adaptation. The genetic impact on native populations of deliberate and/or inadvertent introductions of farmed stock and non-native salmonids has been an area of particular research interest by the group. From 1993 to 2002 Ferguson and Prodöhl, in collaboration with McGinnity (joint QUB/Salmon Research Agency of Ireland, now the Marine Institute of Ireland) and colleagues from University College Cork, Scottish Office Marine and Freshwater Laboratories, Norwegian Institute for Nature Research, Xunta Galicia, and University of Oviedo, Spain, carried out novel investigations in this area. This work was supported by two major EC grants (totalling £3M; QUB was coordinator of one), as well as grants from NERC and the Marine Institute Ireland specifically to QUB. Innovative common garden experiments were made feasible by the previous development of single locus DNA fingerprinting for salmonids (also EC funded); QUB were the first group worldwide to develop and publish the application of genetic markers for the elucidation of previously intractable ecological questions associated with salmonid biology. DNA fingerprinting enabled for the first time common garden experiments to be undertaken under natural conditions from the egg stage onwards and continued in subsequent generations. This, along with the unique freshwater and

marine field facilities of the Marine Institute, enabled large scale experiments to be undertaken in the wild that were subsequently of widespread interest to salmonid biologists and managers in both Europe and North America. During the same period and subsequently, research on salmon and trout involved studies of the distribution and changes in genetic diversity, and local adaptation, in natural populations of both species. The unique trout populations of Lough Melvin were one focus of such investigations. In 2007, Prodöhl received a 7-year grant (value €1 million - Beaufort Marine Award) in Fish Population Genetics to continue research on the impacts of deliberate and/or inadvertent introductions on native salmonid populations. As part of this project, additional common garden studies of native, non-native and farm-origin brown trout are being undertaken.

3. References to the research (indicative maximum of six references)

1. *McGinnity, P., Stone, C., Taggart, J. B., Cooke, D., Cotter, D., Hynes, R., McCamley, C., Cross, T. and Ferguson, A. (1997). Genetic impact of escaped farmed Atlantic salmon (*Salmo salar* L.) on native populations: use of DNA profiling to assess freshwater performance of wild, farmed, and hybrid progeny in a natural river environment. *ICES Journal of Marine Science* 54: 998-1008. (**cited 121 times**)
2. *McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, Ó Maoiléidigh, R. N., Baker, N., Cotter, D., O'Hea, B., Cooke, D., Rogan, G., Taggart, J. and Cross, T. (2003). Fitness reduction and potential extinction of wild populations of Atlantic salmon *Salmo salar* as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society B* 270: 2443-2450. (**cited 256 times**).
3. McGinnity, P., Prodöhl, P., Maoiléidigh, N. Ó., Hynes, R., Cotter, D., Baker, N., O'Hea, B. and Ferguson A. (2004). Differential lifetime success and performance of native and non-native Atlantic salmon examined under communal natural conditions. *Journal of Fish Biology* 65: 1-15.
4. Ferguson, A. (2004). The importance of identifying conservation units: Brown trout and pollan biodiversity in Ireland. *Biology and Environment* 104: 33-41.
5. McKeown, N. J., Hynes, R. A., Duguid, R. A., Ferguson, A. and Prodöhl, P. A. (2010). Phylogeographic structure of brown trout *Salmo trutta* in Britain and Ireland: glacial refugia, postglacial colonization and origins of sympatric populations. *Journal of Fish Biology*, 76: 319-347.
6. Keenan, K., Bradley, C. R., Magee, J. J., Hynes, R. A., Kennedy, R. J., Crozier, W. W., Poole, R., Cross, T. F., McGinnity, P., Prodöhl, P. A. (2013). Beaufort trout MicroPlex: a high throughput multiplex platform comprising 38 informative microsatellite loci for use in resident and anadromous (sea trout) brown trout *Salmo trutta* genetics studies. *Journal of Fish Biology* 82: 1789-804.

*References that best indicate the quality of the underpinning research

Related Research Grants:

- 1993-1996; Sponsor: EU AR1; "An assessment of the genetic consequences of deliberate and inadvertent introductions of non-native Atlantic salmon into natural populations **[£400,000]**
- 1994-1996; Sponsor: EU FP4; "Hybridisation between escaped farmed Atlantic salmon and brown trout: frequency, distribution, behavioural mechanisms and effects on fitness" **[£114,800]**
- 1996-1997; Sponsor: EA England & Wales; "Genetic stock discrimination in Atlantic Salmon & Sea Trout" **[£6,788]**
- 1996-1997; Sponsor: NERC; "Nucleotide sequence analysis of brown trout" **[£26,121]**
- 1998-1999; Sponsor: EA England & Wales; "Mitochondrial DNA analysis of scale tissue from brown trout" **[£13,200]**
- 2000-2001; Sponsor: NERC; "The genetic impact of escaped farmed Atlantic Salmon" **[£36,073]**
- 2000-2001; Sponsor: Marine Institute (Ireland); "Genetic Impact of the introduction of ranched, farmed and non-native Atlantic salmon into a salmon population" **[£27,190]**
- 2007-2015; Sponsor: Marine Institute (Ireland); "Beaufort Marine - Fisheries Genetics" **[€1M]**
- 2008-2011; Sponsor: EU FP7; "Atlantic Salmon SALSEA-MERGE" **[£81,141]**

- 2010-2013; Sponsor: EC (non-framework projects); “Celtic Sea trout” **[£23,700]**
- 2012-2013; Sponsor: Inland Fisheries Ireland (Ireland); “Irish brown trout population structure and genetic stock identification” **[£24,000]**

4. Details of the impact (indicative maximum 750 words)

Current farm production of Atlantic salmon in the North Atlantic is about 1 million tonnes per year. Marine cages are vulnerable to damage by storms, predators and collisions, and escapes inevitably occur. It is estimated that some two million Atlantic salmon escape each year in the North Atlantic, which is equivalent to about 50% of the total number of wild adult salmon in the area. Escaped salmon enter rivers where they breed and interbreed with wild salmon, thereby changing the genetic make-up of wild populations. Farm-reared brown trout are stocked in most European countries where native populations are also present. In Britain and Ireland over two million such trout are stocked each year. Many local angling groups also maintain hatcheries for stocking both species.

The key findings of our salmon studies were that offspring of farmed, first and second generation hybrids, and backcrosses both to wild and farmed salmon showed reduced survival compared with wild salmon, and that repeated escape events can cause a reduction in survival and reproductive success of vulnerable wild populations potentially leading to their extinction. Brown trout investigations showed four detrimental impacts of stocking farm-reared brown trout into wild populations: (1) Loss of genetic diversity among wild populations, such diversity being essential for long-term survival and continued adaptation to changing conditions; (2) Reduction in fitness due to loss of local adaptations as a result of interbreeding with farm-reared trout; (3) Reduction in fitness as a result of interbreeding with farm-reared trout, which are maladapted for life in the wild due to domestication; (4) Loss of key life history types, and consequent reduction in diversity of angling opportunity and experience.

Due to the fact that almost all the brown trout population genetic research in the UK and Ireland had been carried out at QUB, together with key inter-related work on Atlantic salmon, Ferguson was asked by the Environment Agency (England & Wales) to produce a report on genetic impacts of stocking on indigenous brown trout populations. Ferguson's (2007) report is one of the main sources listed under Research References by the Environment Agency (EA) in their 2008 Review of Brown Trout Policy. It was described by the EA as part of their "work with leading authorities on trout fisheries management, analysis of scientific research, and an extensive consultation process". Ferguson's report examined evidence on the impact on wild trout stocks of stocking domesticated fertile brown trout and on the potential alternative use of sterile fish. This policy review was pivotal for the change of brown trout stocking policy in England in Wales. The Environment Agency made the decision in 2008 to stop giving consent to stock rivers and lakes with fertile (diploid) farm strain brown trout in England and Wales from 2015, only stocking with infertile (female triploid) brown trout or the progeny of local broodstock reared under a suitable regime being permitted.

As a direct result of work carried out at QUB and in response to the Species and Habitats Review Report, published in 2007, brown trout has been added to the list of priority fish species in the UK Biodiversity Action Plan, which is the UK Government’s response to the Convention on Biological Diversity, signed in 1992 in Rio de Janeiro. Following advice to the Northern Ireland Department of the Environment’s Environment and Heritage Service (EHS), later NI Environment Agency (NIEA), on the existence of unique brown trout populations, Lough Melvin was declared an Area of Special Scientific Interest (ASSI) in 1997. Under ASSI status, no stocking with farm strain trout is allowed. Indeed any change in management requires NIEA permission. The Wild Trout Trust, a major charity dedicated to the conservation of brown trout in Britain and Ireland, produced a statement in 2012 providing background and advice to fishery managers on brown trout genetics and stocking. This 15-page document includes five citations of QUB work and, as a scientific adviser to the Trust, Ferguson made a substantial contribution to drafting it.

Following concerns about the impact of salmon farm escapes, the WWF set up a dialogue involving key scientists and farm industry representatives. Ferguson was invited to be a member of the working party. The final global standards for the industry (published February 2012) in respect of genetic impacts are based substantially on QUB publications. The North Atlantic Salmon Conservation Organisation (NASCO), an international body established by inter-governmental convention, sought QUB advice on genetic impact of escaped farm salmon and on supportive breeding (use of offspring of native broodstock) on various occasions over the past 20 years. Current (2009-2011) NASCO international guidance draws significantly on this advice and our publications.
European government agencies (e.g. Scotland, Norway) have implemented advice on trout stocking and farm escapes. New legislation came into force on August 1, 2008, regulating the introduction the stocking of all species of freshwater fish within Scotland, including trout and salmon. Internationally, results of QUB studies on salmon escapes have been central to the development of a national policy for the farming of European origin salmon in Canadian waters commissioned by the Canadian Science Advisory Secretariat (Verspoor *et al.,* in press: corroborated by Professor, University of the Highlands and Islands) on behalf of the Canadian Government.

5. Sources to corroborate the impact (indicative maximum of 10 references)

- Ferguson, A. (2007). Genetic impacts of stocking on indigenous brown trout populations. Environment Agency Science Report SC040071/SR, 93pp. ISBN 978-1-84432-798-0. Available at: http://www.environment-agency.gov.uk/research/library/publications/39903.aspx
- Environment Agency (2008). Brown Trout Stocking Review 2007/8. Review Outcome and Summary of Consultation Response (available at: http://www.environmentagency.gov.uk/static/documents/Leisure/consultation_summary_2026751.pdf)
- The UK Biodiversity Action Plan (UK BAP). A list of UK BAP priority fish species is available at: http://jncc.defra.gov.uk/page-5164.
- Advice to DOE on Lough Melvin brown trout is available at http://www.doeni.gov.uk/niea/lough_melvin_assi_citation.pdf and http://www.doeni.gov.uk/niea/print/lough_melvin_assi_vam.pdf.
- The Wild Trout Trust statement on trout stocking available at: http://www.wildtrout.org/node/748
- WWF salmon aquaculture global standard available at: http://www.worldwildlife.org/what/globalmarkets/aquaculture/dialogues-salmon.html
- NASCO Final Report of the Aquaculture, Introductions and Transfers and Transgenics Focus Area Review Group (http://www.nasco.int/pdf/2011%20papers/CNL(11)11.pdf)
- Regulation of trout and salmon stocking in Scotland available at: http://www.scotland.gov.uk/Topics/marine/Licensing/fishintros
- NASCO (2008). Interim Report of the Socio-Economics Working Group (2008). An Economic/Socio-Economic Evaluation of Wild salmon. Available at: http://www.nasco.int/pdf/socioeconomics/se_rep2008.pdf
- Verspoor, E., McGinnity, P., Bradbury, I and Glebe, B. (*in press*). The Potential Direct and Indirect Genetic Consequences for Native North American Atlantic Salmon from Interbreeding with European-Origin Farm Escapes. Report commissioned by the Canadian Science Advisory Secretariat on behalf of the Canadian Government.
- EFSA GMO Panel (EFSA Panel on Genetically Modified Organisms), 2013. Guidance on the environmental risk assessment of genetically modified animals. EFSA Journal 2013 11(5):3200, 190 pp. doi:10.2903/j.efsa.2013.3200 Available online: www.efsa.europa.eu/efsajournal.
- Research Director, The Atlantic Salmon Trust.
- Professor, University of the Highlands and Islands.
- Secretary, the North Atlantic Salmon Conservation Organization.