Institution: University of Edinburgh and SRUC, Scotland's Rural College

Unit of Assessment: 6

Title of case study: Marker-Assisted Selection to breed for resistance to Infectious Pancreatic Necrosis in Salmon

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

Impact: Economic, animal health and welfare: Genetic markers have enabled selection of salmon lines with improved virus resistance

Significance: UK salmon industry benefit estimated at ~£26 million/annum GVA following identification of a genetic trait conferring resistance to an economically devastating viral disease.

Beneficiaries: Salmon farming industry, consumers

Attribution: Work performed by Houston, Bishop, Woolliams and Haley (Roslin Institute, now part of UoE).

Reach: Aquaculture industry internationally, i.e. Europe and South America (Chile).

2. Underpinning research (indicative maximum 500 words)

In recent decades, the viral disease infectious pancreatic necrosis (IPN) has been a major constraint on salmon aquaculture, spreading rapidly among salmon farms in Scotland, Norway, Chile, USA, Canada and other countries. Typical mortality levels in an epidemic are ~25%, and severe outbreaks are known to kill as many as 80-90% of farmed fish. No vaccine is effective in very young fish.

BBSRC-funded research (response-mode grant 2004-2007) at The Roslin Institute, University of Edinburgh led by group leaders Professor Bishop (Roslin Institute and UoE, employed 1988-onwards), Professor Woolliams (Roslin Institute and UoE, employed 1977-onwards) and Professor Haley (Roslin Institute and UoE, employed 1985-onwards) demonstrated that host resistance (i.e. survival) is a heritable trait [3.1] and that the observed genetic differences are almost entirely due to variation in a single quantitative trait locus (QTL) of the salmon genome [3.2]. The large effect of the QTL on resistance was consistent in seawater cages [3.2] and in controlled freshwater disease-challenge experiments [3.3] (funded by a second response-mode grant: 2007-2010). Fish inheriting two copies of the resistant variant of the QTL from their parents have negligible mortality, whereas those receiving the susceptible variant from both parents have mortality levels higher than 50% during epidemics [3.2-3.4] The disease resistance effect does not appear to show any negative correlations with other economically important production traits [3.5].

The results of this research led to a long-term collaborative research partnership between The Roslin Institute and the salmon breeding company Landcatch Natural Selection (LNS) Ltd. In 2008, via a knowledge transfer project (KTP associate Dr Gheyas), a method was developed with the breeding company to incorporate this QTL into selective breeding programs using microsatellite information to select more resistant breeding fish.

Since 2010, Houston (career track fellow, 2010-onwards) has led a BBSRC career-path fellowship project in which the differences in DNA and RNA sequence between salmon carrying resistant alleles and those carrying susceptible alleles have been investigated using high-throughput sequencing technology. This has enabled the detection of more closely linked single nucleotide polymorphism (SNP) markers that show association with resistance to the IPN virus at the population level [3.4].

Incorporation of these improved markers into industry selective breeding programmes has further improved the accuracy and simplicity of genetic tests that enable the identification of IPN-resistant fish at an early stage from a sample of its DNA [3.5]

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

3.1 Guy DR, Bishop SC, Woolliams JA, Brotherstone S (2009) Genetic parameters for resistance to Infectious Pancreatic Necrosis in pedigreed Atlantic salmon (Salmo salar) post-smolts using

a Reduced Animal Model. Aquaculture 290: 229-235. http://dx.doi.org/10.1016/j.aquaculture.2009.02.015

3.2 Houston RD, Haley CS, Hamilton A, Guy DR, Tinch AE, Taggart JB, McAndrew BJ, Bishop SC (2008). Major QTL Affect Resistance to Infectious Pancreatic Necrosis in Atlantic Salmon (Salmo salar). Genetics 178: 1109-1115. http://dx.doi.org/10.1534/genetics.107.082974

3.3 Houston RD, Haley CS, Hamilton A, Guy DR, Mota-Velasco J, Gheyas AA, Tinch AE, Taggart JB, Bron JE, Starkey WG, McAndrew BJ, Verner-Jeffreys DW, Paley RK, Rimmer GSE, Tew IJ, Bishop SC (2010). The susceptibility of Atlantic salmon fry to freshwater Infectious Pancreatic Necrosis is largely explained by a major QTL. Heredity 105: 318-327. http://dx.doi.org/10.1038/hdy.2009.171

3.4 Houston RD, Davey JW, Bishop SC, Lowe NR, Mota-Velasco JC, Hamilton A, Guy DR, Tinch, AE, Thomson ML, Blaxter ML, Gharbi K, Bron JE, Taggart JB (2012) Characterisation of QTL-linked and genome-wide restriction site-associated DNA (RAD) markers in farmed Atlantic salmon. BMC Genomics 13, 244. 13:244. http://dx.doi.org/10.1186/1471-2164-13-244

3.5 Gheyas AA, Haley CS, Guy DR, Hamilton A, Tinch AE, Mota-Velasco JC, Woolliams JA (2010) Effect of a major QTL affecting IPN resistance on production traits in Atlantic salmon. Animal Genetics 41: 666-668. http://dx.doi.org/10.1111/j.1365-2052.2010.02051.x

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

As a result of our research in 2008 the salmon-breeding company with which it was collaborating, Landcatch Natural Selection (LNS) Ltd, implemented marker-assisted selection (MAS) for IPN resistance when selecting its elite and commercial salmon populations. This is the first successful documented example of MAS in any aquaculture species. A license agreement between The Roslin Institute and LNS enabled a molecular genetic test for IPN resistance incorporating the QTL resistance markers to be sold internationally to aquaculture companies.

The size of impact of the research is quantified in an economic analysis by Roslin and LNS, validated by BiGGAR economics. IPN resistance, using MAS, reduces IPN mortality by 25% (i.e. from ~25% on average to virtually zero). After taking account of the market share of LNS for the eggs and smolts required by UK salmon industry, this equates to an economic impact of £26.4 million GVA (comprising reduced costs and losses, as well as greater output of marketable salmon) and between 360 and 450 jobs across the UK. As LNS also supplies 15%-20% of the eggs and smolts required by the global salmon farming industry, similar impacts can be documented overseas as well.

Other important impacts are also identifiable. Salmon farming is heavily concentrated in the Scottish Highlands and Islands, and therefore provides employment in some of the remotest communities in the UK where few alternative opportunities exist. Severe outbreaks of IPN are potentially devastating for such communities; hence this research supports these fragile rural communities.

Implementation of the findings also reduces the ecological impact of salmon farming as IPN is an endemic infectious disease that affects both wild and farmed salmon.

This innovation has been hailed as a highly successful example of the application of BBSRC research for industrial benefit, and led to an effective Knowledge Transfer Partnership[5.1] (KTP).

The innovation and related findings have been widely communicated through different media (including numerous press releases, scientific and industry publications and presentations[5.2-5.7]) to ensure widespread publicity. The KTP associate (Dr. Gheyas) won the KTP Centres in Scotland prize for Best Project Presentation. Dr. Houston won the 2012 Knowledge Exchange and Commercialisation Prize at The Roslin Institute Staff Awards for his role in the commercial application of the IPN resistance tests.

Furthermore, the research translation process has served as a paradigm for other economically important diseases. LNS Ltd received funding in March 2011 via the Technology Strategy Board/BBSRC Genomes UK: Exploiting the Potential of High-Throughput Sequencing funding competition to further develop the high-density salmon single-nucleotide polymorphism (SNP) chip,

which will be a key tool for improving the competitiveness and sustainability of the UK salmon farming industry. The project has resulted in the successful production of the world's first high-density SNP array for an aquaculture species, which is now being applied to select salmon for increased resistance to sea louse infestations in collaboration with the Universities of Edinburgh, Stirling and Glasgow and world-leading microarray supplier, Affymetrix Ltd. This new application of genomic technologies has been made possible by the success in finding genomic solutions to IPN.

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

5.1) Knowledge Transfer Partnership case study on Landcatch Natural Selection: http://tinyurl.com/qzvsw3q

5.2) IPN Salmon gene research progress: UK Scientists close in on salmon virus resistance gene. Published: 31 January, 2011. Source: FISHupdate.com http://tinyurl.com/qexaxc6

5.3) Knowledge Transfer Prize for LNS & Roslin Institute. Published: 10 February, 2009. Source: FISHupdate.com http://tinyurl.com/qj6rjy2

5.4) Landcatch Natural Selection Article. 'Markers show the way forward'. http://tinyurl.com/ps3279q

5.5) Sustained Genetic Progress Boosts Commercial Performance. Published: Thursday, March 27, 2008. Source: The FishSite.com. http://tinyurl.com/owh2n2w

5.6) Genetic discovery gives performance and welfare benefits. Published: 06 February 2008. Source: fishfarmingxpert.com. http://tinyurl.com/p3ops2p

5.7) Salmon breeding takes a 'quantum leap'. Published: Wednesday, August 15, 2007. Source: The FishSite.com. http://tinyurl.com/o2pkukb