

<b>Institution:</b> University of Stirling
<b>Unit of Assessment:</b> A6: Agriculture, Veterinary and Food Science
<b>Title of case study:</b> Improved parasite control in the global Atlantic salmon farming industry
<p><b>1. Summary of the impact</b></p> <p>Sea lice are the principal disease constraint for world Atlantic salmon culture and cost &gt;€33m yearly in the UK and &gt;€305m globally in terms of control measures and lost production. Research conducted by the University of Stirling's Institute of Aquaculture (IoA) has provided tools and strategies for sea louse control in farmed salmon worldwide. Impacts have been delivered through an integrated pest management approach which involves</p> <ol style="list-style-type: none"> <li>(1) introduction of management tools including fallowing, single year-class stocking and area management</li> <li>(2) screening, development, licensing and monitoring of veterinary medicines</li> <li>(3) development of alternative strategies such as use of cleaner fish (wrasse) and sea louse resistant salmon</li> <li>(4) incorporation of integrated pest management principles into public policy and legislation.</li> </ol> <p>These tools and approaches are now being used by the U.K. and global Atlantic salmon industries.</p>
<p><b>2. Underpinning research</b></p> <p>Sea lice are ectoparasitic copepods causing major economic losses for the global Atlantic salmon aquaculture industry. Use of an integrated pest management strategy for sea lice control was first proposed by IoA's Professor Christina Sommerville at the Scottish industry's annual conference in 1994. 'Integrated pest management' is a term encompassing the co-ordinated use of a wide variety of tools and approaches for the effective management of crop and livestock pathogens, particularly to reduce drug resistance development, and this strategy is key to IoA's underpinning research.</p> <p><i>Farm management approaches</i></p> <p>Appropriate use of management tools is a critical aspect of integrated pest management for sea lice. Industry-funded work at IoA (Ref. 1) was the first to provide evidence to recommend fallowing and use of single-year-class stocking policies to assist sea louse control and to examine the effects of treatment through a farm cycle. In the late 1990s the use of Area Management Agreements to co-ordinate farm management within defined areas was developed from this research, ensuring appropriate fallowing after harvesting, synchronisation of treatments across Farm Management Areas and use of effective communication strategies. In addition to farm management approaches, integrated pest management strategies require the development and deployment of a wide range of complementary tools for pest control including use of medicines and biological controls.</p> <p><i>Veterinary medicines</i></p> <p>Following development of sea louse drug resistance to the organophosphate dichlorvos (~1992), the IoA, through its Marine Environmental Research Laboratory (MERL), has increasingly played a central role in the identification, development, licensing, deployment and monitoring of the vast majority of medicines used against sea lice worldwide (1993-2013). In collaboration with industry (including Pfizer, MSD Animal Health, Novartis, Solvay Interco; feed companies Skretting (Nutreco), Ewos and BioMar and producers Marine Harvest), the IoA has helped to develop hydrogen peroxide (research from 1993-2013), azamethiphos (from 1993), teflubenzuron (from 1994-2013), diflubenzuron (from 1996) and the most widely used and successful medicine to date, emamectin benzoate (SLICE®, 1993-2013) see Refs 2-4. Research has included <i>in vitro</i> and <i>in vivo</i> screening of candidate products, efficacy studies to identify dose and treatment regimen, farm-scale trials, regulatory studies to evaluate safety, pharmacokinetics, metabolism and residue depletion and bioaccumulation by filter feeders. Work to develop new drugs is supported by ecotoxicology risk assessments, environmental impact assessments and modelling of environmental concentrations of drugs (Ref. 5) conducted by IoA for industry and government, and incorporated into Scottish Environmental Protection Agency (SEPA) guidelines. Monitoring drug resistance is central to integrated pest management and IoA has been a world leader in industry-funded (Ciba Agriculture, Scottish Salmon Growers' Association Ltd, Schering-Plough Animal Health / MSD Animal Health) research to investigate the molecular mechanisms involved in</p>

## Impact case study (REF3b)

reduced susceptibility to drug treatment and techniques to manage resistance (1993-2013).

### *Non-chemotherapeutant controls*

Since 1993, industry-funded research efforts at IoA have increasingly included non-chemotherapeutant control methods including vaccines (£227,372, 1993-2010), functional / immunostimulant feeds (£209,057, 2008-2013) and trials to help develop genetically resistant salmon stocks. Work conducted with Landcatch Natural Selection (part of Hendrix Genetics) as part of a Defra LINK project (2009-2010) demonstrated substantial scope for the breeding of resistant salmon (Ref. 6).

*Key IoA staff working on sea lice (1993-2013):* Professor C Sommerville, Professor R Richards, Dr R Wootten, Dr W Roy, Professor J Bron, Dr A Shinn, Dr T Telfer, Dr M Roth, Dr J Stone, Professor H Migaud and Dr A Sturm.

### 3. References to the research (Stirling researchers in bold)

1. **Bron, J.E., Sommerville, C., Wootten, R.** and Rae, G.H. (1993). Following of marine Atlantic salmon, *Salmo salar* L., farms as a method for the control of sea lice *Lepeophtheirus salmonis* (Krøyer, 1837). *Journal of Fish Diseases*, 16, 487-493.
2. **Roth M., Richards R.H.,** Dobson D.P., Rae G.H. (1996). Field trials on the efficacy of the organophosphate azamethiphos for the control of sea lice (Copepoda: Caligidae) infestations of farmed Atlantic salmon (*Salmo salar*). *Aquaculture*, 140, 217-239.
3. **McAndrew K.J. Sommerville C., Wootten R. and Bron J.E.** (1998). The effects of hydrogen peroxide treatment on different life-cycle stages of the salmon louse, *Lepeophtheirus salmonis* (Krøyer 1837). *Journal of Fish Diseases* 21(3), 221-228.
4. **Stone, J.,** Sutherland, I., **Sommerville, C., Richards, R.H.** and Varma, K.J. (1999) The efficacy of emamectin benzoate as an oral treatment of sea lice, *Lepeophtheirus salmonis* (Krøyer), infestations in Atlantic salmon, *Salmo salar*. *Journal of Fish Diseases* 22 (4), 261-270.
5. **Telfer, T. C., Baird, D. J.,** McHenery, J. G., **Stone, J.,** Sutherland, I., and Wislocki, P. (2006). Environmental effects of the anti-sea lice (Copepoda: Caligidae) therapeutant emamectin benzoate under commercial use conditions in the marine environment. *Aquaculture*, 260(1-4), 163-180.
6. Gharbi, K., Stear, M., Matthews, L. and **Bron, J.E.** (2011). LINK project LK0691 final report "An experimental and modelling framework for breeding Atlantic salmon for resistance to sea lice"..

### *Grants for research underpinning impact include:*

1. Industry-funded work to develop teflubenzuron, four contracts 1994-1999 £90,000
2. Industry-funded work to develop emamectin benzoate, 19 contracts 1993-2013 £570,864
3. Industry- and government-funded work on drug sensitivity of sea lice, development of bioassays and investigation of mechanisms of resistance, 12 contracts 1994-2013 £485,236
4. Defra LINK: The feasibility of breeding Atlantic salmon for resistance to sea Lice. Professor **Bron**, with Professor Stear and Dr Matthews, University of Glasgow, Dr Gharbi, University of Edinburgh and Professor Roberts, Landcatch Natural Selection Ltd. £94,419

### 4. Details of the impact

Integrated pest management, a concept introduced for sea lice control by the IoA, is now employed by all the major cultured salmon producing countries (see the 2013 Sea Lice Integrated Pest Management workshop <http://aquafeed.com/read-article.php?id=4954>). The impact of IoA's sea louse research in the REF assessment period 2008-2013 is clearly demonstrated by

- 1) industry reliance upon integrated pest management strategies developed through IoA,
- 2) increasing levels of industry support and funding for sea lice research at IoA,
- 3) sustained growth in the Scottish and global Atlantic salmon aquaculture industry
- 4) welfare and economic impact through incorporation of IoA research findings into industry codes of practice and the involvement of IoA in formulation of Scottish Government policies for farmed fish health and welfare.

IoA sea louse research continues to have major impacts in controlling sea louse numbers infecting farmed fish in the UK and globally, reducing economic costs, supporting sustainability and protecting fish welfare.

**Impact case study (REF3b)***Impacts on fish health and welfare:*

IoA research was involved in the development of the majority of veterinary drugs used to control sea lice 2008-13. The Technical Director of the Scottish Salmon Producers' Organisation (which represents >95% UK producers) has stated that "Work carried out at IoA has been directly responsible for providing encouragement and support to international pharmaceutical companies in the identification, testing and licensing of new veterinary products for the treatment of sea lice" and that "In the course of the past decade, IoA staff have undertaken cutting edge scientific work that informs and supports those in the industry responsible for the control of lice and the welfare of fish". By facilitating new treatments, particularly emamectin benzoate (SLICE®), IoA has had a major impact on the control of sea lice worldwide. MSD (Merck) Animal Health confirm that, working with IoA "...we have conducted studies on efficacy and dosing to support the registration of Slice throughout the salmon farming world and recently conducted studies to assess the impact of the development of tolerance and ways to assess it and combat it."

*Impacts on consumer health:*

Improved growth and sustainability of the Atlantic salmon industry, resulting from IoA's impact in improved sea louse control, has impacts on consumer health by provision of affordable and sustainable healthy protein and essential fatty acids. The Managing Director of Marine Harvest (Scotland) Ltd. Comments that "IoA have increased the sustainability of salmon farming in rural communities and reduced environmental impacts through provision of effective assessment methodologies and improved consumer health through sustainable healthy food production as well as providing various essential services for government and industry."

*Impacts on economy and commerce:*

Over recent years, the strategy of UK and global salmon aquaculture has been one of integrated pest management. As recognised by the Managing Director of Marine Harvest (Scotland) Ltd. "IoA have contributed to improved economic sustainability of the salmon farming industry through development of novel chemotherapeutants, integrated pest management, selection for genetic resistance in salmon, involvement in public policy, industry codes of practice and legislative development through chairing and membership of national/international bodies". In summarising commercial impact, the SSPO states "...IoA has made a significant contribution towards better scientific understanding of this commercially important parasite, and that the application of this science by industry has, in a number of important respects, been transformational."

*Impact on management practices:*

The impact of IoA on management practices is confirmed by the Scottish Salmon Producers' Organisation: "The scientific work of the IoA has supported the salmon farming industry in developing a range of strategic and practical approaches focused on minimising impact. Prominent amongst these approaches is Area Management, which involves separating year classes within defined production areas, fallowing after year classes have been harvested, and synchronising and coordinating treatment with approved veterinary medicines across Management Areas. This approach was first developed in Scotland in the late 1990s on the back of new science and now forms the basis of good practice in commercial salmon farming internationally". This impact is also endorsed by Paul Wheelhouse, Scottish Minister for Environment and Climate Change who confirms "We recognise the value of the University's work to develop appropriate management approaches, which include fallowing, single-year class stocking, and the use of cleanerfish". Use of Management Areas, fallowing and single-year class stocking are key tenets in the newest Code of Good Practice for Scottish Finfish Aquaculture 2013 contributed to by IoA.

*Impacts on public policy and services:*

IoA research outputs have had considerable impact upon public policy, industry codes of practice and new legislation. Richards has roles including SSPO veterinary advisor and chair of the Healthier Fish and Shellfish and Farmed Fish Health and Welfare Working Groups within the Ministerial Group on Aquaculture. He is facilitator of the Fish Health thematic area for the EU Aquaculture Technology Platform and Chair of the National Sea Lice Platform. Key elements of IoA integrated pest management strategies and research have led to policy impact through direct input into the Code of Good Practice for Scottish Finfish Aquaculture 2013, and the Aquaculture and

**Impact case study (REF3b)**

Fisheries (Scotland) Bill 2013 as well as input into the conditions to be attached to finfish business authorisations including delivery of single year class stocking of sites, sea lice treatment and fallowing of appropriate scale management areas.

*Impact demonstrated through industry funding of IoA research:*

During the REF assessment period 2008-2013, the IoA had demonstrable and increasing impact through industry funding of sea louse research targeting elements of an integrated pest management strategy. Over this period, industry funding for IoA and MERL includes 41 medicine-associated projects (£1,306,719), seven bioassay/sensitivity/resistance mechanism associated projects (£186,767) and eight functional feed associated projects (£271,340). There are three current Technology Strategy Board projects. The first of these, 2011-14 "Development of a high-density salmon SNP chip: a key tool for improving the competitiveness and sustainability of the UK salmon farming industry", is a collaboration with Landcatch Natural Selection Ltd., Affymetrix UK Ltd., University of Glasgow and University of Edinburgh (£647,339) and follows from the underpinning research showing differential genetic resistance to sea lice in Scottish farmed salmon families. The first SNP chips produced by this project are now being used by the industrial partner to find breeding markers for salmon resistance to sea lice. The second project "Production and implementation of farmed wrasse in the Scottish Salmon industry" is a collaboration with Marine Harvest Scotland Ltd and Scottish Sea Farms Ltd., having a value of £2,139,000 for IoA and MERL, and seeks to provide a sustainable farmed source of wrasse to be used as biological controls (cleaner-fish) to remove lice from salmon. Impacts from this project are already being felt, with recent introduction of wrasse to a trial site in Scotland cutting drug treatments from 8x per farm cycle to none and giving direct savings of 7p per kilo (Scottish production is >158,000 tonnes p.a. and growing). The final project leverages IoA's experience in sea lice and sea louse vaccine development, being part of TSB's Sustainable Protein call. "Development of a novel sea louse vaccine: an environmentally friendly tool for increasing sustainability of protein production in UK salmon aquaculture" is an important collaboration with Pfizer (now Zoetis) and Moredun Research Institute (total £2,992,000) with impact confirmed by the Head of Pfizer/Zoetis Business Development and Global Alliances up to 2013.

**5. Sources to corroborate the impact**

1. Scottish Government Farmed Fish Health and Welfare Working Group  
<http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/MGSA/Farmedfishhealthandwelfarewg>
2. A Code of Good Practice for Scottish Finfish Aquaculture (Jan 2013) showing incorporation of IoA integrated pest management strategies especially section 3.5 Area management and Annex 11 National Strategy for Sea Lice Control  
<http://www.thecodeofgoodpractice.co.uk/publish>.
3. Scottish Government Healthier Fish and Shellfish website underlining contribution of Institute of Aquaculture personnel and research to policy implementation including "single year class stocking of sites, sea lice treatment and fallowing of appropriate scale management areas"  
<http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/18364/18610>
4. Scottish Aquaculture and Fisheries (Scotland) Bill 2013 having direct input from IoA through committee Chairs (Professor Richards)  
<http://www.legislation.gov.uk/asp/2013/7/contents/enacted>
5. Scottish Sea Farms wrasse video showing impact for industry of collaboration with IoA and its Marine Environmental Research Laboratory at Machrihanish  
<http://www.youtube.com/watch?v=56aQgGpX3Ck>

In addition, full written statements from individuals and organisations quoted above are available.