

<b>Institution:</b> University of Stirling		
<b>Unit of Assessment:</b> 6. Agriculture, Veterinary and Food Science		
<b>Title of case study:</b> Transforming Atlantic salmon aquaculture sustainability through the domestication of cleaner fish.		
<b>Period when the underpinning research was undertaken:</b> 1 Jan 2010 to 31 Dec 2020		
<b>Details of staff conducting the underpinning research from the submitting unit:</b>		
<b>Name(s):</b>	<b>Role(s) (e.g. job title):</b>	<b>Period(s) employed by submitting HEI:</b>
Prof. Herve Migaud	Head of Breeding / Genetic improvement	2002 to present
Dr. Andrew Davie	Senior Lecturer	2005 to present
Prof. Sandra Adams	Head of Immunology / Vaccinology	1985 to present
Prof. James Bron	Head of Parasitology	1993 to present
Dr. Michael Bekaert	Senior lecturer	2011 to present
Dr. Sean Monaghan	PDRA	2012 to present
Dr. Adam Brooker	PDRA	07/2016 to present
Dr. Sarah-Louise Counter Selly	PDRA	04/2015 to 11/2020
<b>Period when the claimed impact occurred:</b> 1 Aug 2013 to 31 Dec 2020		
<b>Is this case study continued from a case study submitted in 2014?</b> N		
<b>1. Summary of the impact</b>		
<p>Stirling leads international research targeting the domestication and sustainable production of cleaner fish for biological sea lice control in global salmon aquaculture. Our work has safeguarded the UK's largest food export (farmed salmon, farm gate value over GBP1,000,000,000 in 2020) via practices that preserve wild cleaner fish while reducing chemotherapeutant use and parasite drug resistance. Impacts include:</p> <p><b>Impact 1:</b> high sectoral investment in cleaner fish culture, dedicated staff, and new facilities.</p> <p><b>Impact 2:</b> widespread salmon farm stocking of cleaner fish in UK and Norway, with new development in other salmon-producing countries.</p> <p><b>Impact 3:</b> novel product development and commercialisation, including feeds and vaccines.</p> <p>This work has been recognised nationally, including being awarded the Queen's Anniversary Prize (2018-20).</p>		
<b>2. Underpinning research</b>		
<p>Sea lice, ectoparasites of salmon, constrain sustainable Atlantic salmon aquaculture growth globally and have a major impact on salmon health and welfare, costing the UK and global industry more than GBP50,000,000 and GBP700,000,000 per annum, respectively. Increasing sea louse drug resistance and the resulting lack of treatment efficacy mandates the use of multiple control methods and rotation of treatments, in order to maintain lice at manageable levels. Stirling research was the first to demonstrate the effectiveness of cleaner fish, particularly ballan wrasse and lumpfish as an effective biological control to remove sea lice through their feeding activities. The University of Stirling's Institute of Aquaculture is the global leader on cleaner fish research, being the first to initiate such research in 2010 to address the biological and production bottlenecks preventing the farming of the cleaner fish species. At this time, some farms (&lt;10%) had started to employ wild caught ballan wrasse within the UK and Norway, raising concerns over the long-term sustainability of this alternative sea lice control strategy. Stirling has led the creation of knowledge, protocols and tools to successfully produce and deploy farmed ballan wrasse and lumpfish on salmon farms.</p> <p>Stirling ground-breaking research has identified optimal conditions and industry-amenable procedures for culture, deployment, welfare and effective delousing. The work has been funded by large collaborative research programs since 2012 (GBP2,900,000 for Stirling from a total project budget of GBP15,000,000 including Innovate UK, Sainsbury's, Scottish Aquaculture Innovation Centre, Scottish salmon industry, H2020 and Norwegian Fishery and Aquaculture</p>		

Industry Research Fund (FHF)) in collaboration with Norwegian Research organisations with the organisation of a workshop and co-supervision of experimental trials (NOFIMA).

Key underpinning research (research outputs **R1-R6**) includes:

- **Delousing efficiency:** Stirling provided the first scientific evidence of delousing behaviour and efficiency of ballan wrasse, through development and implementation of a delousing challenge model (**R1**). This provided increased confidence in this control approach and expansion of industry investment.
- **Reproductive biology and genomics:** Stirling made critical breakthroughs in reproductive biology and control of breeding in captivity, leading to the first captive spawning of wild (2013) and farmed (2018) ballan wrasse populations, recently acknowledged by the Aquaculture UK 2019 Applied Research Breakthrough Award: [www.aquacultureawards.com/2019-winners](http://www.aquacultureawards.com/2019-winners). Research outputs include knowledge of spawning rhythmicity, sex differentiation, identification and gender control in ballan wrasse (**R2**), captive broodstock management (lumpfish, **R3**) and first genomics tools for understanding wild population structuring and assigning parentage in captive populations (both species) for future broodstock management and selection.
- **Nutrition:** Research has defined the nutritional and environmental requirements of cleaner fish throughout the production life cycle and provided novel dedicated feeds (formulation and delivery method) to ensure farmed cleaner fish condition and welfare is maintained when sea lice infection is low (**R4**). Nutritional requirements during first feeding, weaning and nursery on-growing have been elucidated in both species, leading to commercial feeds developed by world leading aquafeed manufacturer, BioMar.
- **Health:** Research has explored ballan wrasse immunocompetence, provided new molecular diagnostic tools, characterised key pathogens in ballan wrasse and lumpfish, developed vaccine efficacy-testing protocols (ballan wrasse) and led to the commercialisation of autogenous vaccines by Ridgeway Biologicals own by CEVA Animal Health and Pharmaq own by Zoetis (**R5**).
- **Deployment:** Research focused on understanding cleaner fish behaviour following deployment in salmon cages using innovative hydroacoustic technology and developing acclimation protocols in the hatchery, during transportation and in salmon cages that result in improved welfare, survival and delousing behaviour (**R6**). This research led to standardised deployment protocols implemented throughout the industry.

The research has trained 7 PhD students and 22 Masters students during the REF period. Results have been disseminated broadly through scientific publications (18 published), invited presentations at International scientific conferences and industry events (e.g. Scottish Salmon Producers Organisation, Marine Alliance for Science and Technology for Scotland, BBSRC, and Sainsbury's in the UK, Seafood Fisheries Funds Norway (FHF), Norwegian Research Council and MEDFRI in Norway, sea lice conference in Canada) and publications in trade journals. In addition, two scientific workshops dedicated to cleaner fish research have been hosted by Stirling with representatives from all relevant research organisations in Norway.

### 3. References to the research. University of Stirling authors in **bold** text.

**R1. Leclercq E., Davie A. and Migaud H.** 2014. Delousing efficiency of farmed ballan wrasse (*Labrus bergylta*) against *Lepeophtheirus salmonis* infecting Atlantic salmon (*Salmo salar*) post-smolts. Pest management Science 70 (8), 1274-1282. DOI: [10.1002/ps.3692](https://doi.org/10.1002/ps.3692)

**Funding:** 2012-2015 Innovate UK, Production and implementation of farmed wrasse in the Scottish Salmon industry. Total budget of GBP2,139,000, GBP651,000 for Stirling (PI Migaud).

**R2. Grant B., Davie A., Taggart J.B., Counter Selly S.L., Picchi N., Bradley C., Prodohl P., Leclercq E., and Migaud H.,** 2016. Seasonal changes in broodstock spawning performance and egg quality in ballan wrasse (*Labrus bergylta*). Aquaculture 464, 505-514. DOI: [10.1016/j.aquaculture.2016.07.027](https://doi.org/10.1016/j.aquaculture.2016.07.027)

**Funding:** 2012-2015 Innovate UK, Production and implementation of farmed wrasse in the Scottish Salmon industry. Total budget of GBP2,139,000, GBP651,000 for Stirling (PIs Migaud/Davie).

**R3. Pountney S.M.,** Lein I., **Migaud H., Davie A. (2020).** High temperature is detrimental to captive lumpfish (*Cyclopterus lumpus*, L) reproductive performance. *Aquaculture* 522, 735121. DOI: [10.1016/j.aquaculture.2020.735121](https://doi.org/10.1016/j.aquaculture.2020.735121)

**Funding:** 2016-2020 - *Securing a sustainable supply and the optimal deployment of lumpsucker for sea lice control in the Scottish salmon industry. Total budget of GBP2,438,000, Stirling budget of GBP817,000 (PIs Davie/Migaud) and AquaExcel Transnational Access award with NOFIMA in Norway (2018).*

**R4. Leclercq E., Graham P. and Migaud H.,** 2015. Development of a water-stable agar-based diet for the supplementary feeding of cleaner fish ballan wrasse (*Labrus bergylta*) deployed within commercial Atlantic salmon (*Salmon salar*) net-pens. *Animal Feed Science and Technology* 208, 98-106. DOI:[10.1016/j.anifeedsci.2015.06.026](https://doi.org/10.1016/j.anifeedsci.2015.06.026)

**Funding:** 2014-2016 *Sainsbury project, Development of best management strategies for the commercial deployment of cleaner fish in salmon farms. Stirling budget of GBP175,000 (PI Migaud).*

**R5. Ramirez-Paredes JG.,** Verner-Jeffreys D.W., **Papadopoulou A., Monaghan S.,** Smith L., Haydon D., Wallis T.S., **Davie A., Adams A., Migaud H. (2020).** A commercial autogenous injection vaccine protects ballan wrasse (*Labrus bergylta*, Ascanius) against *Aeromonas salmonicida* vapA type V. *Fish and Shellfish Immunology* 107, 43-53. DOI: [10.1101/2020.07.02.183616](https://doi.org/10.1101/2020.07.02.183616)

**Funding:** 2015-2019 *SAIC project, Scaling up production of farmed wrasse in the Scottish Salmon industry. Total budget of GBP4,000,000, GBP831,000 for Stirling (PIs Migaud/Davie).*

**R6. Leclercq E.,** Zerafa B., **Brooker A.J., Davie A., and Migaud H. (2018).** Application of passive-acoustic telemetry to explore the behaviour of ballan wrasse (*Labrus bergylta*) and lumpfish (*Cyclopterus lumpus*) in commercial Scottish salmon sea-pens. *Aquaculture* 495, 1-12. DOI: [10.1016/j.aquaculture.2018.05.024](https://doi.org/10.1016/j.aquaculture.2018.05.024)

**Funding:** *SAIC projects: 2014 - Infrastructure funds for hydroacoustic equipment. Total budget of GBP150,000 (PI Migaud); 2015-2019 – SAIC project, Scaling up production of farmed wrasse in the Scottish Salmon industry. Total budget of GBP4,000,000, GBP831,000 for Stirling (PIs Migaud/Davie) and 2016-2020 – SAIC project, Securing a sustainable supply and the optimal deployment of lumpsucker for sea lice control in the Scottish salmon industry. Total budget of GBP2,438,000, Stirling budget of GBP817,000 (PIs Davie/Migaud).*

#### 4. Details of the impact

Stirling research has been pivotal in establishing and driving cleaner fish aquaculture in the UK and internationally as a biological control method for sea lice (**R1**). Mowi Scotland (part of Mowi ASA, based in Norway with extensive Scottish operations, the world's largest producer of Atlantic salmon), Scottish Seafarms (SSF) and The Scottish Salmon Company (SSC), together >70% of UK farmed salmon production, formed collaboration agreements with Stirling to initiate programmes of research and development for farming ballan wrasse from 2010 and then lumpfish from 2014. The research addressed many knowledge gaps and made breakthroughs which gave confidence to the industry to invest in facilities, staff and technologies with a commitment to reach full reliance on farmed rather than wild cleaner fish in coming years (**S1**).

##### Impact 1 – Economic benefits

Research-generated knowledge (**R1 to R6**) has provided the resources and confidence for industry-upscaling of cleaner fish farming to meet Scottish demands. All salmon farming companies in Scotland and Norway now therefore recognise the importance of specialist husbandry requirements for cleaner fish deployment in sea net pens, and in the UK have employed dedicated personnel with cleaner fish husbandry responsibilities, comprising 76 new FTE including 24 at Mowi Scotland, 22 at SSF, 10 at SSC and 20 at Otterferry Seafish (**S2/S3**). This job creation has led to improvements in cleaner fish welfare and biological control of sea lice, resulting in a reduction in the use of veterinary medicines for remedial treatments, thereby improving the welfare of farmed salmon. The financial impact is estimated to be equivalent to an increase in annual turnover of more than GBP8,000,000. Research also led to new investments in hatcheries and on

growing sites. The joint venture between Mowi and SSF in the wrasse hatchery in Machrihanish saw large investments in new recirculation systems, live feed production units (more than GBP 500,000/year in CAPEX and GBP1,000,000 annually OPEX since 2014 **S2/S3**). In 2019 Mowi bought two new facilities in Anglesey and upgraded these for producing ballan wrasse, and lumpfish (Ocean Matters) (GBP16,300,000 investment). SSF/SSC, together with Otterferry Seafish, have invested in new broodstock juvenile production facilities, with a new large scale on-growing facility that opened in 2020 (GBP10,500,000, **S4**). Production at OFS of ballan wrasse (started 2010) and lumpsucker (started 2014) reached 250,000 and 700,000 fish respectively commercialised in 2020 with a forecast to reach 500,000 ballan wrasse by 2025.

These benefits have all relied on Stirling research, as according to the Chief Executive of the Scottish Salmon Producers Organisation, who represents the entire Scottish salmon sector with exports to over 50 countries, University of Stirling research “has been pivotal in supporting our widescale use (and production of) cleaner fish” (**S6**).

### Impact 2 - Production benefits

Stirling research led to commercial protocols implemented within the industry in the UK and Norway from broodstock to deployment of first wild and then farmed ballan wrasse and farmed lumpfish, leading to the rapid expansion of their deployment in the global salmon farming sector, starting from the UK, Norway (**S5**) followed by Faroe islands and Ireland, and recently expanding to Canada. The best evidence of research impact is the rapid expansion of the use of farmed cleaner fish by the Scottish industry (and other salmon producing countries), with only a few salmon farms using wild-caught wrasse at research inception (2010-12) to most of the 217 Scottish sea sites using cleaner fish in 2019 and >70% of these using farmed cleaner fish (**S6**). The first sea site which deployed farmed cleaner fish and successfully completed the cycle up to harvest without medicinal treatment was Mowi Loch Leven (**R4** and **R6** study location) and many more sites and production cycles across the Scottish industry have achieved the same since. The use of farmed cleaner fish has been a key milestone for the Loch Leven site which became the first place in the UK to be approved by the international Aquaculture Stewardship Council (ASC), which certifies and labels responsibly-farmed seafood for consumers.

According to Dougie Hunter, the Technical Director of MOWI Scotland, “This innovation has been a major step forward for salmon farming in Scotland towards improved sustainability and fish welfare” (**S2**). Scottish SeaFarms, Head of Fish Health and Welfare stated, “we fully recognise the highly valuable contribution that the University has made for the use of cleaner fish as playing an important alternative means of control of sea lice on farmed salmon. ... This successful collaboration [with Stirling] has proven to be a landmark in the development of cleaner fish, not just in Scotland but globally. The discoveries made and new knowledge gained have significantly advanced our understanding of many of the fundamental areas of fish welfare and biological control of sea lice, and in doing so will help pave the way for successfully scaling up cleaner fish production for the future sustainable growth of the sector” (**S3**).

### Impact 3 - New products developed and commercialised

Stirling research has been central to the development of dedicated feeds (e.g. **R4**) for ballan wrasse with both adult and juvenile hatchery diets developed with feed producer BioMar (one of the three global leaders in sustainable aquaculture feeds) (**S7**) who commercialised 550 tonnes of Symbio feeds and agar blocks between 2014 and 2020 across the UK and Norway for a total value of circa GBP3,700,000. To meet increasing demands, BioMar also invested in new infrastructure in Scotland to manufacture the feeds and dedicated personnel (5 FTE). Extensive research has examined aspects of immunology and immunocompetence (**R5**) to support the development of a proven effective vaccine by Ridgeway Biologicals (owned by CEVA, a leading global pharmaceutical and biotechnological company) in collaboration with Stirling, against atypical *Aeromonas*, the main pathogen responsible for ballan wrasse (and lumpfish) mortalities. The resulting vaccine is the only one authorised for use in the UK and by 2020 more than 23,000,000 doses had been deployed for ballan wrasse (**S8**). Both feeds and vaccines contributed to the improved health, welfare, and delousing efficacy of farmed cleaner fish.

BioMar Scotland MD and Vice President Salmon for the company globally emphasises “the contribution Stirling research had on BioMar business and as such on the global salmon sector”

(S7). Ridgeway Biologicals MD stated, “The research collaboration has been instrumental in opening this novel market for Ceva Ridgeway enabling the development and commercialisation of vaccines, which have a unique formulation” (S8).

### External Recognition of Impact

Stirling cleaner fish research and impact is widely recognised as an innovative and productive model for industry/academia collaboration (S8), receiving notable accolades including:

- Stirling’s Institute for Aquaculture won a 2018-20 Queen’s Anniversary Prize, of which our work on cleaner fish was a major component.
- Finalist (2014) and **winner (2016) of Scottish Enterprise Life Sciences award** (Innovative collaboration award),
- **Winner (2019) Aquaculture UK awards** (Applied research breakthrough),
- **Recognition of Industrial contribution** through Crown Estates 2015 Scottish Marine Aquaculture, Marine Stewardship award,
- 2015 **SCDI ScotRail Business Direct Award** for Excellence in Business Service & Engagement, and
- 2016 **Scottish Food & Drink Excellence Award** for Innovation (S10).

The Scottish Government has also recognised the “major efforts which the sector has made in recent years to tackle the challenge of sea lice both through preventative husbandry and through non-chemical methods such as sustainable use of ‘cleaner fish’” and “recent developments in industry breeding programmes” (S9), achievements which are dependent on our research.

### 5. Sources to corroborate the impact

- S1.** Evidence of MOWI commitment to reach with reliance on farmed cleaner fish: MOWI (9 Aug 2018), ‘Major milestone achieved in sea lice control’, <https://mowiscotland.co.uk/2018/08/09/major-milestone-achieved-sea-lice-control/>
- S2.** Letter from MOWI Technical Director (Dougie Hunter): confirmation of impact from cleaner fish research performed by Stirling.
- S3.** Letter from Scottish Seafarms Head of Fish Health (Ralph Bickerdike): confirmation of impact from cleaner fish research performed by Stirling.
- S4.** Letter from Otterferry Seafish Ltd. Managing Director (Alastair Barge): confirmation of impact from cleaner fish research performed by Stirling.
- S5.** Best practice report from MEDFRI project in collaboration with FHF and NOFIMA. Evidence of International dimension of the impact of the research. <https://www.fhf.no/prosjekter/prosjektbasen/901296/>
- S6.** Letter from SSPO Chief Executive (Tavish Scott): expansion of cleaner fish use in the industry as a result of Stirling research and dissemination through SSPO annual events
- S7.** Letter from BioMar, Vice President Salmon and Managing Director BioMar Scotland (Patrick Campbell): development and commercialisation of cleaner fish feeds from Stirling research.
- S8.** Letter from Ridgeway, Managing Director (Robin Wardle): development and commercialisation of cleaner fish vaccines from Stirling research.
- S9.** Report from session 5 (7 March 2018) of the Scottish Parliament’s Rural Economy and Connectivity (REC) Committee enquiry into the environmental impacts of salmon farming in Scotland. Published by The Scottish Parliament on 27 November 2018. <https://sp-bpr-en-prod-cdnep.azureedge.net/published/REC/2018/11/27/Salmon-farming-in-Scotland/REC-S5-18-09.pdf>
- S10.** External Recognition:
- S10a.** Queens Anniversary Prize (2018-2020) <https://www.queensanniversaryprizes.org.uk/winners/pioneering-aquaculture-work-for-sustainable-food-production-through-innovations-in-fish-farming-and-water-based-food-industries-in-the-uk-and-overseas/>
- S10b.** Scottish Enterprise Life Sciences award (Innovative collaboration award) 2016.
- S10c.** Winner (2019) Aquaculture UK awards (Applied research breakthrough).
- S10d.** Crown Estates 2015 Marine Stewardship Award.
- S10e.** SCDI Business Direct Award 2015.
- S10f.** Scottish Food and Drink 2016 Excellence Award for Innovation.