Institution: Swansea University		
Unit of Assessment: 7		
Title of case study: Using Lumpfish to Control Sea Lice in Salmon Farming		
Period when the underpinning research was undertaken: 2015-2020		
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:**
Carlos Garcia de Leaniz	CSAR Director, Professor	2004 - present
Sonia Consuegra	Professor	2013 - present
Paul Howes	CSAR Manager	2008 - present
Rebecca Stringwell	NACWO/Deputy Manager	2008 - present
Richard Lloyd	Named Veterinary Surgeon	2005 - present
Ben Whittaker	Research Officer	2016-2019
Carolina Gutierrez-Rabadan	Research Officer	2018- present
Sara Barrento	Science Dissemination Manager	2019-present
Period when the claimed impact occurred: 2015 to 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Parasitic sea lice are the biggest threat to salmon farming, a GBP15,000,000,000 industry and the cornerstone of Europe's aquaculture. Lumpfish can reduce the use of anti-sea lice drugs by 80%. Our research has made it possible to culture lumpfish in captivity, thereby reducing the need for harmful chemicals which are rapidly losing their efficacy. We identified the key production bottlenecks and developed standard operating procedures and welfare indicators, which have been adopted by industry. Overall, our research has (**A**) facilitated the selection of locally adapted 'elite' lines of lumpfish better adapted to survive in captivity, (**B**) created jobs, (**C**) improved lumpfish welfare standards and (**D**) played a key role in the economic regeneration of the finfish aquaculture industry in Wales.

2. Underpinning research

Sea lice control costs salmon farmers worldwide more than GBP700,000,000 p.a. and results in a 17% loss of growth and impaired welfare. There is no vaccine against sea-lice infestation. Only a small number of anti-parasitic therapeutants are currently licensed for treatment, and these are losing their efficacy due to evolved parasite resistance. Finding non-medicinal solutions for sea-lice control is a major priority for industry. Using cleaner fish, who eat sea lice, is particularly attractive since they can reduce the use of chemotherapeutants, are more cost-effective than medicating and are potentially less stressful to farmed fish. For these reasons, the number of cleaner fish used by the salmon farming industry has increased exponentially since 2008 and amounted to 50 million in 2020 (+15,000,000 in the UK alone), +64% of which are lumpfish. Such large numbers can only be achieved through commercial production, which our Centre for Sustainable Aquatic Research (CSAR) in Swansea University has pioneered since 2015. To achieve the sustainable production of lumpfish in captivity, our gap analysis [**R1**] identified three main bottlenecks addressed by our research:

2.1. Artificial breeding in captivity. This is necessary to remove dependence on wild broodstock and to ensure a consistent supply of certified, vaccinated lumpfish to lessen the risk of disease transmission. CSAR was the first establishment in the UK to breed locally sourced lumpfish (i.e., native lumpfish) using artificial reproduction in 2015. We pioneered the use of a non-destructive method to assess the health of lumpfish broodstock [**R2, G1-G3, G5**], developed a novel molecular assay to detect and quantify the incidence of microsporidiosis, one of the leading causes of mortality and economic losses in farmed lumpfish [**R3**], and developed the first sperm bank for lumpfish [**G6**].

2.2. Genetic characterisation and elite lines. Not all lumpfish naturally eat sea lice, and many die of starvation following deployment in salmon net-pens. An urgent need has been identified to select the best individuals for sea-lice control. We were the first to show that lumpfish populations are genetically, as well as phenotypically, distinct across the species' range [**R4, G4**]. We showed that some native populations have traits that make them better suited for aquaculture and, crucially, that these should not be translocated while there is a risk of escapees. It also provided the first estimates of effective population sizes of lumpfish, and a genetic baseline of wild populations against which the potential impact of farm escapees can be assessed [**R4**].

2.3. Ensuring better welfare of lumpfish. There is an urgent need to identify the welfare needs of farmed lumpfish, and to develop suitable indicators that can help the industry monitor and improve lumpfish welfare. We developed, in collaboration with our commercial sponsors, the first Operational Welfare Score Index for lumpfish, which is now widely used by industry [**R5, G4, G6, G7**].

3. References to the research

All publications have been peer-reviewed and 4 are published in Q1 journals (JCR 2019). Papers have been supported by funding from The European Regional Development Fund, Marine Harvest Scotland and Oceans Matters Ltd. (in **bold**: Swansea University staff who conducted the research).

[R1] **Powell, A.**, Treasurer, J.W., **Pooley, C.L., Keay, A.J., Lloyd, R.,** Imsland, A.K., **Garcia de Leaniz, C.** (2018) Use of lumpfish for sea-lice control in salmon farming: challenges and opportunities. Reviews in Aquaculture 10: 683–702. https://doi.org/10.1111/raq.12194

[R2] **Lloyd, R., Garcia de Leaniz, C.** (2020) The use of laparoscopy for coelomic organ evaluation, biopsy and disease screening in broodstock Atlantic lumpfish, *Cyclopterus lumpus* Linnaeus. Journal of Fish Diseases 43:1107-1110. https://doi.org/10.1111/jfd.13218

[R3] **Naung, M., Uren Webster, T.M., Lloyd, R., Garcia de Leaniz, C., Consuegra S** (2021) A novel qPCR assay for the rapid detection and quantification of microsporidia (*Nucleospora cyclopteri*) in lumpfish (*Cyclopterus lumpus*). Aquaculture 531:735779 (published Aug 1 2020). https://doi.org/10.1016/j.aquaculture.2020.735779

[R4] **Whittaker, B. A., Consuegra, S., Garcia de Leaniz, C.** (2018). Genetic and phenotypic differentiation of lumpfish (*Cyclopterus lumpus*) across the North Atlantic: implications for conservation and aquaculture. PeerJ 6: e5974. https://doi.org/10.7717/peerj.5974

[R5] **Gutierrez-Rabadan, C.**, **Spreadbury C., Consuegra, S., Garcia de Leaniz, C.** (2021). Development and validation of an Operational Welfare Score Index for farmed lumpfish *Cyclopterus lumpus* L. Aquaculture 531, 735777 (published Aug 4 2020). https://doi.org/10.1016/j.aquaculture.2020.735777

Grants to CSAR – funding secured through direct private investment, EU programmes and UKRI.

[G1] Garcia de Leaniz, C. (PI) Consuegra, S. (PI), Howes, P. (CoI) Stringwell, R. (CoI). LUMPFISH. Optimising the use of lumpfish as biological control of sea lice in Salmon Farming. Marine Harvest Scotland, 2015-2020. GBP826,431.

[G2] Garcia de Leaniz, C (PI), Consuegra, S. (PI) Howes, P. (CoI), Stringwell, R. (CoI). Better lumpfish - Phase 1. The Scottish Salmon Company. 2018-2020. GBP400,000.

[G3] Garcia de Leaniz, C. (PI) Consuegra, S. (PI), Howes, P. (CoI) Stringwell, R. (CoI). Native Lumpfish. Ocean Matters. 2018-2020, GBP36,900.

[G4] Garcia de Leaniz, C. (PI) Consuegra, S. (PI), Howes, P. (CoI) Stringwell, R. (CoI). SMARTAQUA: Aquaculture Beyond Food. Welsh Government and the European Regional Development Fund. 2017-2020, GBP1,388,557

[G5] Garcia de Leaniz, C. (PI) Consuegra, S. (PI), Howes, P. (CoI) Stringwell, R. (CoI). UK Lumpfish. Three Sixty Aquaculture. 2019-2023. GBP65,000.

[G6] Garcia de Leaniz, C., Consuegra, S. (PIs) Knowledge Economy Skills Scholarships (KESS 2), part-funded by the Welsh Government's European Social Fund (ESF) convergence programme for West Wales and the Valleys. ca. GBP92,736 including: PhD scholarship: Improving the health and welfare of farmed lumpfish for sea lice control in the salmon farming industry; in collaboration with Ocean Matters. 2019-2021, and MRes scholarship: Development of a sperm bank for supporting the cleaner fish industry in Wales; in collaboration with Three-Sixty Aquaculture. 2019 - 2020

[G7] Garcia de Leaniz, C. Consuegra, S. (PI), Howes, P. (CoI) Stringwell, R. (CoI) UK Seafood Innovation Fund: Tools for improving the welfare of lumpfish 2020-2022. GBP248,153.

4. Details of the impact

The key aim of the lumpfish project has been to develop sustainable practices to produce a novel species to aquaculture – the lumpfish *Cyclopterus lumpus* [**R1**]. We have developed a disease screening programme for lumpfish [**R2, R3**] and protocols (including a set of microsatellites for paternity analyses) for breeding and rearing native lumpfish, selecting lumpfish with desirable traits (i.e., elite lines) such as affinity for eating sea lice, low stress response, and high welfare [**R5**].

4.1 Artificial breeding in captivity

CSAR was the first establishment in the UK to breed locally sourced lumpfish. By focusing on innovative breeding (including a novel sperm bank development), husbandry and diagnostic techniques, we made it possible to culture the large number of cleaner fish needed by the salmon farming industry to combat sea-lice.

We have made the production of lumpfish more efficient and environmentally sustainable [**R1-R5 and a series of Standard Operating Procedures [C2] freely available to industry**], which has in turn resulted in salmon with fewer sea lice and less use of chemicals, as noted by our sponsors:

"The 150,000 fish you have supplied will support the cleaning of 1.8 million salmon in our cages and having the cleanerfish in the cages has resulted in a reduction in the need for chemical treatment by around 40-50% and on some sites as much as 100%. Farm managers at our sites have commented on the quality of the fish that have been supplied by your team" [Cleaner Fish Supervisor, The Scottish Salmon Company, **C1**].

Stemming from **R2** & **R3** are a series of **standard operating procedures (SOPs)** which include innovative techniques on pathogen screening, larvae transport, breeding, rearing and vaccination. All nine SOPs are freely available to download on Swansea CSAR site [**C2**] and used by fish farmers:

"*Your standard operating procedures (SOP's) for lumpfish production have proven very useful*". [Facility and Business Manager, Memorial University of Newfoundland, Canada, **C3**].

"….thank you for providing us with your standard operation procedures, feeding plans and advice on the biofilters etc. The SOPs have been very useful as were the feeding plans" [Hatchery Operative, Ocean Matters, **C5**].

"*The research we have engaged in since 2014/15 has influenced all of the Cleanerfish sector in the UK …. it has been very satisfying to see protocols we developed and practiced at CSAR being adopted by the broader industry." "The development of the first sperm bank in the UK for lumpfish will also go a long way to ensuring sustainability in the supply of disease-screened sperm for the industry"* [Director, The Cleaner Fish Company **C4**].

4.2 Genetic characterisation and elite lines

Innovation [**R4**] has allowed the production of elite lines of native lumpfish at CSAR increasing from 5,000 juveniles in 2014 to over 2,000,000 in 2019, most of which are now coming from locally sourced stocks instead of relying on lumpfish imports.

"*Together we have sent over 2 million lumpfish larvae to UK Cleanerfish on-growers and over 530 thousand deployable fish to Salmon farms. The fish produced at CSAR have been well received and have gained a reputation of being both robust and of near perfect condition which has resulted in good survival and de-lousing rates post deployment'*… *through your research, I have seen shifts in the industry desire to focus on local strain lumpfish rather than importing Icelandic and/or Norwegian strain lumpfish."* [Director, The Cleaner Fish Company, **C4**].

CSAR has provided salmon farms in Scotland with 6,500,000 lumpfish with a market value of ca. GBP10,000,000 [**R1**]. The value to the salmon industry, through improved sea lice control and lower medication is much higher, as losses due to sea lice damage are estimated to be GBP700,000,000 per year. Innovative production systems designed and developed at CSAR have been used by Ocean Matters (now MOWI Scotland) and Three-Sixty Aquaculture at their newly built facilities [**C5-C6**]. Our research on reproduction and larviculture has made it possible to produce 4,000,000 lumpfish/year at Ocean Matters and has also resulted in the setting of a new commercial hatchery [**C6**] in Swansea in 2019 to produce native lumpfish (Three-Sixty Aquaculture) directly helping with the economic regeneration of the region.

4.3 Ensuring better welfare of lumpfish

We trained fish farmers on the use of our Lumpfish Operational Welfare Score Index [**C7**] and produced percentile length-weight charts to enable farmers to quickly recognise underweight fish [**R5]**. To ensure the uptake of these novel methods, we organised the first Workshop on Lumpfish Welfare in May 2019 supported by the UK Animal Welfare Network, UKRI, the RSPCA, Compassion in World Farming, fish farms, and feed companies [**C7**]. A Compassion in World Farming research manager at the workshop noted:

"*This event is very important for the aquaculture industry because the industry as a whole is looking more and more into fish welfare. This event helped the industry to have a baseline to look into fish welfare*" [**C7**].

4.4 Employment and socio-economic innovation

Our applied research has directly resulted in the creation of twelve new jobs in Wales (4 people employed by Three-Sixty Aquaculture [**C6]**, 7 people by Ocean Matters, 1 person by The Cleaner Fish Company [**C8]**). Private R&D investment in the Lumpfish project exceeded GBP1,000,000 during 2019 [**C8,** pg 2 and pg 18] and resulted in two new products to the market in the UK (disease-screened native lumpfish larvae; and disease-screened native lumpfish broodstock – [**C8],** pg 2, pg 19). More broadly, our lumpfish studies have contributed to a more competitive and sustainable salmon industry, as fewer sea lice means better survival, growth, welfare and consumer acceptance [**C1]**. This affects an estimated 150 jobs directly related to the cleaner fish sector (ca. 50 jobs in Wales) and 1,415 jobs directly employed in salmon farming in the UK [**C9,** Table 31, pg 27].

"Based on the research papers and book contributions produced by your team….we have now finished the construction of our main facility in Swansea, which will be capable of producing up to 1 million lumpfish…We now have an excellent team of staff, four of which learned most of their Lumpfish expertise at CSAR and we are confident they will use this foundation to help us grow." [Managing Director, Three-Sixty Aquaculture, **C6**].

5. Sources to corroborate the impact

[C1] Letter, Cleaner Fish Supervisor, The Scottish Salmon Company (PDF)
[C2] Lumpfish SOP (PDF), also available on https://www.swansea.ac.uk/bioscience/csar/projects/lumpfish/

[C3]	Letter, Facility and Business Manager, Memorial University of Newfoundland, Canada (PDF)
[C4]	Letter, Director, The Cleaner Fish Company (PDF)
[C5]	Letter, Hatchery Operative, Ocean Matters (PDF)
[C6]	Letter, Director, Three-Sixty Aquaculture (PDF)
[C7]	Workshop evaluation (PDF) also available on http://smartaqua.org.uk/symposium-on-welfare-in-aquaculture/first-symposium-on-welfare-in-aquaculture/
[C8]	Socio Economic Impact (PDF)
[C9]	Aquaculture Survey Scotland (PDF) also available on https://www.gov.scot/publications/scottish-fish-farm-production-survey-2018/