Institution: University of Stirling		
Unit of Assessment: 6. Agriculture, Food and Veterinary Sciences		
Title of case study: Combatting hunger, poverty, and ecosystem overexploitation with sustainable aquaculture production		
Period when the underpinning research was undertaken: 2003-2019		
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:**
Trevor Telfer	Professor	1995 – present
Lynne Falconer	PDRF	2012 – present
Lindsay Ross	Professor (Emeritus)	1977 – present (retired 2016)
Period when the claimed impact occurred: 2014-2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Our research into the carrying capacity of aquaculture ecosystems has become embedded in policy and practice in Europe, Latin America, and Africa. This has dramatically improved farm management and led to large, sustainable, increases in fish production, helping to reduce poverty and hunger while minimizing environmental impact.

Impact 1: UN (FAO) and EU policy now draw on our work, bringing aquaculture regulatory frameworks and licensing in line with environmental sustainability.

Impact 2: In Ghana our work has enabled the burgeoning aquaculture industry to support the food security of approximately 2,000,000 people.

Impact 3: In Mexico, our approach has allowed the establishment of 10 new farms producing USD9,000,000 worth of tilapia annually.

2. Underpinning research

Aquaculture is the fastest growing food production sector globally but its reliance on water-based resources means it is only sustainable if the carrying capacity of the production environment is not exceeded or mitigated if already surpassed. For aquaculture to contribute to the United Nations Sustainable Development Goals of SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption) and maintaining SDG 14 (Life Below Water) it must be developed to ensure efficient use of environmental resources and within the capacity of the environment to support it. University of Stirling Institute of Aquaculture research into carrying capacity and its prediction has provided the means for such efficiency to become established across the world.

Our research shows that the carrying capacity in suitable sites for aquatic food production encompasses physical, ecological, production and socio-economic aspects of the environment. Our interdisciplinary and collaborative methods for integrated modelling and assessment of nutrient loading, biodiversity, waves and water movement and socio-economic gains, combined with production scenarios, have allowed incorporation of carrying capacity, location and site suitability, and its trade-offs to be included in future development and governance policy for locations in Europe, Central America, and Africa. This work has been supported by a total of GBP1,317,800 of funding awarded to Stirling from national and international funding organisations, such as the Irish Government and INAPESCA (Mexico), Darwin Initiative, the Leverhulme/Royal Society, FAO, and EU H2020.

Key underpinning research (research outputs **R1**-**R5**) includes:

- **The first study using computer-based environmental models** to predict carrying capacity for management of fish farming in a specific marine coastal area (**R1**) for environmental regulation (see Impact 1).
- **A definitive and widely disseminated FAO-UN Technical Guidance report** framing site suitability and use of carrying capacity and models for aquaculture development (**R2**). This forms a basis for aquaculture management under the United Nations “Ecosystem

Approach to Aquaculture" Framework within the Code of Conduct for Responsible Fisheries (see Impact 1).

- **Development of an innovative multidisciplinary approach** involving spatial and carrying capacity modelling for identification of aquaculture development zones in sub-Saharan African lakes (**R3**). Application of modelling combined with training in carrying capacity modelling for governmental and NGOs led to a sustainable aquaculture policy for Lake Volta, Ghana, which is now used as an exemplar for fish farm development in sub-Saharan lake systems (see Impact 2).
- **Use of carrying capacity modelling for site suitability assessment** to ensure development of sustainable aquaculture production in Lake Infiernillo, Mexico (**R4**). This has now extended to four further water bodies, has demonstrably increased commercial tilapia production in cages (see Impact 3).
- **Application of carrying capacity models to develop a platform for new policy recommendations for aquaculture licensing** (see Impact 1). Computer models and guidance in licensing using an online platform came from international, multi-partner research through the EU H2020 TAPAS project (2016-2020), coordinated by the University of Stirling (Telfer) (**R5**).

3. References to the research

University of Stirling authors in **bold** text. Funding details in ***bold italic***

R1. **Telfer, T.C.** and Robinson K.A. (2003) *Environmental quality and carrying capacity for aquaculture in Mulroy Bay, Co. Donegal*. Marine Environment and Health Series, Volume 9. Marine Institute, Dublin. 99 pp. ISSN. 1649 0053. hdl.handle.net/10793/228
Funding: GBP15,000 (PI: Telfer) *Marine Institute, Ireland, internal funding.*

R2. **Ross, L.G., Telfer, T.C., Falconer, L**., Soto, D. and Aguilar-Manjarrez, J. (2012). *Site selection and carrying capacities for inland and coastal aquaculture.* FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 46 pp. + 282 pp. www.fao.org/3/a-i3322e.pdf
Funding: GBP66,500 (PI: Ross) *from Food and Agriculture Organisation of the United Nations - funding for technical workshop Dec 2010*

R3. Asmah, R., Karikari, A., **Falconer, L., Telfer, T.C.** and **Ross, L.G.** eds (2016) *Cage aquaculture in Lake Volta, Ghana. Guidelines for a sustainable future*. CSIR Water Research Institute, Ghana and University of Stirling, UK. 112 pp. ISBN 978-1-908063-40-3. http://hdl.handle.net/1893/24680
Funding: GBP180,000 (PI: Ross) from *Royal Society/Leverhulme. Africa Award Grant No. AA120043 (2012-2015)*

R4. **Ross, L.G., Falconer, L.,** Campos Mendoza, A. and Martinez Palacios, C.A**.** (2010). Spatial modelling for freshwater cage location in the Presa Adolfo Mateos Lopez (El Infiernillo), Michoacán, México. *Aquaculture Research*, 42(6): 797-807. DOI:10.1111/j.1365-2109.2010.02689.x
Funding: ~ GBP500,000 (PI: Ross) *CONACyT, Mexico, national funding*

R5. **Telfer, T., Falconer, L.,** Kaas, H., Jackson, D. (2018). TAPAS – Tools for Assessment and Planning of Aquaculture Sustainability – Horizon 2020. Impact, 8: 9-11. DOI: 10.21820/23987073.2018.8.9
Funding: GBP1,071,400 (PI: Telfer) *EC H2020 TAPAS Research and Innovation Grant No. 678396 (2016-2020).*

4. Details of the impact

Impact 1: Embedding sustainability in national & international policy & regulations

As the fastest-growing food sector, the UN Food and Agriculture Organization (FAO-UN) recognises the potential of aquaculture development to bolster food security but has also been cognizant of the need for this to be economically and ecologically sustainable. Stirling's pioneering

work on carrying capacity and site selection in aquaculture (**R4**) has translated this recognition into policy that is now being followed globally. As the FAO-UN states, "**Stirling has been central to the development of carrying capacity thinking – concepts, tools, models, implementation pathways – in aquaculture**". This has been "**underpinned by its global research orientation, capacity building and international reach**" (**S3**). This has "**undoubtedly made significant contributions to the implementation of the Code of Conduct and the Ecosystem Approach to Aquaculture**" (**S3**).

The basis of the carrying capacity research at Stirling, and its impact today, came from an approach developed in Mulroy Bay, Ireland, in 2003. This employed spatial and temporal computer-based models to calculate the capacity for aquaculture through impacts on nutrient loading and subsequent dissolved oxygen demand. This was a novel approach at the time as it encompassed multiple culture systems with fish and shellfish in the same body of water. The work informed the Marine Institute, Ireland, (Irish Government) of sustainable levels of aquaculture and resulted in implementation of improved environment practice for aquaculture, which, they confirm, "**are still used to this day to inform aquaculture licensing within the bay**" (**S1**).

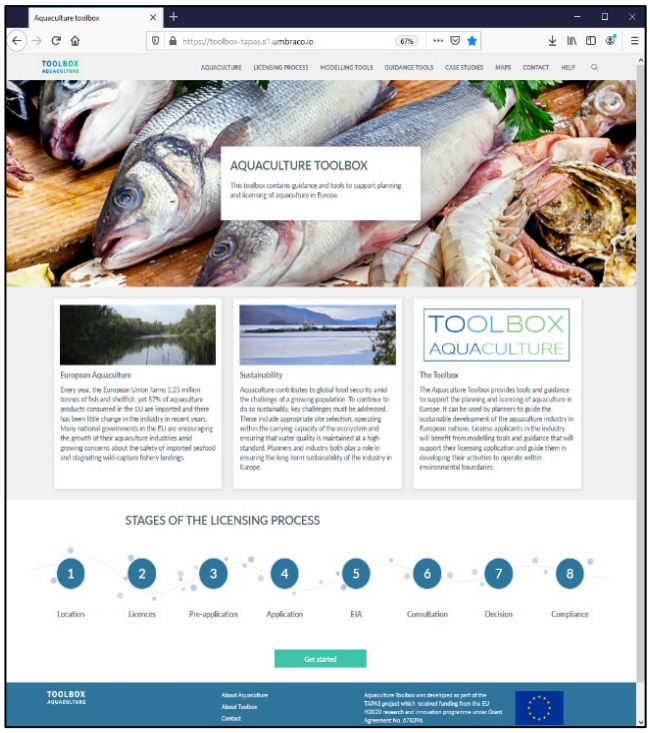

Figure 1. The Aquaculture Toolbox to support planning and licensing of aquaculture in Europe

EU aquaculture, including the UK, produces **1.3 million tonnes** of seafood, worth **EUR4,400,000,000, providing employment for around 39,000 people**. Since 2008 there has been no increase in production in part through poor licensing and regulatory frameworks. The EU H2020 TAPAS project (2016-2020), coordinated by the University of Stirling (Telfer), developed policy and licencing guidance and recommendations, modelling tools based around carrying capacity, and a decision support toolbox (Figure 1) to aid implementation, see: https://www.aquaculturetoolbox.eu

These guidelines and recommendations have recently been incorporated in the **"Updated Strategic Guidelines for the Sustainable Development of EU Aquaculture" produced by DG MARE** to implement new production strategies for European aquaculture in the future (**S2**).

Impact 2: Supporting economic and food security in Ghana

Ghana, a country of approximately 29,000,000 people (latest figure, April 2019), depends on fish for 60% of its dietary protein, while 10% of its population work in the fisheries industry. Yet overexploitation of the country's marine fisheries has seen declining harvests since the 1990s and caused a seafood trade deficit of over USD300,000,000 by 2013. In response to this, the Ghanaian government launched the Ghana National Aquaculture Development Plan in 2012 and created the Ministry of Fisheries and Aquaculture Development in 2013 to rapidly and substantially increase aquaculture production.

Stirling research has allowed this initiative to successfully and sustainably develop the aquaculture industry. It has contributed to the **economic security** of the **58,000 Ghanaians** who directly work in the aquaculture industry and supported increased food security for the equivalent of **2,000,000 people** who source their protein from aquaculture, an increase of more than **450,000 people (29% increase)** since our impact in Ghana began. Specifically, our work on geographic information

system (GIS) decision support models and environmental measurements on Lake Volta (the largest and principle water body for aquaculture in Ghana) has meant that "**cage aquaculture management has been significantly improved and management zones implemented, contributing to quicker commencement of aquaculture business … within the lake**" (Director of the Council for Scientific and Industrial Research (CSIR) Water Research Institute, Ghana. **S4**). Without such management zones it is possible that aquaculture on Lake Volta would have become unsustainable, undermining food security.

Our work has been essential in the "development and use of tools for carrying capacity assessment" (**S4**). We additionally **trained and built capacity** with over 40 representatives from all major NGOs and government departments in Ghana (**S4**), resulting in improved use of our management tools for sustainable aquaculture development and helping "underpin greater knowledge and understanding of cage aquaculture management and regulation in Lake Volta" (**S4**). Questionnaires (2015) showed **95% of the participants in our training found our work to be of benefit to aquaculture development for Lake Volta**. A follow up questionnaire in 2019 revealed that 67% of the same stakeholders use our tools and training for aquaculture management and practice (**S5**). Ghana's Council for Scientific and Industrial Research conclude that our work "is contributing significantly to production of a much-needed high-quality product" (**S4**).

Impact 3: Supporting sustainable aquaculture expansion in Mexico

Aquaculture production in Mexico fell by 28% between 2000 and 2013, undermining Mexican government aims to sustainably increase per capita fish consumption and improve rural health and economic wellbeing. Our research has significantly contributed to a reversal of this trend. We have brought a focus on carrying capacity, as Dr Antonio Campos Mendoza of the Biotecnología e Innovaciones Acuícolas y Pecuarias de Michoacán (BIAP) explains, this has led to "**increase[d] awareness of the key issues and tools to manage sustainable aquaculture. This has been achieved through engagement of BIAP with farmers, regulators and decisions makers, promoting the scientific management of natural resource use in fish production**" (**S7**). This has resulted in significant advances and **increased production of tilapia** in fish cages in central Mexico, first in Lake Infierillo (**R5**) and then to four further water-bodies.

This impact was achieved through workshops in carrying capacity modelling for the National Fisheries Department (INAPESCA), where tools and training enabled better planning for improved sustainability of freshwater aquaculture throughout Mexico (**S6**), "This capacity building has helped **underpin implementation of the strategic plan** for cage aquaculture development throughout the republic" (**S7**). This combination of research and training has led to an additional **4,000 tonnes per annum** of commercial tilapia production in five lakes, representing 7% of total tilapia production in Mexico, and **boosting local income by USD9,000,000 annually** (**S7**). This success has **released further Mexican government funding** so our work can continue to develop and enhance tilapia production into the future.

5. Sources to corroborate the impact

S1. Testimonial from Dr Francis O'Beirn, Section Manager – Licencing and Policy Advice, Marine Institute, Ireland to corroborate the impact and changes in practice and change in the production levels within Mulroy Bay and associated water bodies.

S2. Reference to the policy document "*Update of the strategic guidelines for the sustainable development of EU aquaculture*", as a specific footnote mentioning the project by name, developed by DG MARE on European governance of aquaculture.

S3. Testimonial from Dr Malcolm Beveridge, Acting Branch Chief, Aquaculture Branch, Department of Fisheries, at the Food and Agriculture Organisation of the United Nations (FAO) throughout 2016 and 2017. Corroborates the impact of the carrying capacity research on FAO aquaculture policy and the Workshop and Technical report on use of carrying capacity on application of the 'Code of Conduct for Responsible Fisheries'.

S4. Testimonial from Director of the CSIR Water Research Institute, Ghana, corroborating the effect of using a carrying capacity approach to aquaculture zoning and production of fish in cage farms within Lake Volta.

S5. Evidence of the impact of the capacity building with academic, governmental and NGO staff in Ghana. Initial (**S5a**) (2015) and follow-up questionnaires (**S5b**) (2019) to original capacity building stakeholders demonstrates that the training in use of carrying capacity and modelling tools has benefited governance and development of aquaculture in Ghana.

S6. Testimonial from Juan Carlos Lapuenta Landero, Deputy General Manager, Directorate for Aquaculture, INAPESCA, Mexico, confirming the importance of the research and the capacity-building and training workshops.

S7. Testimonial from Dr Campos Mendoza, University of Michoacán and BIAP, confirming the contribution the initial and continuing research on carrying capacity and site suitability has made to continued funding from the Mexican government and the commercialisation of tilapia culture from nothing to present levels.