FISH FARMING IN SCOTLAND

OPTIMISING ITS CONTRIBUTION TO CLIMATE AND ENVIRONMENTAL POLICIES

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Funded by The Open University in Scotland.
17th August 2021

Cite as:

McGoohan, A., Tait, J., Raybould, A., Parris, S. & Hammond, K. (2021) Fish farming in Scotland: Optimising its contribution to climate and environmental policies. https://www.innogen.ac.uk/media/304

Executive Summary

Aquaculture is a rapidly growing contributor to Scotland's food-related economy, particularly the circular bio-economy that will be more environmentally, economically and societally sustainable. This policy report, funded by the Open University Scotland, demonstrates the role of innovative technologies in contributing to this improved sustainability of aquaculture in Scotland, meeting key government policies on Net Zero carbon emissions, the circular economy, zero waste, marine biodiversity, and improving the nutritional quality of the nation's diet. Where relevant we draw attention to the interactions between meeting climate change targets and contributing to biodiversity targets.

Globally, wild-capture fisheries have little capacity to expand without risking a collapse in fish stocks and seriously damaging marine biodiversity. The capacity of seafood to meet the world's increasing demand for protein will therefore need to come from farmed sources. This highlights the importance of being able sustainably to increase the production of protein foods based on aquaculture, and the role of innovative technologies in meeting that need.

The background research used information from published literature and reports, and from industry and policy contacts, and the report focuses particularly on innovation in fish feed development, fish farming systems, fish processing, and waste and by-product management. It also considers needs for future developments in life cycle analysis (LCA) and animal health and welfare. Given the complexity of the underlying systems, and the limited development and lack of standardisation in greenhouse gas accounting methods, a quantitative comparative analysis of the innovations considered is not yet possible. However, it is possible to judge the relative potential contributions of different innovations to overall climate change and biodiversity targets, as an indication of productive areas for innovation support and for further development.

Innovations and their contributions

The contributions of innovations to sustainable food production will be additional to the baseline climate-change benefits of moving from red meat to seafood-based protein in people's diets. On average, global aquaculture production has significantly lower GHG emissions per kg of edible product (carcass weight): beef production globally averages 45kg CO_2-eq/kg compared to average global aquaculture production at around 5kg CO_2-eq/kg. The potential benefits from the innovations described here would be additional to these baseline numbers, with variation depending on the local context. For example, beef and sheep production in Scotland is already more sustainable than in many other regions of the world and is making progress in further reducing greenhouse gas emissions from those sectors.

Innovation in aqua-feed production

Aqua-feed accounts for over 90% of fish-farm gate GHG emissions and, at 40-75% of total production cost, it is the most expensive component of aquaculture production. Innovation in feed production has the greatest opportunity to contribute to fish farming's climate change mitigation and to improving biodiversity-related impacts. Today's aquafeed has shifted from its previous reliance on fishmeal and fish oil from wild capture fisheries,

replacing this with vegetable ingredients such as soya meal and rapeseed oil, so that Scottish fish diets now contain roughly 50% plant based ingredients (contributing 73% of GHG emissions from feed) and roughly 46% marine based ingredients (contributing 24% GHG emissions from feed). Both these feed sources, agricultural land-based and marine, raise biodiversity challenges and today's ingredients have also resulted in a reduction in the omega-3 fatty acid content of farmed fish of around 50% between 2006 and 2015. However, the Scottish salmon industry has retained a higher marine ingredient content in its feed compared to other regions, motivated by the high quality standards of Scottish salmon. The following locally produced innovative sources of protein feedstock will reduce the biodiversity impacts of wild-caught fish ingredients, the climate change impacts of agricultural production and transport, and the biodiversity impacts of plant based ingredients.

Micro-algae

Globally *around 16 million tons of fish are captured to produce fish oil and fish meal ingredients for feed, and m*icro-algae are already being used as a source of both protein and omega-3 oils. *One tonne of algae-based oil is estimated to save up to 30 tonnes of wild fish and the use of these oils is estimated to deliver reductions ranging from 45% to 95% in global warming potential of aquafeed. Production and use of algal aquafeed are currently limited by scale-up challenges and cost but these are expected to be resolved soon.*

Whisky by-products (pot ale and spent wash) are used as a source of feedstock for algal fermentation in Scotland, contributing to the circular bioeconomy. They could provide enough ingredients to meet the current protein demand in feed for the aquaculture industry, as well as supply future demand from industry growth. However, there will also be demands on this by-product from other industry sectors with circular economy ambitions.

Insect meal

In trials, insect meal from black soldier fly (BSF) larvae has replaced 100% of fishmeal in Atlantic salmon diets, with no difference in nutritional profile, growth rate or feed conversion ratio. They have a low biodiversity impact and energy demand, using no arable land or wild fish stocks and with reduced water use. Insects have negligible levels of omega-3 oils and could substitute for fish meal and vegetable meal, but not the oil-based component of the feed. The food source for the larvae is non-domestic food waste, avoiding competition with human food sources. If only 10% of available by-product streams is redirected to BSF farming it could produce 2.7kt of insect meal for Scotland's salmon farming industry along with an increased economic value. There would be an additional 10% of carbon savings, compared to anaerobic digestion of the waste, saving 69 kg CO_2eq/tonne of input. Using low-grade waste heat to fuel the process, the carbon savings from BSF farming could be increased to 153kg CO_2eq/tonne of input with further savings from future decarbonisation of the electricity grid.

Single celled protein (SCP)

Micro-algae, yeast, bacteria and fungi are highly productive and can be grown using a variety of feedstocks with a focus recently on the use of waste residues and by-products. This would support a more circular economy, potentially reduce the carbon footprint and increase the overall environmental performance of feed production systems.

- Microorganisms are being used to convert methane gas to a product with 71% protein and 9% fat and feeding trials have shown increased growth and improved feed efficiency. As for the other aquafeed innovations, this would reduce the amount of land required compared to soybean meal (1692 km^2 required to produce 40,000 tonnes of usable protein from soy compared to 0.04 km^2 for SCP), along with 77–98% less water needed compared to soy and wheat production (US data). Compared to the USA, the efficiency of the UK electricity grid would amplify the climate change benefits from adoption of SCP and other related aquafeed inputs and if 100% biogas from waste streams was used to produce the protein, the carbon footprint could be reduced from 5819 kg CO_2eq/tonne to 2274 kg CO_2eq/tonne.
- Micro-organisms are also being used to metabolise CO_2 (a power station by-product) and hydrogen to produce SCP with a comparable nutritional profile to fishmeal with a claimed reduction in carbon footprint of 25%.

New types of production system.

New production systems are being designed to increase production capacity, reduce environmental impacts, meet planning-related challenges, and increase overall control of production systems. There are concerns about the increased energy demand and potentially higher carbon footprint of these technologically advanced systems but some of these could be addressed by using renewable energy sources and advances in decarbonising the electricity grid will also improve their sustainability. There is a lack of LCA-related and other information on these production methods making it difficult to judge the real benefits from technological improvements and to compare different systems.

Offshore high energy systems

These systems could increase the production capacity of fish farming and reduce some sources of environmental concern about current production methods. There are technical challenges in locating farms offshore, and risks related to workforce health and safety but there would also be benefits to fish health, reduced environmental impacts from waste, and scope for the industry to develop higher capacity sites. Cages are 28,000m^3 -125,000m^3 in size and have been designed to alleviate animal health issues caused by sea lice and algal blooms, and to incorporate waste capture technologies. Embedded renewable energy solutions would improve GWP of these facilities. These sites also require smolts to be larger and more robust to withstand the harsher environment, requiring new arrangements to increase the growth size of smolts before transfer to off-shore systems. New inshore closed and semi closed nursery systems and larger land based recirculating aquaculture systems are part of the solution to this issue.

Closed containment aquaculture systems

These systems can be used as nurseries or for salmon on-growing and can be placed in inshore waters or offshore. They benefit from the ability to control and filter the water supply entering the system, and pumping the water from deep levels removes the threat of introducing harmful algae and sea lice into the cages. Adopting closed containment sea pens for all smolt production in Scotland could enable the output from current sea based on-growing sites to be increased by 70%. These systems reduce energy consumption by 75%, increase the feed conversion ratio, and reduce fish mortalities to less than 0.5%.

Recirculating aquaculture systems

These closed containment systems are mainly used for freshwater aquaculture on land, acting as hatcheries and smolt growing systems for salmon. They have been used for many years and the technology is not novel, but there have been improvements in production capacity, smolt mortalities, energy systems, waste recovery, and water cleaning systems that will all contribute to climate change and biodiversity targets.

Food processing

Food processing innovations are also beginning to have an impact on the aquaculture environmental footprint. For example: reusable bulk bins for transport have been introduced with an estimated saving to date of 4,100 tonnes of carbon and considerable scope for expansion; and biodegradable packaging is being developed, based on chitin extracted from shell by-products from farmed crustaceans.

By-product and waste utilisation

Waste and by-product utilisation is an integral part of several of the innovations described, using by-products from other sectors as inputs to fish farming as part of a circular economy approach. There are additional circular economy opportunities using by-products from fish farming as inputs back into the fish farming value chain or beyond fish farming into other sectoral value chains (see Figure below).

- Organic particulates (uneaten fish food and faeces) from land-based RAS systems can be used as biofuel or fertiliser and innovative approaches to capture this resource are being developed for other production systems.
- Fish mortalities, which cannot be used in the human food chain, can be disposed of by incineration, rendering, in vessel composting, or anaerobic digestion at approved plants. The option to use fish oil as a replacement for diesel is being investigated and could contribute to a localised circular economy.
- By-products from food processing can be used to create food grade protein and omega-3 oils for terrestrial livestock feed, pet food and pharmaceuticals, further reducing the reliance on fish meal and fish oil from wild capture fisheries.

Biodiversity and sustainable development goals

A shift in diets from red meat to fish and shellfish consumption, along with adoption of some of the innovations described here, can contribute to sustainable production and consumption (Goal 12), including sufficient, healthy diets (Goals 2 and 3), economic growth and productive employment (Goal 8), fostering innovation (Goal 9), and combatting climate change (Goal 13). In the context of biodiversity, they contribute to sustainable use of marine and terrestrial ecosystems (Goals 14 and 15).

Conclusions

Potentially the greatest contribution to Net Zero and other policy targets will come from shifting a proportion of current diets from red meat, with its high contribution to GHG emissions, to finfish and shellfish consumption. Ensuring that growth in the seafood sector focuses on fish farming rather than wild fish capture, will have little impact on global warming potential but, if managed sustainably, it has the potential to be more beneficial to marine ecosystems and biodiversity. This report has explored how innovation in aquaculture sectors can contribute to meeting multiple government policies and objectives, including Net Zero, a circular economy, zero waste, marine and land biodiversity targets and UN Sustainable Development Goals.

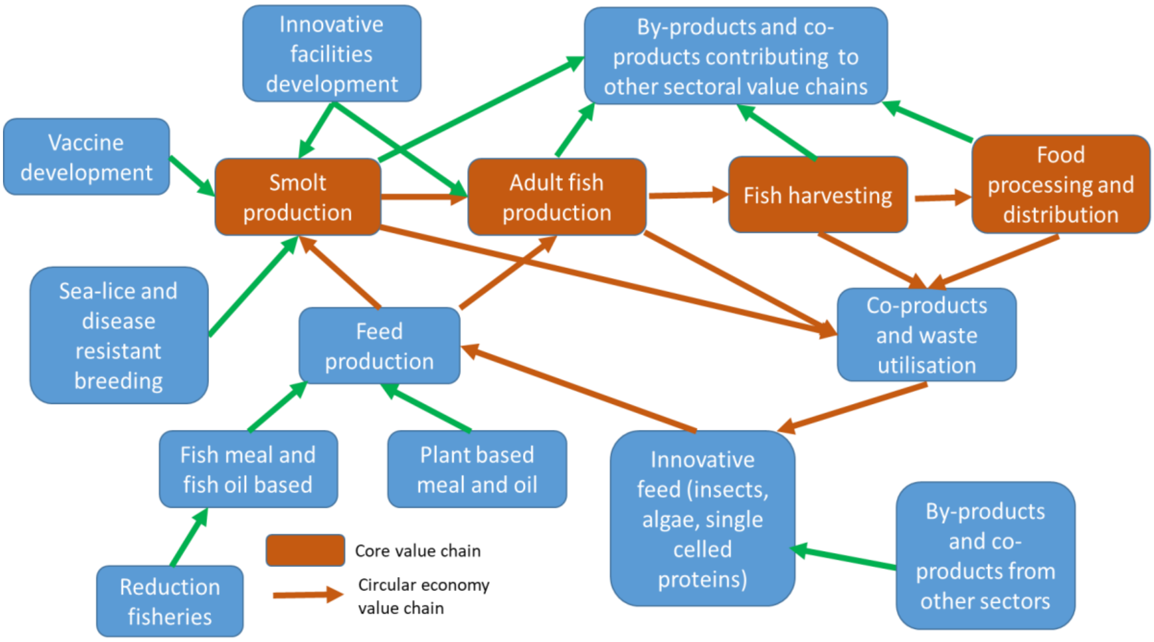
Aquaculture does present recognised environmental challenges involving GHG emissions and biodiversity impacts and continuing to address these issues, and ensuring that the most sustainable, effective and efficient adaptations are promoted, will be an important factor in gaining public acceptance and approval for the sector as a whole and for the roll-out of government policies. The innovative technologies discussed in this report could make significant contributions to these agendas, although there are trade-offs to be considered, for example, where an innovation may improve GHG emissions but have a negative impact on biodiversity or vice versa.

The innovations considered in this report all have a potential to contribute to the relevant policy goals, with varying degrees of impact.

- **Aqua-feed innovations** will have the biggest positive impact on both GHG emissions (Net Zero policies) and aquatic and land biodiversity (SDGs). They will also contribute to several circular economy value chains and zero waste agendas.
- **Innovative production systems** so far seem likely to have greater energy demands, and therefore GHG emissions, than those currently in use, although this could become less relevant as energy systems become less reliant on fossil fuel inputs. They will also contribute to reductions in the impact of pollutants and improvements in fish health, and will be necessary for the expected expansion of the aquaculture sector in Scotland.
- **Fish processing** is a key component of the aquaculture value chain and innovative developments are already contributing to a reduction in GHG emissions. This component of the value chain will also be an important contributor to the circular economy.
- **Waste and by-product management** will also make more modest contributions to reductions in GHG emissions and will be important contributors to several circular economy value chains.

Clearly, some innovations, considered in isolation, will have a greater contribution than others to climate change and biodiversity impacts, but this should not lead to a simplistic approach to prioritising policy initiatives and investment. A systemic approach, taking account of the entire value chain (see figure below) and the interactions among businesses and policies, will be needed to deliver the outcomes that are nationally optimal for Scotland and internationally competitive.

The circular economy value network and the role of innovative technologies for Scottish salmon farming



Recommendations

The policy role is not to pick winners, but to create a supportive innovation ecosystem so that potential winners are not unnecessarily killed off in the early stages of development.

This report helps to identify what needs to be done to fill the research, development and policy gaps that exist in the aquaculture sector and to put Scottish aquaculture on an optimal footing, balancing the sometimes-competing demands of different environmental goals and different sectoral interests. We recommend the following short-list of actions to deliver these outcomes.

1. More investment in the development of life cycle analysis tools for the aquaculture sector is needed, to judge the contributions of innovative technologies to different value chains and to support company investment decision making, and government policy development and implementation. This should cover both the development of effective methodologies and standards for their application to ensure comparability across different analyses.

2. At the national level, a systemic approach is needed, modelling the roles and contributions of the innovations discussed here, of the others that we were not able to include, and of new technologies as they emerge. Also, given the distributed nature of the industry, there are opportunities to build networks of smaller scale local recycling initiatives as contributions to the overall circular economy that is Scotland's ambition.

3. A systemic approach is also needed to understand the interactions between companies, innovators, investors, policy makers and regulators, stakeholders and consumers, that will underlie success or failure of innovations at all levels. The approach should focus on the options with the biggest potential gains and those where synergistic interactions between different innovation initiatives could facilitate development and multiply positive outcomes or minimise negative outcomes.

4. An essential part of this systemic approach will be better communication about innovative technologies and their potential contributions to national environmental, health and economic objectives, particularly in the context of the UN COP 26 meeting in November 2021. There is an important current story to be told about the improvements in sustainability profile that have already been made by Scottish aquaculture and it will be helpful in enabling future innovative developments for the sector if citizens and interested stakeholder groups are more aware of these achievements and of the coming opportunities presented by innovative technologies.