

An aerial photograph of a salmon farming operation in the ocean. Several large, circular pens are visible, each divided into sections by a network of lines. A small boat is moving across the water in the upper left, leaving a white wake. The water is a deep, dark blue.

OFF THE MENU

The Scottish salmon industry's failure to deliver sustainable nutrition

**FEED
BACK**

CONTENTS

1	INTRODUCTION	4
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2	THE ROLE OF FISH IN MEETING GLOBAL NUTRITIONAL NEEDS	6
----------	---	----------

3	CAN SALMON FARMING IN SCOTLAND CONTRIBUTE TO MEETING NUTRITIONAL NEEDS IN A WAY THAT IS ECOLOGICALLY SUSTAINABLE?	11
----------	--	-----------

4	ARE THERE MORE ECOLOGICALLY SOUND WAYS TO MEET NUTRITIONAL NEEDS FROM SEAFOOD?	23
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5	CONCLUSION AND RECOMMENDATIONS	31
----------	---------------------------------------	-----------

	REFERENCES	34
--	-------------------	-----------

	ANNEX I	38
--	----------------	-----------

	ANNEX II	39
--	-----------------	-----------

EXECUTIVE SUMMARY

Eating fish could be framed as a wicked problem – one where multiple interdependencies mean that an attempt to solve one aspect of the problem may exacerbate others. Eating seafood is important for good health – seafood contains nutrients such as omega 3 which can prove difficult to obtain elsewhere in our diets – but at the same time, wild fish populations are under severe stress, and the complexity of fisheries policy and the rapidly shifting status of different fish stocks means assessing sustainability is a challenge for the average shopper looking for their fish dinner.

Aquaculture (farming seafood) is promoted as a sustainable solution to our ever-increasing demand for the natural availability of wild seafood, as a means of alleviating pressure on overfished species while providing the public with a healthy source of protein and important micronutrients, such as omega 3. More than half of the seafood we eat globally is farmed. As the world's fastest-growing food-production sector, farmed seafood will account for 60% of global fish consumption within the next 10 years. Farmed Atlantic salmon has become a major sector within the aquaculture industry, with farmed salmon consumption popular in markets including the EU, Japan and the US. In the UK, farmed salmon has risen to be the single most frequently purchased seafood in supermarkets. But does aquaculture provide the nutritional and environmental solution we need?

A core problem besets aquaculture production. 'Fed' aquaculture is reliant on wild-caught fish as a key feed ingredient, usually small 'forage fish', which are processed into two ingredients, fishmeal and fish oil: every year, around 15 million tonnes of wild fish from across the globe are used for this purpose. The omega 3 content in farmed salmon is obtained through feeding salmon with these ingredients, in particular fish oil. Many of the species used to make fishmeal and fish oil, such as herring, sprat and capelin, could be eaten directly by people, although they are not widely consumed currently. Fishing for these wild fish may have a negative effect on ocean ecosystems, but more than this, it is highly inefficient to feed wild fish to farmed salmon, to deliver nutrients to human diets which could be obtained by eating the wild fish directly. Alongside wild fish caught for this purpose, by-products and trimmings from fish caught for human consumption are used in salmon feed production.

This report, taking the Scottish farmed salmon industry as an example, shows how farmed salmon fed on wild fish is an inefficient and environmentally poor way to produce micronutrients for human diets. The report explores how we could meet our micronutrient needs without depleting ocean resources. This report uses data from the Scottish salmon industry, which produces approximately 166,000 tonnes of farmed salmon a year¹, to model different scenarios for obtaining micronutrients from seafood. Our findings show that by directly consuming a wide variety of small, oily, wild-caught fish, alongside increasing our consumption

¹ Average production 2010–2018 (<https://www.gov.scot/publications/scottish-fish-farm-production-survey-2018/pages/5/>).



of farmed mussels (which do not require feed and provide high levels of some micronutrients) as well as consuming a smaller quantity of farmed salmon, we could access the same level of micronutrients **as through the current level of farmed salmon production, while avoiding the capture of 77% of wild-caught fish currently used in salmon feed.** Consuming a variety of seafood is in line with NHS guidance **'to ensure there are enough fish and shellfish to eat, choose from as wide a range of these foods as possible. If we eat only a few kinds of fish, then numbers of these fish can fall very low due to overfishing of these stocks'.**

Salmon farming can provide a mechanism to prevent micronutrients from leaving the food system, but only if it restricts itself to using truly unavoidable by-products from capture fisheries, rather than fish caught specifically for feed. Ensuring the integrity of by-products supply chains, and avoiding the demand for by-products driving increased catches, requires regulation and governance. To fulfil this scenario, based on current data, the farmed salmon industry in Scotland would need to reduce in size by two thirds. The need for a just reorganising of employment is also discussed.

In high-income countries, where nutrition needs are generally well met and overconsumption of animal protein is both a health and environmental challenge, aquaculture can only be considered a sustainable approach to meeting nutritional needs if it does not rely on wild resources which could be directly eaten by people. This report re-frames debates concerning whether or not to eat fish and shows there is enough fish in the sea if marine resources are sustainably managed. Going beyond the question 'should we eat farmed salmon?' we get a richer more diverse scenario which could deliver a varied diet for human nutrition, more fish in the sea and a healthy prognosis for our ocean.

INTRODUCTION



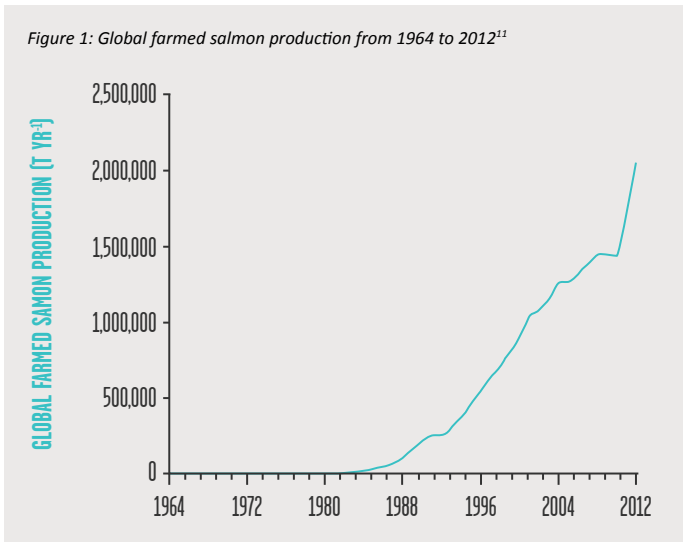
Humans need a balanced and varied range of nutrients and micronutrients in their diets to maintain optimal health. Fish has been a part of many communities' diets around the world for millennia: fish and crustaceans are the primary source of protein for roughly one third of the world's population, and modern nutritional science has recognised fish and other seafood as a healthier source of protein compared to most meats, and a good source of omega 3 fatty acids, vitamins and micronutrients^{1,2}. Eating seafood is correlated with a lower risk of coronary heart disease and stroke³⁻⁵.

However, in supporting human health by eating fish and seafood we face a dilemma. Globally, the health of our ocean and of its populations of marine life are being eroded by industrialised fishing, pollution and the impacts of global warming, to the extent that their ability to continue to support human diets into the future is coming into question. In 2019, the Intergovernmental Panel on Climate Change issued a stark warning: carbon emissions from human activities are causing ocean warming, acidification and oxygen loss, all with a deleterious effect on ocean life, including fish populations, with implications for food production and human communities. The impacts of warming on the distribution of fish populations poses challenges for the ways that the global community seeks to manage fisheries: regulation is less effective due to changes in where fish populations are found⁶. Against this backdrop, global fish populations are already under considerable strain from fishing. A third of fish stocks were being fished at unsustainable levels in 2015, and 60% were 'maximally sustainably fished'⁷. The world is on a dangerous course towards permanently damaging our ocean's ability to renew and to sustain both its ecology and human needs.

In the UK, and across much of the northern hemisphere, decisions about what fish to eat have shifted radically since the second world war. Whereas fish may have once been an occasional treat, and a wider variety of fish were consumed, nowadays it is common to eat a much smaller range of fish, largely sourced from industrialised fisheries and aquaculture. At the top of this limited list is a product which has only entered our diets in the past 40 years⁸: farmed salmon. Of the top 10 species consumed in the UK by value in 2019, salmon took one third of the market, worth £1,069 million⁹.

Farmed salmon is produced in sea-cages in waters around countries like Norway, Scotland, Canada and Chile. Farmed Atlantic salmon is the fastest-growing food-production system in the world¹⁰, and emerged as a major sector of the consumer seafood market in the 1980s and 1990s (Figure 1). Commercial farming of Atlantic salmon began in Scotland in 1969, and data collected by the Scottish government since 1979 demonstrate significant increases in average farm size and number of farms, and the consolidation of the industry to around six large companies, several owned by major multinational corporations¹¹. The farmed salmon industry, and the Scottish salmon industry in particular, has heavily relied on claims regarding both health and sustainability to market its products¹². This framing has been highly successful – between producers and retailers, farmed salmon is now the most frequently purchased seafood in UK supermarkets⁹. Consumption of wild pelagic fish, such as sardines, herring and anchovies, meanwhile, has fallen. Other farmed species, such as mussels, are available but make up a far smaller proportion of chilled seafood sales, only 0.6% by value in 2019⁹.

Figure 1: Global farmed salmon production from 1964 to 2012²¹



To explore the sustainability claims of the salmon farming industry, we examined the major inputs required to produce salmon – the feed it eats. Farmed salmon is fed on a carefully calibrated diet, including plant-based ingredients such as soya, wheat and pea protein, and marine ingredients that mimic the carnivorous diets of wild salmon: fishmeal and fish oil produced from wild-caught fish. Without the inclusion of fish oil in particular, it is very difficult to produce farmed salmon that contains a high enough level of key micronutrients, such as omega 3, which are key elements in the marketing and branding of farmed salmon as a healthy product to UK consumers. In this way, the salmon farming industry is reliant on wild-catch fisheries, particularly those focused on pelagic fish – small oily fish which form a cornerstone of the ocean food web¹³.

This report questions the status quo when it comes to how we access important nutrients from seafood, and how we achieve healthy diets within environmental limits. By using modelling based on the availability of key micronutrients in farmed Scottish salmon, wild pelagic fish from fish populations located in northern European seas, farmed mussels and seaweed, we assess whether farmed salmon is a truly sustainable way to deliver healthy diets. Using this modelling we demonstrate how UK diets could change to incorporate micronutrients from a wider variety of seafood products, including sustainably caught wild fish, as well as more diverse types of farmed seafood.

This report also explores the role of the farmed salmon industry in Scotland, the third largest producer of salmon worldwide, and the custodian of the UK's largest food export by value¹⁴. We question the claims made by the Scottish salmon industry regarding both the environmental status of the product they supply, and the justifications they offer for the ongoing use of wild fish specifically caught to produce ingredients for farmed salmon feed. We explore how the Scottish salmon industry could improve its sustainability credentials, including considering the role mortalities on salmon farms plays in undermining efficient feed use. We also examine the role of by-products in producing feed for farmed salmon, and important policy considerations to take into account when regulating the use of by-products. Finally, we evaluate the potential of other, less resource-intensive, forms of aquaculture, such as unfed aquaculture of molluscs, including mussels, and plant-based sources of nutrients such as seaweed. We propose a model for the Scottish seafood industry based on the optimal production of nutrients with the minimal damage to vital and hard-pressed ocean ecosystems.

THE ROLE OF FISH IN MEETING GLOBAL NUTRITIONAL NEEDS

The UK's National Health Service (NHS) guidelines recommend two portions of fish every week, one of which should be an oily fish¹⁵. Seafood is particularly important as a source of protein, several micronutrients that which are difficult to obtain from other sources, including omega 3, and other nutrients such as vitamin D and selenium. For some communities in the Global South, fish may represent one of the few available sources of high quality protein, and of essential nutrients to prevent malnutrition¹⁶.

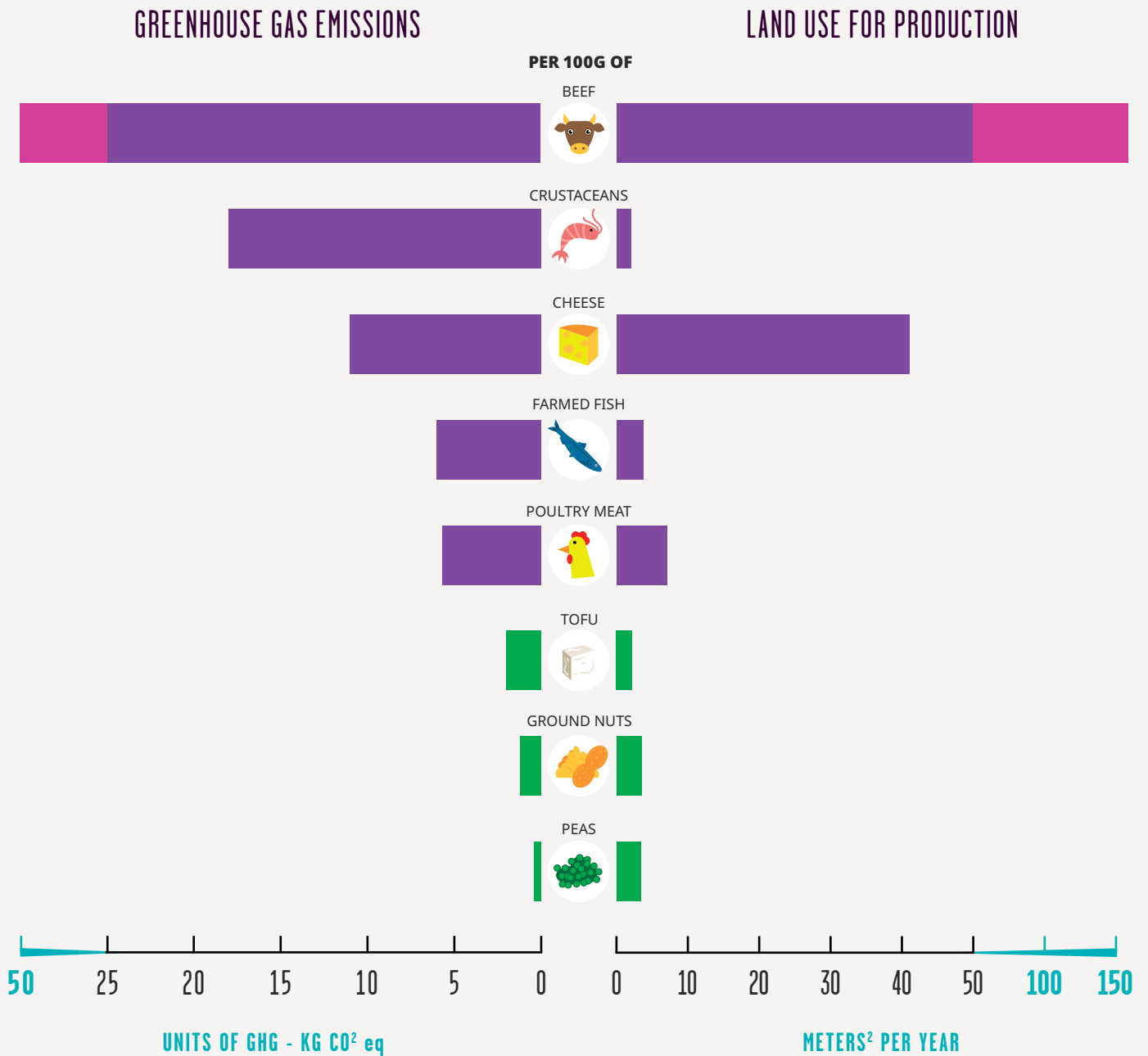
PROTEIN

Protein is an essential nutrient for the body's growth and repair. While protein has received much attention in popular and sports dietary advice, in general people in the UK and other Global North countries eat more protein than recommended guidelines, especially from animal sources¹⁷. Fish is highlighted as a protective factor against heart disease, with the WHO recommending individuals eat 1–2 portions a week¹⁸. However, there is scientific consensus that for environmental and health reasons we should fulfil the bulk of our protein requirements from plant-based sources^{19–23}. It is far more efficient to eat plant-based proteins directly, than to feed plants to animals in order to produce protein for human consumption. (This competition between plant protein for animals and plant protein for people is known as the 'food–feed competition'²⁴. Even farmed salmon – one of the most efficient farmed animal-feed converters – does not stack up against direct human consumption of available protein used in feed, either plant-based or marine-based: **for every 100g of protein in salmon feed, only 28g are made available in the human food supply**²⁵. While farming fish shows potential to produce protein with very low land requirements (with some land used in the production of feed ingredients such as soya), even the lowest impact fed-aquaculture systems still exceed greenhouse gas emissions of vegetable proteins²⁶ (Figure 2).

OMEGA 3

Omega 3 long-chain fatty acids – notably eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) – occur in the ocean food chain after they are synthesised by microalgae and cyanobacteria, then bioaccumulated through the trophic chain from smaller aquatic organisms to larger fish²⁷. Numerous British and EU expert panels recommend that the general adult population should consume approximately 250mg of the two main forms of omega 3 fatty acids which are beneficial to human health – EPA and DHA – per day²⁸, through the consumption of one portion of about 140g of oily fish per week²⁹. Eating oily fish and seafood is correlated with lower levels of heart disease and stroke^{3–5}, and several studies have shown that people from the Mediterranean, Japan and Greenland with a diet rich in omega 3 have been shown to have a lower risk of heart disease than people in countries like the UK³⁰. On average, people in the UK consume much less fish and seafood, with only 33% eating fish twice a week³¹.

Figure 2: Greenhouse gas emissions and land use per 100g of protein of different animal and plant sources



Citation: ²⁶ Poore, J. & Nemecek, T. Reducing food's environmental impacts through producers and consumers. Science 360, 987-992 (2018).



OTHER MICRONUTRIENTS

Other micronutrients available in oily fish include selenium, vitamin D and iodine. Vitamin D helps the body to regulate the amount of calcium and phosphate it absorbs: these nutrients are needed to keep bones, teeth and muscles healthy. Without a good source of vitamin D, the body may have difficulty making use of other micronutrients, and a lack of vitamin D is linked to rickets in children and a bone condition called osteomalacia in adults³². Vitamin D is found in oily fish, red meat, egg yolk and fortified foods, but it can also be obtained from direct sunlight on the skin when outdoors³³. With the support of Professor Helen McDonald of the University of Aberdeen, the BBC conducted an experiment to compare sunshine, vitamin D supplements and oily fish as sources of vitamin D and found that vitamin D levels increased in all three groups by roughly the same amounts³⁴. It is important to include the right amount of iodine in our diets to ensure good thyroid function, which maintains healthy cells and metabolic rate³³. Iodine is available in fish and shellfish, as well as in plant foods (although the level may vary depending on the availability of iodine in the soil)³⁵. Seaweed is also an alternative source. Selenium supports immune and reproductive function. It can be consumed by eating brazil nuts, fish, meat and eggs³³.

NO MORE FISH IN THE SEA?

Aquaculture is frequently framed as a solution to address the basic discrepancy between the value of fish in human diets, and the alarming rate of decline of global fish populations: instead of eating wild fish, stocks of which are dwindling, humans can eat farmed fish, thus gaining access to key nutrients without further degrading wild ecosystems. Unfortunately, the story is not so straightforward. Farming of 'fed' aquaculture species has far outstripped the production of 'unfed' species¹¹ – such as mussels or oysters (see chapter 4) – with the result that demand for aquaculture feed ('aquafeed') has also risen. While efficiencies have been made, particularly in terms of the proportion of feed that comes from wild marine sources, wild fish remains an essential ingredient in farmed carnivorous fish production. It is the fish oil content of farmed salmon feed which delivers a large part of the micronutrient content of the salmon product. At least for the moment, no commercially scalable alternatives exist to replace this wild marine content (see chapter 4). It is therefore important to establish whether the evidence supports producing and consuming farmed salmon as the best use of the essential micronutrients within a sustainable food system. This question is particularly pertinent when reviewing the micronutrient inequalities playing out around the globe, and the commercial incentives associated with one form of production or another. Farming has changed salmon from a luxury product to a global commodity that is an affordable staple seafood product for consumers in the industrialised world¹¹.

GLOBAL MICRONUTRIENT AND FOOD SECURITY

Outside of affluent countries like the UK, where in general a wide range of micronutrients is available through our diets, low-income communities around the world commonly struggle to access balanced diets and can face malnutrition. Consuming more seafood in some countries could play an important role in easing these inequalities and decreasing the poor health and longevity outcomes associated with micronutrient deficiencies.

A startling paper on fisheries from a global food security and equity perspective, recently published in the journal *Nature*¹⁶, discussed the role global fisheries could play in tackling micronutrient deficiencies. The authors argued that in several countries in which nutrient intakes are inadequate, a fraction of local and regional fisheries catches could meet or exceed the dietary requirements of populations living within 100km of the coast. In these countries, a small fraction of the available production from fisheries has the potential to close nutrient gaps. For example, the dietary risk of iron deficiency in Namibia is severe (47%); however, only 9% of the fish caught in the exclusive economic zone of Namibia is equivalent to the dietary iron requirements for the entire coastal population¹⁶.

In other words, **making equitable use of the nutrients available from marine sources is vital to meeting the world population's nutritional needs**. Without access to nutrients from wild seafood, many populations are deprived of a source of nutrients, which could make a considerable impact on their health, wellbeing and life expectancy. Indeed, the study found that in 22 countries in Africa and Asia, meeting the dietary requirements for all children under 5 would require 20% or less of current fisheries catches¹⁶. Yet in many of these countries, a very large proportion of fisheries catch is destined not for local, or even global, human consumption, but to make fishmeal or fish oil³⁶, commodities vital to the growth of the aquaculture industry, including farmed salmon. In comparison to the difference local consumption of locally caught seafood could make to some communities' nutritional status, production of farmed fish for markets in rich countries is a far poorer use of available micronutrients.

In fact, globally, 90% of fish used in fishmeal and fish oil production comes from food-grade or prime food-grade fish³⁶ (prime food-grade fish are almost never forage fish). And yet current evidence suggests that the omega 3 fatty acids in the world's remaining fish stocks are insufficient to meet the global population's daily requirement for omega 3 fatty acids²⁸: From a global food security perspective, we absolutely cannot afford to waste any omega 3 available from the seas. This report explores whether salmon farming is an effective and equitable way to deliver these micronutrients to human diets.

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*Overconsumption of protein is in itself a form of food waste, as excess consumption is functionally excreted as opposed to being stored. Over-consumptive waste at the consumer level has the potential to cancel any sustainability gains made at the producer level. This ultimately calls into question the equity of food distribution. Given the rich micronutrient profile of most seafood, efforts should be invested to improve access to seafood across socio-economic communities and encourage groups that commonly suffer from nutrient deficiency to adopt more seafood in their diets.*³⁷

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Tlusty, et al. 2019



BOX 1: NUTRIENTS FOR WHOM?

*The question of who eats what is one that goes far beyond individual food preferences and deep into the power dynamics of the global food system. This is played out in innumerable ways, from the commodification of land previously occupied by indigenous communities to grow commodities such as soya³⁸, to the high levels of waste tolerated in supply chains controlled by major food retail corporations³⁹. In the arena of seafood, fisheries that extract wild fish to produce fishmeal and fish oil (FMFO) for animal feed, aquaculture and other non-food uses pose similar questions. Some fisheries targeted to produce FMFO rely on fish species which are not currently widely consumed directly by local people: in Peru, where anchoveta fish support the world's largest reduction fishery, there has been an increase in the direct human consumption of anchoveta from 5,000 to 160,000 tonnes over a few years⁴⁰. One of the barriers to increased local anchoveta consumption in Peru is the fact that 'the increased global demand for FMFO has created a perverse incentive in that fishing boats currently are paid more for landing anchoveta for reduction than they are for landing a fresh product for direct human consumption⁴⁰. The round sardinella fishery in North Africa is a good example: sardinella is a staple dish in Senegal and the Gambia. More recently, fisheries targeting international FMFO markets have claimed a high proportion of the sardinella catch from Morocco to Guinea. The commodification of fish that are directly eaten by people may have several impacts: as a commodity on the global feed market, communities may find that they are no longer able to access previously plentiful and affordable foods. Livelihoods may shift, perhaps resulting in some new employment, for example in the factories producing FMFO. However, there is no guarantee that fish which previously played an important role in maintaining food security and fulfilling nutritional needs will be replaced by an equally nutritious alternative. Meanwhile, **fish which previously fed people is used to feed farmed fish ultimately intended for an entirely different geographical and social market: a deeply inequitable exchange.** The question of whether regulation or certification are adequate tools to enable the just and sustainable use of wild fish in farmed fish feed is further explored in Feedback's report **On the hook: Certification's failure to protect wild fish from the Scottish salmon industry.***

CAN SALMON FARMING IN SCOTLAND CONTRIBUTE TO MEETING NUTRITIONAL NEEDS IN A WAY THAT IS ECOLOGICALLY SUSTAINABLE?

One way of producing a food product which contains protein and key micronutrients is aquaculture, or fish farming. However, when the process of production relies on finite natural resources such as wild fish, it is important to ask whether this approach to meeting the population's nutritional needs within environmental boundaries is the right one. Certainly, proponents of aquaculture, and of salmon aquaculture – a booming piece of the larger industry – see it in this light. Scotland's salmon farming industry presents itself as a sustainable solution to the question of how we access sufficient micronutrients through our diets, while relieving the burden on ocean life. Commercially, Scottish farmed salmon is an enormous success story: Scotland is the third largest salmon producer globally⁴³, and it is the UK's largest food export by value, with over half of Scottish production going to export¹⁴. The main markets for farmed Scottish salmon are the UK, the EU (predominantly France, Ireland and Germany), China and the US¹⁴.

Creating a sustainable food system, which nourishes people fairly while preventing further environmental degradation, requires complex trade-offs. To help understand whether Scottish salmon farming in its current form makes a constructive contribution to this goal, Feedback did a set of calculations using data on salmon feed ingredients and nutrition from the best publicly available sources we were able to find². In Feedback's report 'On the hook: Certification's failure to protect wild fish from the Scottish salmon industry', we explore the sources of wild fish used in Scottish salmon feed, based on industry data, which vary from the Peruvian anchoveta fishery, to menhaden from the United States, and large volumes of fish from European waters, such as capelin, herring, sprat and blue whiting³. Most of these species are suitable for human consumption, if not widely consumed currently in Global North markets. The industry has also greatly increased the volume of marine ingredients it uses made from by-products (usually trimmings such as heads and bones) of fish caught for human consumption (see chapter 4 for a deeper discussion of the role and risks of by-product use). In Scotland, roughly two thirds of fish oil is made from wild-caught forage fish and one third is made from trimmings and by-products of the fishery industry⁴. In 'On the hook: Certification's failure to protect wild fish from the Scottish salmon industry' we explore the sources of wild fish used by the Scottish salmon industry, and conclude that the means the industry currently uses to try to ensure the sustainability of these sources – primarily via certification – are inadequate.

² Please see Annex 1 for a full breakdown of the calculations, data sources and explanatory notes.

³ See Feedback fisheries report: 'On the hook: Certification's failure to protect wild fish from the Scottish salmon industry'.

⁴ Please see Tab 5 'By-products' in the spreadsheet supplementary materials for assumptions and sources on proportion of by-products used (www.feedbackglobal.org/salmonfeeddata).

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Fish are very good for you and our salmon is particularly high in Omega 3 – something that is true in general in Scotland – but we feed ours with a high marine diet which is very good for the fish and means they have high levels of Omega 3. So the good news is that salmon is a healthy product and is in steady supply and people will get a lot of benefit from eating fresh salmon.

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The Scottish Salmon Company⁴¹

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To date, only marine ingredients provide commercial-scale volumes of the long-chain Omega-3 oils in farmed fish that are important for good human nutrition. The amazing multiplier power effect of aquaculture, based on a diet rich in protein, enables the salmon farming sector to grow on average 4.5kg of fish using 1kg of wild fish where the wild fish superior nutritional benefits are used in conjunction with other protein sources to meet the needs of the farmed salmon in a single package.

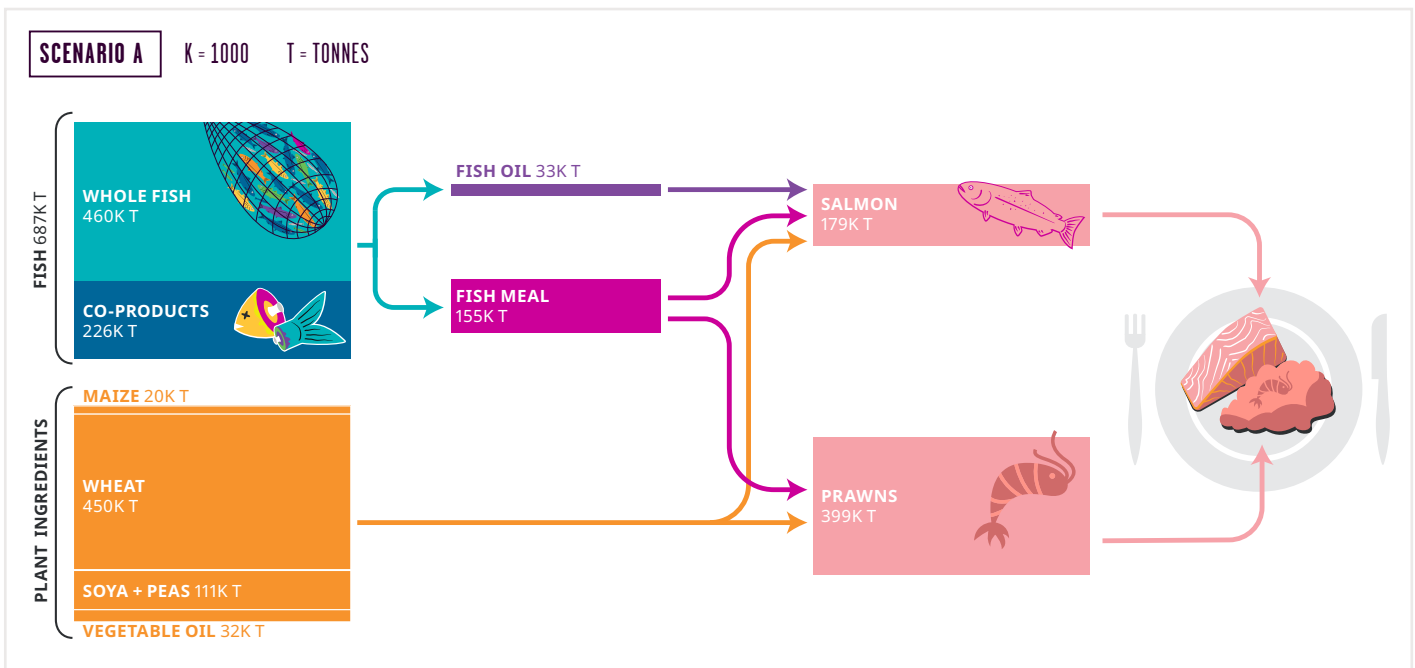
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IFFO blog following their management team's trip to Scottish Sea Farms⁴²

Processing wild fish, either whole or trimmings, produces two feed ingredients: fishmeal and a smaller quantity of fish oil. Fish oil contains more concentrated nutrients and is therefore the limiting ingredient in salmon farming: the amount of fish oil in feed represents the level of wild marine ingredients below which it is difficult for companies to go without compromising quality, principally the level of micronutrients in the final salmon product. When making fish oil for salmon feed from a given amount of wet fish, the fishmeal that is automatically produced alongside will be more than is needed for the salmon farming. This means that demand for fish oil from the salmon industry inevitably results in a certain amount of *leftover* fishmeal which can be used for other purposes⁵.

Research has already shown that farmed salmon is not a net producer of protein – in other words, looking across all ingredients included in farmed salmon feed, less protein comes out in the form of edible salmon than goes in, in the form of ingredients made from plants and wild fish²⁵. Therefore, to answer the question of whether farming salmon is a good way of putting healthy food on our tables, we need to turn our attention to the micronutrients available in farmed salmon.

SCENARIO A: BUSINESS AS USUAL INFOGRAPHIC



In 2014 the Scottish industry produced 179,000 tonnes of salmon for human consumption⁴⁴. The industry required 33,000 tonnes of fish oil to grow this salmon⁴⁵, which we estimate to be equivalent to around 461,000 tonnes of wild-caught fish¹². Once processed, this wild fish would have also yielded around 155,000 tonnes of fishmeal. As the Scottish industry only required around 55,000 tonnes of fishmeal, the remainder could theoretically have been used to produce 400,000 tonnes of prawns (see Box 2 and www.feedbackglobal.org/salmonfeeddata for full calculations).

⁵ See Box 2 for an explanation on how we have followed the method of the Marine Ingredients Organisation IFFO to ensure such spare fishmeal is not wasted in our calculations.

Under this 'business as usual' scenario, we assume that a person eats one weekly portion of farmed Scottish salmon (140g), plus 312g of prawns farmed using the remaining fishmeal that is automatically produced alongside the fish oil needed in the salmon feed (Box 2). Looking at UK government nutritional data for salmon and prawns⁴⁶ this means that this person would access 1.3g of EPA and 1.2g of DHA from these portions per week. Experts and governments generally recommend around 250mg of EPA and DHA per day²⁸, so the total of 2.5g of weekly intake in this scenario is more than sufficient. As we started assessing the amount of EPA, DHA and other micronutrients available in the wild-caught fish that was fed to the salmon and shrimp in the form of fish oil and fishmeal, we noticed that the sum of micronutrients from fish such as herring, anchovy, sprat and sardines currently fed to salmon is much larger than the micronutrients that end up on our plates in the form of farmed salmon⁶. We therefore decided to develop two additional scenarios (B and C – described in subsequent sections) to see how wild fish resources could be used more efficiently to bring nutrients to our diets, compared to consuming only salmon and prawns.

BOX 2: MAKING SURE FISHMEAL IS NOT WASTED

To create our model, we followed the recommendations of the international marine ingredient's organisation, IFFO. IFFO argues that although farming salmon requires relatively high levels of fish oil, the leftover fishmeal that is a by-product of fish oil production can be used in other industries, such as prawn farming, which improves the efficiency of the use of wild fish. Given that salmon requires much more fish oil than fishmeal, we have followed IFFO's method in our model by including farmed crustaceans in our calculations so that all of the fish oil and fishmeal of wild-caught fish is used and nothing goes to waste⁴⁷.

Farmed prawn is an important global aquaculture sector consuming significant volumes of fishmeal⁴⁸. To fully use all fishmeal leftovers after we have produced the necessary fish oil for salmon, we calculated that for every kilo of salmon produced, an additional 2.23kg of prawns could be produced. This does not mean that we believe prawn and shrimp farming is the best use of such spare fishmeal. Some information on the environmental concerns surrounding prawn farming can be found in Feedback's report 'Fishy Business: the Scottish salmon industry's appetite for wild fish and land'¹². It is possible that from an environmental perspective it may be preferable to use this fishmeal for carp, chicken or pig farming (more information in the section on by-products) but we have used the prawn example because we found good data on farmed prawn diet formulation, and it is the second most consumed farmed seafood in the UK.

⁶ The exception is vitamin D, and this is further discussed in Scenarios B and C below (chapter 4).

There are a number of steps that could be taken by the Scottish salmon and seafood industry to improve the environmental impact of its 'business as usual' scenario, from a feed perspective, and thereby achieve best nutritional value for least environmental impact.

It is important to note that aquaculture poses environmental challenges in several areas other than feed, most notably in terms of the risk of pollution of the natural environment surrounding fish farms, both from waste feed and excretion from the farmed fish being released into surrounding waters, and from chemicals used to treat farmed fish also affecting surrounding organisms. More information can be found in the 'Review of the Environmental Impacts of Salmon Farming in Scotland' prepared by the Scottish Parliament⁴⁹.

1. REDUCE FARMED SALMON MORTALITIES



Scotland's farm-raised salmon have a good environmental story to tell. It is a story of top-quality feed, sourced from sustainable sources, of the lowest lice levels for six years, controlled largely by natural methods which have helped reduce medicine use to extraordinarily low levels.



Scottish Salmon Producers Organisation⁵⁰

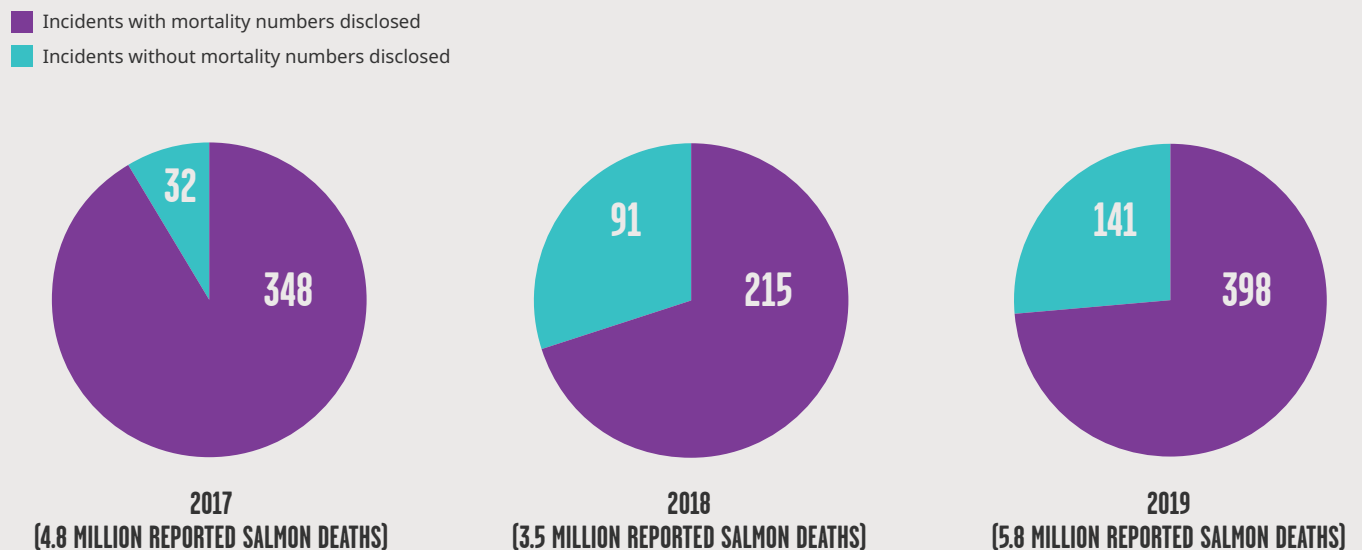
Mortalities of farmed salmon on Scottish farms continues to be a controversial issue, with media coverage of incidents suggesting high mortality rates, and much debate between campaigners and industry over what level of mortalities would be acceptable. The Scottish Government collects data on farmed salmon mortalities⁵¹, which provides a fairly comprehensive outlook on variation between farms and over time. An analysis of the data from 2016 to 2019 (the latest years with full data available) showed a significant increase in mortalities in these years, rising from just under one million in 2016, to 5.8 million in 2019. Part of this increase is likely to reflect improvements in reporting over this period, but it is still a startling high percentage. It is difficult to establish what these figures represent as a percentage of total production in Scotland in these years, because accompanying data on production volumes is given in tonnes, rather than as number of individual fish reared. However, using some basic assumption about tonnage to number of fish, these figures represent a rise from 3% to 6%.⁷

Another estimate put finfish (covering trout as well as salmon) mortalities in 2015 at 6.7%, although the variation between geographical sites is very high⁵². For example, Grieg Seafood's 2019 annual report reported survival rates of less

 ⁷ Full calculations shown in Annex 2.

than 90% in 2019, and as low as 83% in 2018⁵³. Salmon farming can result in catastrophic individual ‘mortality events’: in 2018/19 there were 42 such events where over 10% of the fish in a specific farm died. In one event in 2018/19, 50% of a farm’s salmon died, more than 1.5 million fish. The number of incidents reported between 2016 and 2019 rose by a startling 650%, but there was also a significant rise in the number of mortality incidents where companies did not disclose the number of fish deaths, from 32 undisclosed incidents in 2017 (10% of total reported incidents) to 141 (26% of the total) in 2019. Full industry transparency is required to give policymakers and civil society an accurate view of the effectiveness of the Scottish salmon industry in fulfilling their aims as producers of sustainable protein.

Figure 3: Salmon mortality incidents in 2017, 2018 and 2019



These figures are very concerning. High mortalities, beyond the worrying implications for animal welfare, pose serious questions for the good use of wild marine ingredients in farmed salmon feed. Put simply, the wild fish and other ingredients in feed are going to waste when salmon die before they are harvested for human consumption. Disposal of the dead salmon is also costly and environmental impactful.

2. EXPLORE NOVEL FEED INGREDIENTS

‘Novel feed ingredients’ in the context of salmon farming largely refers to the development of products which do not rely on wild fish to deliver vital micronutrients in salmon feed. There is a broad consensus that the development of novel ingredients is vital to support the growth of the fed aquaculture sector^{48,54}, and that the industry supports this goal. While cost has been a barrier to the widespread production and use of many feed alternatives,

there has been progress: algal oil and insect meal are two novel ingredients currently on the market. They are more expensive than wild fish, but can be produced at a high enough scale for use in salmon feed⁵⁴. Processed poultry proteins are already used in salmon farming elsewhere though not in Scotland⁵⁵.

ALGAL OIL

Algal oil is derived from marine algae. A life-cycle assessment looking at the use of algal oil to replace fish oil in salmon diets found that a zero fishmeal and fish oil diet increases the global warming potential of salmon by 38%⁵⁶. Feedback understands that this is in part related to the energy-intensity of algal oil extraction, but also to a transition to the use of crops such as soya in an attempt to be free from wild fish sources. The conclusion of the study points to the trade-off between marine resources and land resources – both under grave environmental pressure.

Veramaris® Algal Oil in combination with vegetable crops enables growth of salmon aquaculture that is independent of limited fish stocks. Marine impacts through fishing are eliminated at the cost of agricultural impacts. Can we make a trade-off?⁵⁶ In other words, when we decouple salmon production from wild caught fish, it becomes plagued with the same sustainability issues that affect livestock dependent on feed crops that drive land use change, deforestation and food-feed competition⁵⁷⁻⁵⁹.

INSECTS

Insects such as black soldier fly larvae or termites can potentially offer rich protein content and favourable lipid profiles for aquaculture feeds, but there is a concern around the presence of indigestible components, the bioaccumulation of pesticides and the low amount of polyunsaturated fatty acids in terrestrial insects⁵⁴. In addition, from a sustainability perspective, for insects to become a viable ingredient in sustainable salmon feed, they should only be fed on by-products of the food industry that cannot be used directly in pig or chicken feed, such as household food waste or manure⁶⁰. The challenge is that currently European legislation does not permit the feeding of these waste streams to insects, meaning that insects eat feed crops and by-products that might be more efficiently fed directly to livestock in the first place. A key concern regarding insect meal for aquaculture is that it can replace fishmeal but not fish oil – for salmon farming, fish oil is what sets the amount of wild fish required and as a recent analysis highlights ‘reducing fish oil inclusion in feeds is far more efficient at reducing forage fish demand than lowering fishmeal inclusion’⁶¹. See Feedback’s first report on salmon for further information on the environmental trade-offs regarding the use of insect meal in salmon feed¹².

In essence, any shift towards alternative feed ingredients that reduce the need for wild fish must be very carefully examined to avoid replacing one sustainability problem with another. Currently, none of the Scottish salmon companies uses alternative feed ingredients at scale to replace wild marine ingredients.

PROCESSED ANIMAL PROTEINS

Rendering is the process that converts by-products from the meat and livestock industry into usable and safe materials, called 'processed animal proteins' or PAPs. In Europe, there are 18 million tonnes of animal material processed each year⁶². In 2013, the European Commission re-authorised PAPs derived from non-ruminant animals (such as pigs and poultry) for use in aquaculture feed.

Poultry meal is considered a nutritious ingredient for carnivorous fish such as salmon and is commonly used in salmon farming in Canada and elsewhere. However, the Scottish salmon industry has yet to include poultry meal in its feed formulations because of a perceived resistance from retailers and consumers. However, outside of Scottish production, we import and consume seafood that is fed on poultry proteins: for example, aquaculture products like warm-water prawns from countries such as Indonesia, Thailand, Vietnam, China and Bangladesh⁵⁵. If we want to achieve a truly circular food system, we will need to overcome legislative and market barriers to ensure the optimal use of high quality proteins currently leaving the food system.

3. MAKE BETTER USE OF NUTRIENTS AVAILABLE FROM FARMED SALMON

The farmed salmon that reaches our supermarket shelves – neatly-sized fillets – does not use the whole fish, and a significant proportion of the total nutrients available per fish are not made available for human consumption. In 2015, 46% of Scottish salmon by-products (i.e. parts of the fish not meeting the criteria for the primary market purpose) went to livestock feed, 22% to pet food, and 15% to human consumption⁵². Most salmon by-products used for human consumption were transported to other countries, where they were either used directly for food production (fish head soup, barbecued belly flaps) or further processed for the food service or retail industries (surimi, pâtés, mousses). Processors have reported that UK consumers, while generally amenable to regional food items made from livestock by-products, such as black pudding and haggis, have thus far been more conservative with fish by-products⁵². The primary exception is in the form of trimmings, which can be used to generate many different value-added and smoked products, but even here in 2015 only one tenth of trimmings went to domestic human consumption, despite this use offering the highest value of any by-product⁵². Further opportunities exist in the transformation of by-products into protein powders and hydrolysates, salmon oil supplements, and collagen supplements. If the industry were to maximise the processing of by-products for human consumption and select animal feeds, Scotland could increase food production from fish farming by over 60% and increase by-product revenue by 803%, without expanding industry production at all⁵².





4. TRANSITION TO USING BY-PRODUCTS AND TRIMMINGS ONLY TO PRODUCE SALMON FEED

A further feed option is to eliminate the use of marine ingredients made from wild fish caught solely for salmon feed altogether. Feedback modelled the nutritional output of the industry if Scottish salmon were only fed using fish oil made from trimmings or by-products⁸.

To find out how useful farmed salmon is for bringing nutrients like omega 3 oils, selenium and vitamin B12 to our diets, Feedback did a set of calculations using data on salmon feed ingredients and nutrition from the best publicly available sources we were able to find. For total volumes of marine ingredients in Scottish salmon feed, we found reliable data for 2014⁴⁵ which we considered sufficiently representative for our estimates, given that we expect forage fish dependency ratios (FFDR) in 2019 not to be significantly different due to high salmon mortalities. Feedback can recalculate these figures with more up-to-date volumes of fishmeal and fish oil when these are made available.

WE CREATED THREE SCENARIOS:

- » **Business as usual:** maintaining current levels of salmon production using both trimmings and wild-caught fish to produce fishmeal and fish oil for salmon feed
- » **Trimmings only salmon farming** producing about one third of current volumes of salmon given that one third of the fish oil used in European salmon feed comes from trimmings
- » **Trimmings only salmon farming, combined with mussel farming for human consumption**

Please see the Feedback salmon feed calculations spreadsheet, available for download alongside this report on www.feedbackglobal.org/salmonfeeddata.

We estimate that roughly one third of fish oil in feed used by the Scottish industry comes from trimmings⁹. In order to only use fish oil and fishmeal made from trimmings in the salmon's feed, we assumed that the industry would have to shrink to one third (33%) of current production volumes of Scottish salmon – also shrinking the amount of fishmeal available for farmed prawns (see Box 7 for a discussion of the need to address the impact this would have on livelihoods). This also results in a two thirds reduction of the volumes of plant-based ingredients used in salmon feed under the 'business as usual' scenario.

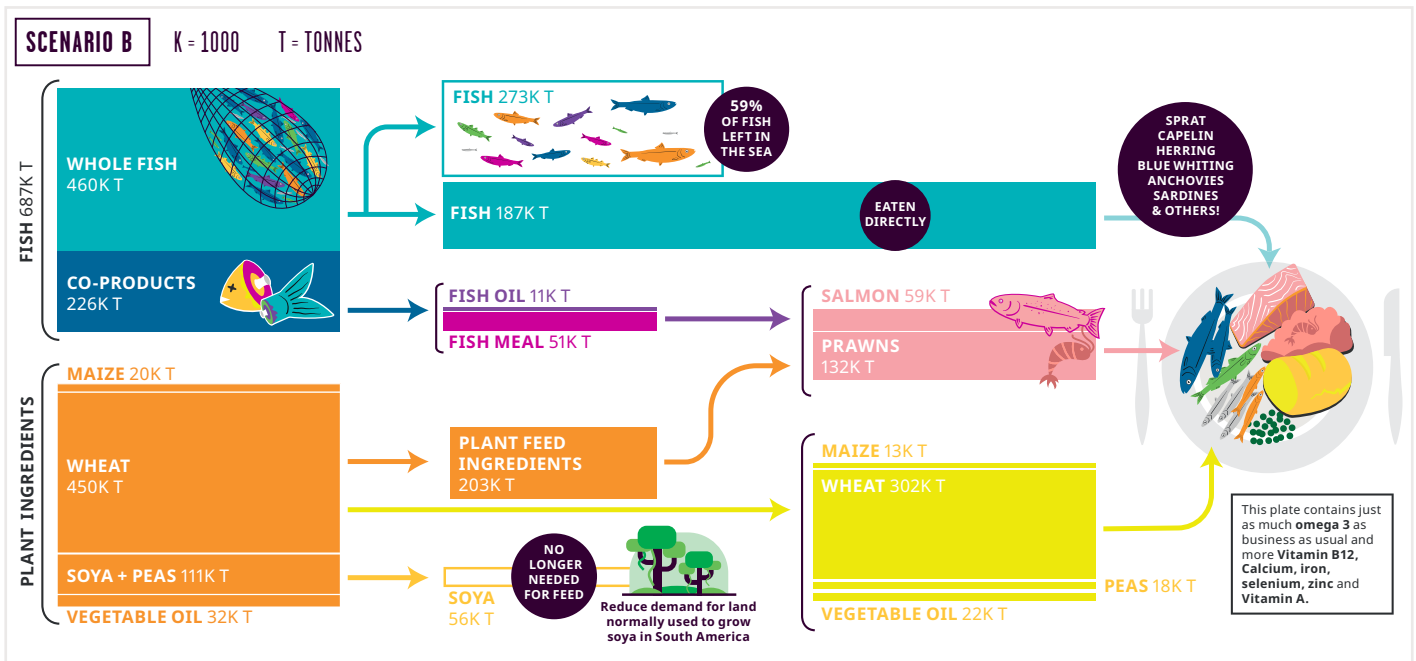
In order to make the same volumes of micronutrients available under this scenario as under 'business as usual', we estimated the quantity of wild fish that would need to be consumed to 'top up' the nutrients available from the reduced,

⁸ As trimmings of fish with high omega 3 content such as mackerel and herring are commonly used in the production of fish oil for Scottish salmon⁴³⁻⁴⁵ and the accompanying fishmeal, we assumed that the quality of fish oil produced in this way is similar to that of wild fish caught specifically as a feed ingredient.

⁹ See Tab 5 in the Feedback salmon feed calculations spreadsheet, available for download alongside this report on www.feedbackglobal.org/salmonfeeddata.

trimmings-only farmed salmon and prawn production. To calculate the total nutrient value of wild fish currently used to produce fish oil and fishmeal, we used average nutritional values for the species of wild fish most commonly caught for feed, according to industry data (Table 1).

SCENARIO B INFOGRAPHIC



Anchoveta and anchovy	14.6%
Sardine and sardinella	13.4%
Capelin	6.9%
Menhaden	10.5%
Lesser sand eel	7.9%
Blue whiting	27.6%
Sprat	6.5%
Herring	4.8%
Other	7.8%
TOTAL	100%

Table 1: Estimated proportions of species of wild-caught fish in the production of fishmeal and fish oil based on MOWI⁶³, Biomar⁶⁶ and EWOS Cargill⁶⁵

In this trimmings-only scenario, we found that if we secure similar levels of omega 3 and other key vitamins and minerals from wild fish, rather than from farmed salmon and prawns, we can leave 59% of the wild-caught fish currently being used for feed in the sea¹⁰.

¹⁰ Note that these calculations are on the basis of micronutrient availability, not volumes of fish. In these calculations we have not accounted for difference in edible portions of fish. For example, if we were to eat small wild-caught fish whole, which is quite common in many European countries for fish such as sardines or herring, then our estimates could potentially yield better results.

These findings point to the potential of a shift to consuming a greater variety of wild fish to meet micronutrient needs. However, to ensure sustainability, it is of crucial importance that we do not turn to consuming only one type of wild-caught fish instead of salmon. One example is wild-caught mackerel, which is one of the most widely consumed wild fish in the UK but has bounced in and out of sustainability certification schemes since the first certification in 2007. The solution lies in eating a variety of fish and not simply focusing on one species (see Box 3).

As with many aspects of eating sustainably, adaptability and flexibility is key. While supply chains are not currently set up to enable broad consumption of a wide variety of fish, it is possible to envisage a future scenario in which we eat small amounts of many different kinds of fish that can be caught in our regions, such as herring, mackerel, Biscay anchovy, capelin, sprat, blue whiting, sardines and many others. **Spreading consumption across many species and eating them directly, rather than using them to feed salmon, allows us to significantly reduce the amount of each species of fish caught, while fulfilling our nutritional needs.** In addition, we also free up plant-based crops currently used in salmon and prawn feed (Table 2), which offer excellent contributions to healthy diets if eaten directly. We could also choose to reduce the use of soya, which continues to be a major driver of deforestation⁶⁷.

Table 2: Estimated amounts of plant-based ingredients no longer needed in salmon and prawn feed if we limit salmon and prawn production to that which can be done using marine ingredients from by-products alone. See www.feedbackglobal.org/salmonfeeddata for calculations and data sources².



	TONNES
<i>Soybean meal</i>	57,000
<i>Other plant protein (faba beans, peas, etc)</i>	18,000
<i>Vegetable oil (mostly rapeseed)</i>	21,000
<i>Wheat</i>	302,000
<i>Corn</i>	14,000
Total crops no longer needed for aquaculture feed	412,000

BOX 3: WHAT FISH CAN I EAT?



To ensure there are enough fish and shellfish to eat, choose from as wide a range of these foods as possible. If we eat only a few kinds of fish, then numbers of these fish can fall very low due to overfishing of these stocks.



NHS Guidance⁶⁸

Making decisions about what fish to eat and what not to eat can be challenging. There is wide awareness that some fish is more sustainable than others, but even informed shoppers may struggle to keep up with the changing status of some fish populations and fishing methods. Certification is widely used as the best available 'proxy' for sustainability, but as we explore in 'On the hook: Certification's failure to protect wild fish from the Scottish salmon industry', certification may not provide the full story. Mackerel provides a good case study. In 2019, British mackerel was stripped of its Marine Stewardship Council (MSC) certification because stock in the northeast Atlantic dropped below a precautionary threshold, while catches remained far higher than advised by scientists. Mackerel has bounced in and out of the MSC certification scheme since the first certificate in 2007⁶⁹. Rising sea temperatures have caused mackerel to migrate north, leading Iceland and the Faroe Islands to unilaterally increase their quotas. This has led to the so-called 'Mackerel War' which has flared on various occasions since 2010 – Britain and Norway, backed by the EU, on the one hand, and Iceland and the Faroe Islands on the other, have not been able to agree a joint approach to catch sizes and quotas. As a result, total quotas between all mackerel fisheries were set far above scientific advice. It is difficult for retailers to keep up with this changing picture, let alone the average consumer.

In an additional demonstration of the impact of rapidly changing demand, in 2011, Hugh Fearnley-Whittingstall launched his 'Mission Mackerel' campaign in a bid to entice consumers to eat more mackerel. Sales of fresh and canned mackerel climbed 14% in the five months thereafter. While Fearnley-Whittingstall encouraged consumers to buy more, he also advised that stocks needed to be managed responsibly⁷⁰ and later warned that politics had started getting in the way of sustainable management⁷¹. Feedback understands that the MSC is using the learnings from the mackerel case, particularly in terms of fisheries governance and 'yo yo fisheries' (fluctuating fisheries), to help improve the MSC standard⁶⁹. Mackerel's experience provides a salutary case study on the need to eat a wide variety of wild fish, rather than fixing on one species, and of the potential for rapid change in fish consumption patterns. Celebrity chefs, restaurants and public procurers can play an important role in helping people adapt to a wider shift towards a more varied fish diet.

Under this model of trimmings-only aquaculture feed production, a new question arises regarding the sustainability of by-products in the fisheries supply chain. This is a complex question which deserves close attention, as decisions around the proper use and regulation of by-products are relevant to many pathways towards a more circular food economy. In Box 4, we discuss some of these issues in more detail.

BOX 4: THE BY-PRODUCT PITFALL

Under a circular food system paradigm, farm animals can play a crucial role in feeding humanity by recycling by-products back into the food system^{72,73}. In a sustainable system, the amount of animal-source food in the human diet is determined by the available sources of animal feed that do not compete directly for arable land or fisheries with human-edible crops and fish. (We do not in this section consider other required uses of land for sustainability, such as afforestation and ecosystem restoration.) In other words, we only feed livestock with unavoidable by-products, surplus food and marginal grasslands not suitable for agriculture. Initial estimates have shown that this route can provide up to one third (9–23g) of the daily protein needs of an average global citizen (50–60g) without using additional arable land⁵⁷. This principle of avoiding ‘food–feed competition’ applies equally to the use of wild-caught, human-edible seafood: under a circular food system model, these resources should only be used to feed people directly, not as feed for farmed animals, including salmon.

Turning to the use of by-products of foods – like wild fish – which are intended for human consumption in the first instance, it is sometimes argued that by-products are effectively free from environmental burden. However, it is not so simple to decouple the use of by-products from the impact of their primary production. For one thing, not all by-products are created equal – the trimmings of a resource-intensive fishery will carry a larger embedded environmental impact than those from a low-impact fishery⁷⁴. For example, the Aquaculture Stewardship Council has banned the use of trimmings from threatened species in aquaculture farms certified under their standard. Furthermore, the use of by-products for a secondary market does not prevent the primary production model from being unsustainable, and where a by-product market contributes to the profitability of a product there is a risk that this creates further demand and effectively perpetuates an unsustainable fishery. There are reports of seafood processing companies making higher profits on the trimmings than on the fillets, as the markets for the latter are very optimised⁷⁴.

Pursuing this logic, it could be argued that what the aquaculture feed industry calls ‘by-products’ may actually be the main product, with the highest economic value. This would mean that the mackerel fillet

*one buys in the shop is a by-product of the parts of the mackerel that are used to produce fishmeal and fish oil. It is at least perfectly reasonable to argue that **there are no such things as fishery by-products, but rather a set of different co-products with different end-uses of similar economic value. This means that using so-called ‘by-products’ in the production of salmon feed is a similarly powerful driver in wild-capture fisheries than the direct human consumption of fish fillets.** We recommend that we differentiate between human-edible fishery by-products, regardless of current market demand, and unavoidable by-products where human consumption is not possible. In doing this, they are considered ‘co-products’ as opposed to ‘by-products’.*

Where we do make use of by-products in animal agriculture or aquaculture, it is also sensible to make sure that the species produced are those capable of making the best use of the available nutrients in by-products. Chickens appear to be better ‘converters’ of protein and calories in feed than farmed salmon²⁵, but from a micronutrient perspective, farmed salmon may be better able to make best use of the micronutrients available in fish oil from trimmings and by-products. It is therefore preferable to use fish oil that does arise from genuine fisheries by-products of the human supply chain in aquaculture feed. More research is needed to determine the criteria to decide in what circumstances which farm animals (for example, carp, chickens, pigs) are most efficient at recycling by-product fishmeal within a circular food system.

One common but particularly unfortunate use of fisheries and other food by-products from a sustainability perspective is the pet food industry. On the basis of data on the Australian importation of fresh or frozen fish for the canned cat food industry, it was estimated that the amount of raw fishery products directly utilised by the cat food industry equates to 2.48 million metric tonnes per year. This estimate, plus the estimated global fishmeal consumption for the production of dry pet food, suggests that 13.5% of the total 39 million tonnes of wild-caught forage fish is used for purposes other than human food production⁷⁵.

ARE THERE MORE ECOLOGICALLY SOUND WAYS TO MEET NUTRITIONAL NEEDS FROM SEAFOOD?

While overall the UK population consumes less fish than the NHS recommends³¹, we also consume a very limited number of types of fish and seafood, with salmon, cod and tuna at the top of the list taking roughly 20% of the market each, by volume⁷⁷. This echoes trends across other food groups, where certain sub-types of each food category – usually those most conducive to industrialised and intensive farming methods – become dominant over a wider and more varied diet. Farmed salmon has been described as ‘the chicken of the seas’⁷⁸ and there are many parallels between the extreme proliferation of cheap, industrially-produced broiler chickens and the growth of the farmed salmon market. Both animals are at the centre of a high-tech, consolidated supply chain, with a small handful of very large, international corporations controlling much of global production: in Scotland six companies alone control 99% of farmed salmon production⁷⁹.

There have been many environmental challenges noted because of the global growth of industrialised chicken, from deforestation to make space for feed production⁶⁷, to local air pollution due to intensive chicken units⁸⁰. Here too, the story of farmed salmon finds echoes: salmon farms in Scotland have been dogged by local controversy surrounding their impact on the seabed and local ecosystems⁸¹, as well as the broader feed sustainability issues we are exploring in this and other reports. The alternative to widespread consumption of one or two species is a ‘less and better’ approach⁸²: consuming less of a product which can be environmentally damaging (an option we explore above in the trimmings-only scenario), and where possible consuming ‘better’, which in this case refers to a much wider variety of smaller, locally caught wild fish. It could also encompass other farmed seafood products which are currently not very widely consumed, but which show great potential in terms of meeting our nutritional needs with minimal environmental impacts. Two such products are mussels and seaweed.

THE POTENTIAL OF ‘UNFED’ AQUACULTURE

Sustainably expanding the aquaculture of ‘unfed’ aquaculture species – those that do not depend on external feed inputs for nutrition – such as bivalves (for example, mussels and oysters) and seaweed, can substantially increase nutritious food and feed with a lower impact on the marine environment⁵⁴. Unfed aquaculture is also less reliant on chemical inputs than the production of fed species, like salmon, which also means a reduced impact on the immediate aquatic environment⁵⁴; filter feeders such as mussels can even have a positive impact through improving water quality⁸³. However, unfed aquaculture in the sea should be constrained by the limitations of the ecological carrying capacity of local environments, particularly under the impact of global heating, and farm scale, density, design and techniques are all important to ensure sustainable outcomes⁵⁴. This section explores the potential of mussels and seaweed to offset the need to access key micronutrients via farmed salmon and wild fish.

“

Essentially we feed fish to fish, so we catch fish in various parts of the world, process them into salmon food, and then feed them to salmon. That is highly inefficient.

”

Professor Sir Ian Boyd, speaking as the Chief Scientific Adviser for the Department for Environment, Food and Rural Affairs⁷⁶



MUSSELS

Mussels have been described as a ‘future food’ for their potential to deliver high levels of micronutrients and thus replace some forms of animal-source products currently common in diets²⁷. A recent study of mussel consumption found that 6 of the 11 people eating only mussels for seafood (and no oily fish) six times over two weeks, improved their omega 3 status to a degree that is associated with at least a 20% reduction in sudden cardiac death risk²⁸. Overall, the study concluded moderate improvement in omega 3 status but noted that some other sources of long-chain fatty acids should be included to also improve status of a third micronutrient called DPA (docosapentaenoic acid).

In contrast to oily fish – where there are maximum recommended weekly portions because pollutants found in oily fish may build up in the body – there is no upper limit for the safe consumption of shellfish⁶⁸. As a result, mussels may be an effective approach to safely increasing omega 3 status. Other bivalves such as oysters and clams also contribute plenty of omega 3, with oysters even capable of offering a higher omega 3 content compared to wild salmon or anchovies⁸⁴.

SEAWEED

One frequently overlooked source of micronutrients, in particular iodine, is seaweed: researchers have identified a possible relationship between high iodine intake, high seaweed consumption and astonishing Japanese health statistics, with one of the world’s highest life expectancies and an extraordinarily low rate of certain types of cancer⁸⁵. Observational studies in South East Asia have found that the wide presence of seaweed in diets can bring possible benefits against chronic diseases such as cardiovascular disease, cancer and diabetes⁸⁶; however, there are some health risks from overconsumption so it is important that seaweed available for sale in the UK is further tested and labelling is improved⁸⁶. With regard to seaweed production, caution is required to avoid negative effects such as light shading and the creation of new habitats for disease⁵⁴, but there are multiple potential positive impacts such as the possibility to sequester carbon from the atmosphere⁸⁷, reduction of wave height during storms, provision of additional habitat for at-risk species and improvement of water quality.

COULD OTHER FORMS OF AQUACULTURE BETTER CONTRIBUTE TO GOOD NUTRITION THAN FARMED SALMON OR WILD FISH?

We modelled a third scenario for accessing micronutrients needed for a healthy diet, using farmed and wild seafood. In this scenario we assumed that Scottish salmon production was constrained to the level possible using a trimmings-only approach to sourcing fishmeal and fish oil for salmon feed. In addition, we assumed the human consumption of a regular portion of 140g of mussels, delivering vitamin B12 and good levels of omega 3. **In this scenario, we found that it is possible to access the same level of micronutrients as in the ‘business as usual’ approach, with a far lower consumption of wild fish: in fact, it is possible to leave 77% of wild-caught fish currently used for salmon and prawn feed in the sea.**

By eating a broad mix of seafood, including a small amount of trimmings-fed farmed salmon, farmed mussels and a wide variety of small wild fish, we can meet our micronutrient needs from seafood, while putting much less pressure on wild ocean life. This finding calls into question the Scottish salmon industry's claims that their approach to producing protein and micronutrients for the public's plate is a good use of wild resources. Instead, we ask whether other, more holistic and sustainable approaches to aquaculture may deliver both a flourishing regional seafood food economy, and a sustainable nutritional contribution to the nation's health.

SCENARIO C INFOGRAPHIC

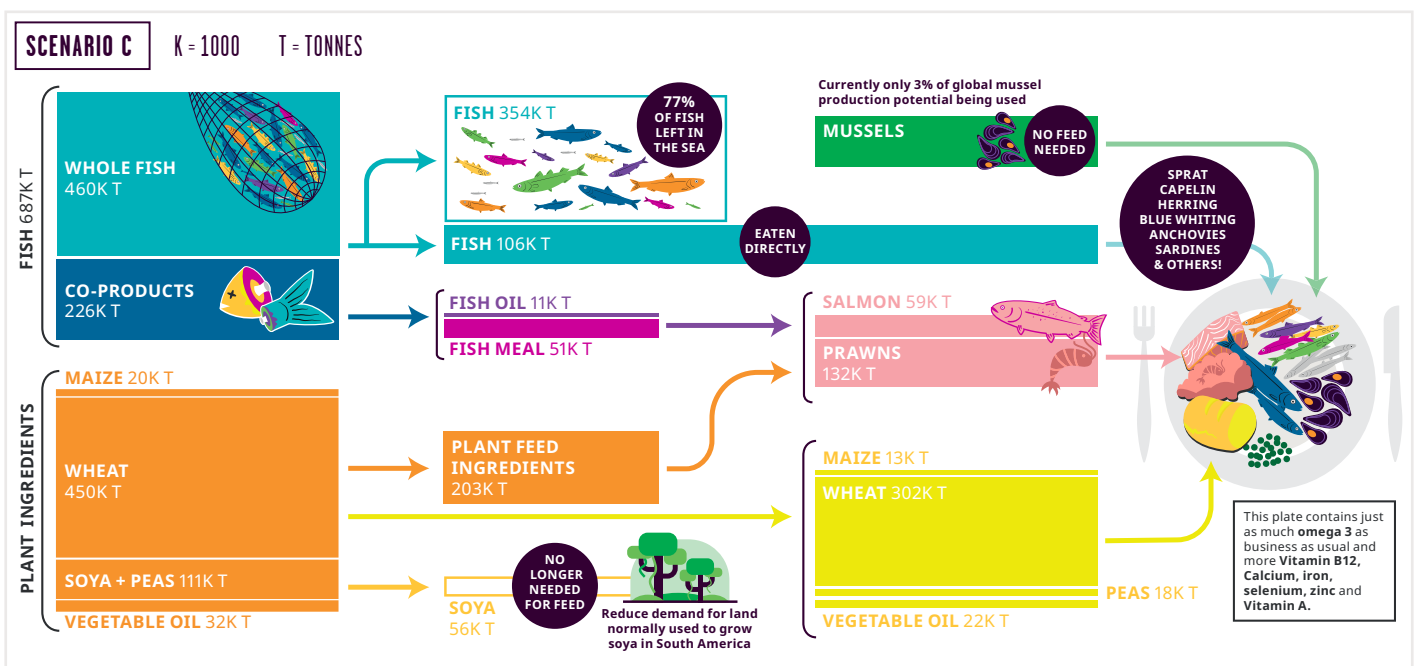


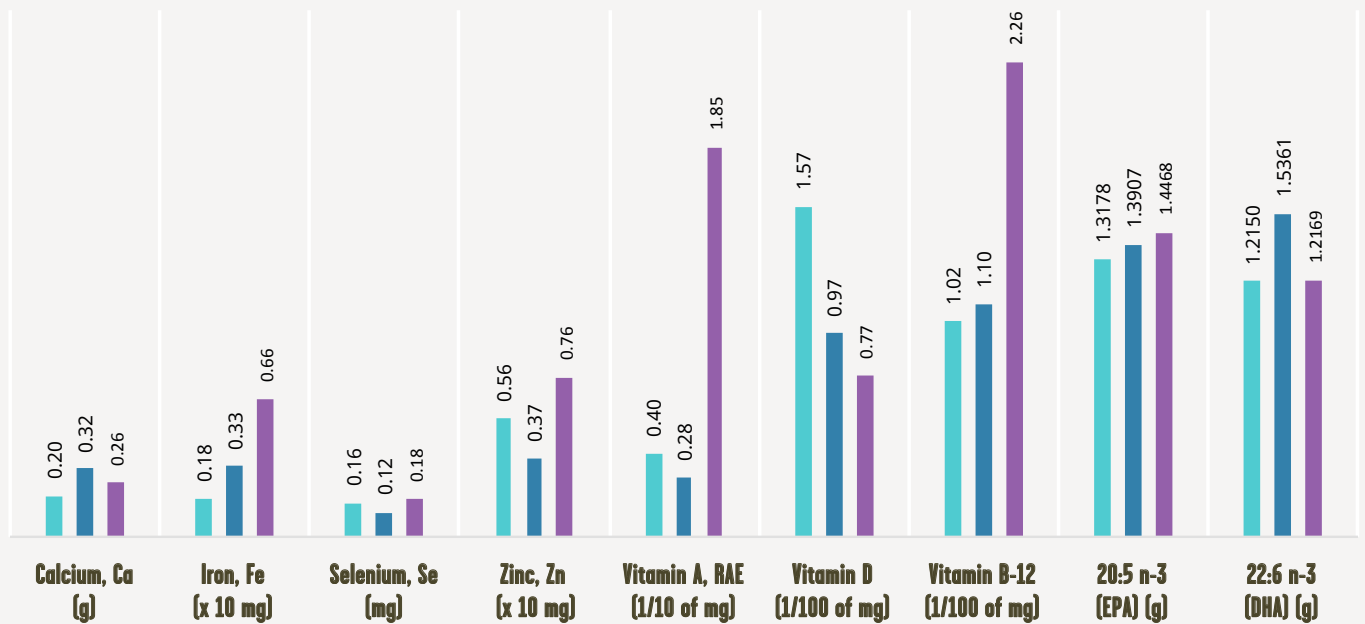
Figure 4 shows the micronutrient outputs of the three scenarios we have discussed in this report. Across almost all categories Scenario C, promoting a more diverse and varied range of seafood consumption (trimmings-only salmon, small oily fish and mussels), outperforms Scenarios A (salmon only) and B (trimmings-only salmon and small oily fish).

Both Scenarios B and C achieve equivalent or better EPA and DHA levels compared to the 'business as usual' scenario of eating farmed salmon alone. Scenario C performs best for Iron, Selenium, Zinc, vitamin A, vitamin B12 and EPA, while Scenario B performs best for Calcium and DHA. The only micronutrient that bucks the trend is vitamin D which is significantly higher in Scenario A. However, as we have explored in chapter 2, vitamin D is also available from a variety of other sources, including sunlight and fortified foods.

Figure 4: Different seafood production strategies to achieve healthy diets

NUTRITIONAL PROFILES FOR DIFFERENT SEAFOOD PRODUCTION SCENARIOS

- SCENARIO A - 140g: One weekly recommended portion of oily fish is 140g. Per 140g of salmon, we can also produce 312g of prawns if we are to use all available fishmeal and fish oil, so the nutrition from prawns is included.
- SCENARIO B - 140g equivalent: Salmon and prawn production is limited to the marine feed ingredients from trimmings only. Part of the 'saving' in wild-caught fish is added to the profile for people to eat directly in order to achieve a similar DHA and EPA.
- SCENARIO C : Salmon and prawn production is limited to marine feed ingredients from trimmings only. Part of the 'saving' in wild-caught fish is eaten directly. We add a portion of mussels to further reduce the use of wild-caught fish.



BOX 5: AN APPETITE FOR LAND

While in the two alternative scenarios to 'business as usual' the demand for farmed salmon feed ingredients is reduced substantially, to one third of previous levels, this smaller Scottish salmon industry will still be reliant on some non-marine ingredients, such as soya, peas and wheat, which could in theory be eaten by people. These plant-based ingredients are not problem-free. Malcorps et al.⁴⁸ have noted that:



Complete fishmeal substitution by plant ingredients could lead to an increasing demand for freshwater (up to 63%), land (up to 81%), and phosphorus (up to 83%). These are significant increases, as only a share of 20–30% of the feed is actually substituted. This is mainly caused by the inclusion of resource intensive crops... such as soybean meal concentrate, rapeseed meal concentrate, pea protein concentrate, and corn gluten meal.



Limiting salmon farming to the scale possible with trimmings-based marine ingredients alone must also therefore be complemented by research on how to replace plant-based ingredients with unavoidable by-products from the food industry. Poultry farming using only food by-products is already viable in Europe⁸⁸. Modern, circular pig farming using feed made from surplus food is practiced in Japan and could be possible in Europe if legislation is introduced to ensure that this is done safely⁶⁰. From the perspective of a sustainable food system that makes best use of nutrients, the question is: which by-products from the food system are best used in which type of farm animal production?

A NEW SCOTTISH AQUACULTURE INDUSTRY?

We have modelled a set of scenarios showing that it is more than possible to reduce the burden we place on the ocean, and access all the micronutrients currently provided by farmed Scottish salmon, through consuming a wider variety of farmed and wild seafood. Our calculations have shown it is possible to fulfil nutritional needs while leaving up to 77% of current catches for salmon feed in the ocean: this represents approximately 350,000 tonnes of wild fish.

These findings have major implications for the size of the salmon farming sector in Scotland. **Until the industry can evidence that alternative feed ingredients can replace the role of fish oil in producing micronutrient-rich farmed salmon without increasing other environmental impacts such as greenhouse gas emissions, it should not increase production beyond that which is supported by the availability of trimmings-based ingredients.** Here, regulatory caution is needed to ensure that demand for fish oil made from by-products does not misalign incentives, resulting in the by-product becoming the driver of fisheries expansion. The industry has already grown by 91% since 1997⁷⁹, and the Scottish Salmon Producers' Organisation has previously said that it targets growth of up to 160% by 2030, from a 2018 baseline⁴⁹. This growth is very clearly not coherent with the goals of sustainability and of best use of nutrients from the ocean. **To ensure a fair distribution of micronutrients from seafood, it is essential that we withdraw from feed intensive aquaculture species like salmon, and explore the potential of other, more circular forms of aquaculture.**

Developing the Scottish unfed aquaculture sector is one option which should be explored. In 2018, Scotland produced around 6,800 tonnes of farmed mussels, as well as 4,000 tonnes of farmed oysters⁸⁹. In this section we briefly explore the potential to safely and sustainably grow the Scottish farmed shellfish industry.

SCOTTISH SHELLFISH PRODUCTION POTENTIAL

Globally, over half of global mariculture (aquaculture in the sea) production is shelled molluscs, compared to finfish, such as salmon, (27%) and crustaceans (17%)⁷. The ocean has the potential to produce nearly 768 million tonnes of bivalves, and about 60% of this production would be profitable at roughly the current price for blue mussels. Current production of bivalves is just 15.3 million tonnes per year⁵⁴. Insufficient demand and prohibitive regulatory barriers are important reasons holding back the growth of the sector.

Europe only produces 5.5% of the world production of marine bivalves and production has decreased since 1998. The decrease in mussel production is partly due to a reduction in physical space due to competing claims with nature conservation, and technical challenges around mussel seed and initial growth⁹⁰. Yet high latitude maritime nations have the potential to produce high quality bivalves due to higher levels of omega 3 in colder climate bivalve species⁸⁴. Since the lack of seed supply is a prime factor limiting the development of bivalve farming, hatcheries should produce more bivalve seed resources. In addition, research efforts should also focus on screening potential bivalve species for fast growth and omega 3 accumulation potential⁸⁴. In the case of Scotland, the Shellfish Water Protected Areas designation order identifies 84 waters as 'shellfish water protected areas' and the Scottish Government has introduced a package of measures to ensure the continued protection and improvement of shellfish growing waters by integrating these within the river basin management planning process. In the case of conflicted interests over sea areas, the ongoing protection of sea areas for shellfish production should be prioritised over salmon farming.

ENSURING BIVALVE FARMING DOES NO HARM

While bivalve farming is considered to be less impactful on the local environment than fed finfish farming, in part due to the lack of pollution of the seabed by uneaten feed, there are still some potential environmental impacts. Bivalve farming needs to take account of conservation goals, and of the carrying capacity of the natural environment around a site⁹¹. *Production* carrying capacity of a site is the stocking density at which harvests are maximised, and this depends for example on the predicted currents transporting plankton that mussels graze on and other biological factors specific to a site. *Ecological* carrying capacity also includes impacts on other organisms and habitats in the ecosystem, for example in relation to the impact of plankton depletion on other planktivore species and increased sedimentation affecting seafloor ecosystems. As ecological carrying capacity is generally much lower than production carrying capacity, care is needed to ensure that local environmental preservation is prioritised over excessive production in any one area⁹¹.

There are also potential local environmental benefits to bivalve farming: it may help buffer estuaries and coastal ocean waters against the effects of eutrophication (when a body of water becomes overly enriched with minerals and nutrients potentially resulting in excessive growth of algae and oxygen depletion) or increase the abundance of commercially important species locally^{83,91}. Moreover, the enhancement of water clarity due to filtration allows deeper light penetration and therefore can increase the growth of seagrasses that are an important nursery habitat for many fish, crustaceans and molluscs; bivalves are therefore capable of enhancing estuarine nursery habitats⁸³. These natural functions of bivalves can be employed in aquaculture not only to mitigate the environmental effects of the culture, but also to create added value and services for the surrounding environment. It has been therefore suggested that bivalve restoration should be a component of restoring historical baseline conditions and functioning of estuaries. The restoration of oyster in the Chesapeake Bay is the most famous example of bivalve restoration effort⁸³.

BOX 6: THE POTENTIAL OF INTEGRATED MULTI-TROPHIC AQUACULTURE IN SCOTLAND

Integrated Multi-Trophic Aquaculture (IMTA) is acknowledged as a promising solution for the sustainable development of aquaculture. IMTA farmers combine species that need supplemental feed, such as finfish, with algae and filter feeders such as shellfish which use the organic and inorganic materials and by-products from the other fed species for their own growth. Deposit feeders, such as worms, sea urchins and sea cucumbers, that feed on organic material on or within the sediment can also be part of the system. The natural ability of seaweed, shellfish and deposit feeders to recycle the nutrients (or wastes) that are present in and around fish farms can help growers improve the environmental performance of their sites. Integrated aquaculture of shellfish–fish, shellfish–shrimp and shellfish–seaweed has become the new trend for mariculture development in China⁹⁰.

At a local scale, IMTA can be an adaptive strategy for ocean acidification, where seaweed or seagrass are key components that reduce the effects of acidification by absorbing and assimilating dissolved CO₂ from surrounding water⁹². IMTA can be applied not only to marine environment, but also to the hatchery system, in which the incoming seawater is first treated (which can act as a buffer against low pH seawater) with macroalgae or microalgae and then supplied to the shellfish tanks. As a result, IMTA can effectively reduce the impact of ocean acidification in bivalve farms, and farmed bivalves can gradually acclimate/adapt to changes in carbonate chemistry. Hence, the role of IMTA in mitigating the impact of future ocean acidification on coastal bivalve farms and shellfish hatcheries is worthy of attention⁹².

IMTA is being encouraged by EU policies such as the Blue Growth Strategy and the Atlantic Action Plan, but there still are socio-economic, administrative and legal bottlenecks hampering its development to its full potential. British researchers, including from the Scottish Association for Marine Science, are involved in two large EU-funded projects^{93,94} focused on developing IMTA systems so they can become viable options for aquaculture in Europe. We hope that the salmon industry can throw its weight in and build on the findings to place salmon farming fully within a circular food system.

SCOTTISH SEAFOOD JOBS

The salmon industry is an important employer in Scotland, especially in remoter areas around the west coast and islands. In 2018, over 2.6 million people (aged 16 years and over) were in employment in Scotland⁹⁵. The Scottish salmon industry creates around 1,700 jobs¹¹ directly⁴⁴ and the industry estimates it creates a further 10,000 jobs indirectly⁹⁶. For comparison, over 200,000 people work in tourism⁹⁷.

Comparing the job production potential of the farmed salmon and farmed shellfish industries yields interesting results. The Scottish salmon industry is worth £878 million, dwarfing the shellfish industry at £9.5 million, and approximately 217 full-time jobs¹² ⁸⁹. A simple calculation shows us that **for every £1 million of industry value, the shellfish industry generates 23 jobs compared to only 2 jobs for the salmon industry**. In other words, not much growth is needed in the shellfish sector to create significantly more jobs relative to the salmon sector.

The fishing industry in Scotland is also a major coastal employer and economic sector, with nearly 5,000 people employed on fishing vessels, and Scottish fishing vessels land around two thirds of fish caught in the UK by volume, and nearly 90% by value⁹⁸. Pelagic fish, such as mackerel and herring, make up the highest proportion of landings, with mackerel accounting for 29% of total fish landings⁹⁹.

In thinking about a future for Scottish coastal communities that is sustainable, just and generates social as well as economic value, it is important to consider a broad range of options. Could community-owned local aquaculture businesses both promote production within local and global ocean boundaries, as well as providing fair jobs for coastal communities? The New Economics Foundation has proposed a 'Blue New Deal' to revitalise coastal communities around the country, and protect the natural resources they depend on¹⁰⁰. It suggests prioritising small boat fishing over larger, industrialised fleets, a collaborative regional approach to seafood hubs, and focusing on water quality targets to ensure a balance between aquaculture production, local ecosystems and community enjoyment of local waters.

BOX 7: A JUST TRANSITION IN GLOBAL FISHERIES

Fisheries currently employ more than 35 million people globally. In order to rebuild global fisheries, between 15 and 22 million fishers would need to be moved to other livelihood activities¹⁰¹. Significant support will need to be provided to allow a transition from fishery livelihoods which cannot be supported by a sustainable approach to global fish populations (see Feedback's report 'On the hook: How certification is failing to protect wild fish populations from the Scottish farmed salmon industry') and a strong equity approach will

*need to be taken to ensure the rights and livelihoods of artisanal and small-scale fishermen and women are prioritised over industrial export-oriented fisheries. One way to align economic and cultural incentives with environmental stewardship is a 'socially equitable rights-based fisheries management', which assigns a property right to extraction or to a given area of the ocean⁵⁴. In any case, **it is better to undertake this transition as part of a rebuilding policy rather than having it forced upon us through a collapse of fish stocks.***

11 These are mostly full-time roles, with only a small proportion part-time, with two part-time roles accounted for as one full-time. This includes both salmon and smolt production.

12 137 full-time staff and 161 part-time; we have simply assumed two part-time positions are equal one full-time role.

CONCLUSION AND RECOMMENDATIONS

This report has explored an important question: how do we provide for high quality, accessible micronutrients from seafood, while respecting environmental limits, and where possible, enhancing natural ecosystems? The current dominant model of Scottish aquaculture, focused on scaling up production of a single species, highly reliant on feed ingredients made from thousands of tonnes of wild fish which could be eaten by people, is not a sustainable answer to this question.

Instead, this report has demonstrated that alternative models are available to us, and that these models could allow us to reduce our reliance on wild fish for nutrients, either directly or via farmed salmon. We have shown that direct human consumption of a wide variety of small oily fish, alongside an increase in mussel consumption, could deliver similar contributions of omega 3 and other micronutrients as the current Scottish farmed salmon industry, while avoiding the capture of up to 77% of fish current caught to be used in salmon feed. Producing smaller volumes of farmed salmon in Scotland, using only truly unavoidable by-products from fisheries in feed, can also play a valuable role in preventing micronutrients from leaving the food supply chain.

In order to deliver the vision set out in this report, we make the following recommendations:



Recommendations for a truly sustainable Scottish salmon farming industry

- » Limit salmon farming to that which is possible using fishmeal and fish oil made from unavoidable fishery by-products alone. Any human-edible fish should be destined for direct human consumption, not salmon feed. Based on current available figures, this means that the Scottish salmon industry will need to shrink by at least two thirds.
- » Develop feed formulations that replace human-edible plant-based ingredients such as wheat, soya and peas with unavoidable by-products of the food industry, as is already done in certain chicken farms.
- » Address the shocking mortality levels affecting salmon farming in Scotland in the last few years. Mortality levels of between 10 and 20% are unacceptable. Shrinking industry production may provide some relief from very high mortality levels.
- » Support Integrated Multi-Trophic Aquaculture pilot schemes where the environmental impact of salmon farming is further managed through co-cultivation with seaweed and bivalves such as mussels.
- » Until we have a clear understanding of the carbon footprint and other environmental impacts of the production of alternative feed ingredients, caution and scepticism are required in projecting growth that depends on the development of alternatives to replace essential marine ingredients in feed.
- » Both salmon and capture fisheries should develop the necessary infrastructure to maximise the use of fishery by-products in human consumption.
- » Aquaculture certification schemes and standards that include processing facilities, such as Global Aquaculture Alliance's Best Aquaculture Practice Facility Certification could encourage, educate and incentivise facilities in maximising the use of their processing of by-products while ensuring that the correct proportion of the environmental impact of original fisheries is allocated to these by-products.

Recommendations for policymakers and certifiers

- » Feedback does not support certification of any fish or fish populations intended for use as feed for either aquaculture or animal agriculture **under any circumstances** – this includes pet food. Schemes such as the MSC, in order to be credible, should not certify so-called 'reduction fisheries'. In the case of fish intended for direct human consumption, we find that there are severe limitations with certification schemes, but we acknowledge that currently in the absence of a more comprehensive and effective fisheries governance policy, these schemes **can be a useful way** for the public to assess the relative sustainability of the fish they buy. Certification of fish for direct human consumption should continuously adapt to the *actual* status of fish stocks, not *projected* status. Please see our report 'On the hook: Certification's failure to protect wild fish from the Scottish salmon industry' for more information on certification.
- » Develop policy and regulation that restrict the disposal of by-products, to drive industry innovation in maximising the use of fishery by-products in human consumption.
- » Unfed aquaculture of bivalves, such as mussels, and seaweed has great potential to deliver essential micronutrients to our plates at a much lower environmental cost and requires policy support to live up to its potential in contributing to healthy diets, a healthy planet and thriving Scottish coastal economies.

Recommendations for retailers

- » To ensure that natural limits on wild fish populations are not exceeded, commit to completely phasing out the use of fishmeal and fish oil sourced from wild-caught fish in its aquaculture supply chain, including setting a date to achieve this target of no later than 2025.
- » Commit to offering and promoting a wide range of seafood – including a greater diversity of sustainably caught wild fish, and aquaculture products produced without the use of fishmeal and fish oil – that can deliver the same key nutrients as mass-marketed farmed seafood, such as salmon, sea bass and prawns.
- » For more information on how UK supermarkets are tackling the use of wild-caught fish in their supply chains, see our report produced with the Changing Markets Foundation 'Caught Out: Supermarket Scorecard'.

Recommendations for chefs and consumers

- » Do not consume farmed salmon until the feed used by the industry is made from by-products and the key recommendations highlighted above are implemented.
- » Promotion and consumption of only a very limited number of wild fish species should be avoided: Feedback's findings concur with NHS advice for fish and shellfish, which states that **'to ensure there are enough fish and shellfish to eat, choose from as wide a range of these foods as possible. If we eat only a few kinds of fish, then numbers of these fish can fall very low due to overfishing of these stocks'**⁶⁸. We need more guidance and support from chefs and food writers on preparing and eating a much wider range of fish.
- » Chefs, retailers and other influencers should promote the consumption of mussels, of a wide variety of different oily fish which should be eaten whole as much as possible, and of fishery by-products.

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ANNEX I

To find out how useful farmed salmon is for bringing nutrients like omega 3 oils, selenium and vitamin B12 into our diets, Feedback did a set of calculations using data on salmon feed ingredients and nutrition from the best publicly available sources we were able to find.

For total volumes of marine ingredients in Scottish salmon feed, we found reliable data for 2014, which we considered sufficiently representative for our estimates given the non-linear variations between FFDRs over the last 5 years – as made publicly available on the Global Salmon initiative website. Feedback can recalculate these figures with more up-to-date volumes of fishmeal and fish oil (FMFO) when these are made available.

With this information about the volumes of wild fish and trimmings used in making fish oil and fishmeal for salmon feed, we compiled all available information to come to an estimate of the proportions of different species of wild fish used to make FMFO for feed. We combined this information with nutrition data for cooked portions of these fish where available from the UK Department of Health. Where species were not covered by the UK Department of Health, we looked at the USDA nutrition database, Oregon University and the Spanish government nutrition database. Detailed information is available in the nutrition spreadsheet (www.feedbackglobal.org/salmonfeeddata).

We then created three scenarios:

» **Scenario A - Business as usual: maintaining current levels of salmon production.**

In this scenario we assumed the industry uses FMFO made from both by-products from wild fish caught for human consumption, and wild-caught fish caught specifically for FMFO production. As the process of producing FMFO delivers a larger quantity of fishmeal per raw ingredients than fish oil, our calculations considered that 'leftover' fishmeal that was not used for salmon farming would be used for farmed prawn production. In this scenario we calculated the number of micronutrients for a 140g portion of salmon, combined with the additional nutrition provided by 312g portion of prawns.

» **Scenario B: Salmon farming using fish oil made from trimmings and by-products of fish caught for human consumption.**

In this scenario we assumed that the industry uses only FMFO made from by-products, producing an estimated one third of current volumes of salmon given that currently around one third of the fish oil used in European salmon feed comes from trimmings. Please see the By-Products tab in the salmon feed calculations spreadsheet for more detail on how we came to this estimate. We then calculated the micronutrients available in the fish no longer used in salmon feed, alongside the micronutrients in a small portion of farmed salmon in order to calculate the minimum amount of wild-caught fish needed to deliver at least as much EPA or DHA (omega 3 fatty acids) compared to Scenario A.

» **Scenario C: Trimmings only salmon farming, combined with mussel farming for human consumption.**

This scenario is a further development of Scenario B, but with the addition of micronutrients from a portion of mussels. We then adjusted the wild-caught fish needed to deliver at least as much EPA or DHA compared to Scenario A.

Please see the Feedback salmon feed calculations spreadsheet which includes all data sources, available for download at www.feedbackglobal.org/salmonfeeddata.

ANNEX II

Table 3: Farmed salmon reported mortality rates in Scotland

2016:

<i>Total number of produced fish</i>	35,680,674
<i>Number of fish mortalities</i>	986,032
<i>Total number of attempted produced</i>	36,666,706
% MORTALITIES OF TOTAL	3%

2017:

<i>Total number of produced fish</i>	36,716,695
<i>Number of fish mortalities</i>	4,842,501
<i>Total number of attempted produced</i>	41,559,196
% MORTALITIES OF TOTAL	12%

2018:

<i>Total number of produced fish</i>	28,636,991
<i>Number of fish mortalities</i>	3,500,390
<i>Total number of attempted produced</i>	32,137,381
% MORTALITIES OF TOTAL	11%

2019:

<i>Total number of produced fish</i>	34,964,385
<i>Number of fish mortalities</i>	5,846,848
<i>Total number of attempted produced</i>	40,811,233
% MORTALITIES OF TOTAL	14%

Calculated on the basis of data available on: <https://www.gov.scot/publications/fish-health-inspectorate-mortality-information/>

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