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Future of the Sea: Trends in Aquaculture

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Evidence Review
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Future of the Sea: Trends in Aquaculture

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Contents

Executive Summary

- Aquaculture has grown in the last 40 years to be an important component of the UK seafood sector with a production value in excess of £590 million to the UK economy.
- The strong government support for the Scottish aquaculture industry has contributed to its growth and ongoing plans for expansion up to 2030.
- There are global and national drivers for aquaculture in the UK to develop further, including: increasing demand for seafood for export and, domestically, a limit to the expansion of capture fisheries, and the development of technology that will reduce the environmental impact and increase the social acceptance of aquaculture.
- Climate change, energy prices, government policy and social acceptance of aquaculture will shape how aquaculture develops in the next 50 years.
- There is significant potential for aquaculture to further develop across the UK especially in semi-contained recirculating aquaculture systems (RAS) on both land and sea, and in offshore cage aquaculture.

1. An Overview of UK Aquaculture

This report is a forward look to the potential prospects of aquaculture in the UK over the next 50+ years, evidenced using primarily governmental sources for production and economic data and, as far as possible, peer-reviewed papers for underpinning science background and analysis. The focus on the report is aquaculture for food production; it does not discuss non-food-related aquaculture such as ornamentals. The industry in the UK is largely Scottish, and dominated by salmon. There is little evidence of a serious competitor to salmon emerging in terms of value and volume in any of the mid-latitude countries that currently major in salmon, including the UK. When the technology exists to go offshore with salmon farming, the relative advantages that countries with fjordic coastlines have (e.g. Scotland, Norway and Chile) will likely diminish, and countries with less sheltered coastlines (e.g. England and Wales) may increase their production.

Aquaculture policy is devolved and the framework differs in detail in each administration of the UK where aquaculture schemes and operations are conducted. Policy is much more fully established in Scotland (Scottish Government 2016) than elsewhere in the UK – an effect of the concentration of the UK aquaculture industry in Scotland. Scotland's aquaculture regulatory process, particularly as related to pollution, is regarded as world leading and is a model of good regulatory practice as evidenced through the mandatory adoption of the Code of Good Practice for Finfish Aquaculture, and the industry adoption of specific assurances and standards such as Label Rouge designation and the RSPCA 'Freedom Foods' Scheme: this contributes to the Scottish price premium achieved for Atlantic salmon compared to Norwegian products. Scotland has a rugged coastline, dominated by unindustrialised fjordic estuaries (sea lochs) with excellent opportunities for shelter from wave energy, together with large freshwater resources. This makes Scotland an ideal environment for the development of the industry. In contrast, much of the English coastline is exposed to storm-generated waves and many of its estuaries are highly industrialised. However, these differences will lessen as aquaculture moves into more-exposed offshore locations across the UK. Following the general EU trend (European Commission 2013), aquaculture in the UK has not expanded at the global rate, despite evidence that aquaculture makes a very positive contribution to the UK economy (Alexander et al. 2014) and food security (GFS 2014). The reasons for this are complex and are currently being researched, but often relate more to social/regulatory issues than economic or environmental issues (European Commission 2016), with the need to simplify administrative procedure, and to develop spatial planning for aquaculture being cited as primary blockers on the growth of aquaculture, although environmental constraints such as parasitic sea lice, and their potential effects on wild salmonids, remain a significant problem for the salmon sector (Torrissen et al. 2013).

In addition to sea lice, several other environmental effects require appropriate regulation by government and industry in order to control and mitigate their impacts. These include localised pollution of the sea bed from the release of faecal material from net-cage fish farms causing changes in local biodiversity; release of dissolved nutrients from fish farms that have the potential to stimulate primary production; release of dissolved and particulate-bound medicines from fish farms that have the potential to affect local biodiversity and; escapes of fish from a variety of causes which can have both ecological and genetic impacts on wild populations. Social impacts from both fish and shellfish farming include reduction in visual amenity and loss of wilderness values in some settings (Jones et al. 2015). The extent to which these issues apply at a particular site is a function of the suitability of the receiving environment for the scale and methods of farming practised, but also reflects the extent to which farmers adhere to best practices. Whether or not these issues are environmentally relevant or important at a particular site, public perception of impacts may remain and present significant barriers to expansion. The aquaculture industry is becoming increasingly aware of the need to achieve a “social licence to operate” (Leith et al. 2014). The important actors are the government who wish to secure sustainable economic benefits, the public who influence the democratic regulatory process at both local and national level (through various representations to the media and to working groups, etc.), the aquaculture industry and its investors, and consumers who at present create a large and growing demand for aquaculture products.

Aquaculture has considerable social benefits: for example, Scottish aquaculture production generates at least £1 billion in turnover across the UK and supports 8,800 jobs (Alexander et al. 2014). These are located not only in fragile rural production areas but also in deprived urban areas where much processing takes place (Alexander et al. 2014). Conversely, aquaculture development may detract from the natural heritage values in some environments, as well as reducing space for other sectors, especially fisheries. There are relatively few studies on public attitudes to aquaculture development but those that have been undertaken do not point to a widespread antipathy to aquaculture (Whitmarsh and Palmieri 2009; 2011), especially when appropriate information is provided (Altintzoglou et al. 2010; Chu et al. 2010).

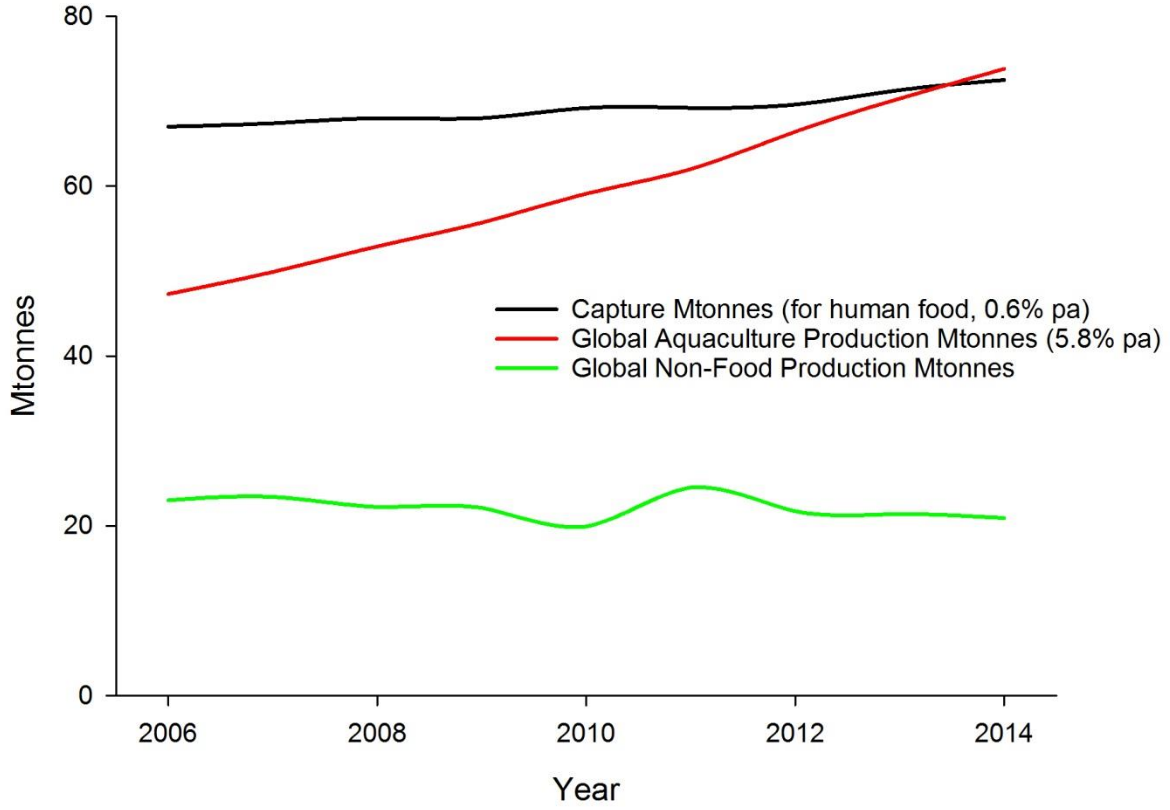


Figure 1. Aquaculture now provides more human food than fisheries

Data source: FAO (2016)

Aquaculture is a food-producing sector presently intimately associated with fisheries and terrestrial agriculture. In developed countries, the industry is consolidating both internally and globally. In Scotland there are now only 16 salmon-producing companies operating 254 sites (Marine Scotland Science 2016) compared to 69 companies operating 162 sites in 1995 (Fisheries Research Services 2002). Aquaculture is an innovative, biotechnology-driven and rapidly growing industry, often located in areas exposed to risks from extreme weather. Large-scale aquaculture has been developed only in the last ca. 40 years, but it already provides more human food than fisheries (Figure 1; FAO, 2016), from which production has plateaued. Globally, fisheries are close to or beyond sustainable limits and catches are not expected to increase in the short to medium term (Msangi et al. 2013). The increasing global demand from both a growing and more affluent (in absolute terms) population can only be satisfied through the continued growth of aquaculture production.

1.1 The Current State of the UK Industry

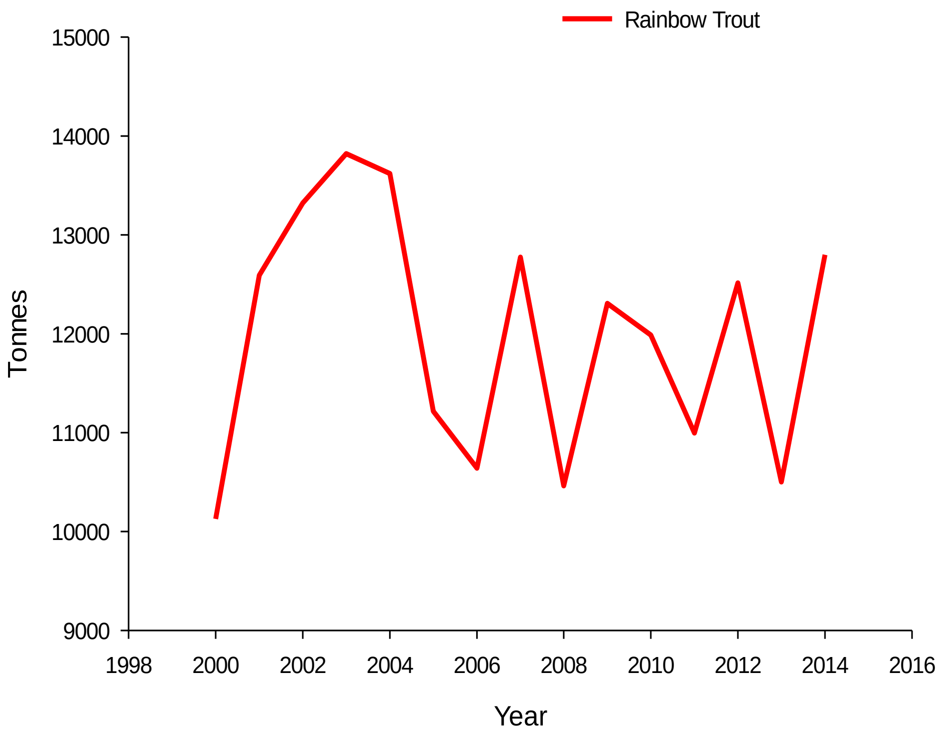
The UK produces a narrow range of aquaculture species. Rainbow trout (Figure 2) dominates freshwater culture. Salmon smolts (juvenile salmon) are also grown in freshwater before ongrowing in the sea, with 45.5 M individuals put to sea in 2015 (Marine Scotland Science 2016), equivalent to ca. 3000 t biomass.

Scotland is by far the biggest aquaculture producer in the UK by volume and value (Table 1). In the marine environment, Atlantic salmon (*Salmo salar*) dominates, and is almost entirely produced in Scotland (Jennings et al., 2016). Scotland also produces a third of UK mussels (Figure 3). Scottish mussel production is mostly cultured using ropes suspended in the water on which the mussels are grown for a period of 2–3 years (suspended production). There is increasing Scottish production of wrasse and lumpfish in the marine environment, which have proven effective in removing sea lice from salmon (SAIC 2015).

Table 1. Aquaculture production volume and value, and direct employment in the UK in 2012

Source: Ellis et al. (2015) from Jennings et al. (2016)

Country	Production (volume)		Production (value)		Employment	
	t	%	£m	%	Number	%
England	15,624	7.6	31.6	5.3	1,081	33.5
Wales	9,452	4.6	10.4	1.8	134	4.1
Scotland	174,531	85.1	541.7	91.7	1,898	58.7
Northern Ireland	5,528	2.7	6.7	1.1	118	3.7
UK (total)	**205,134**	**100.0**	**590.5**	**100.0**	**3,231**	**100.0**



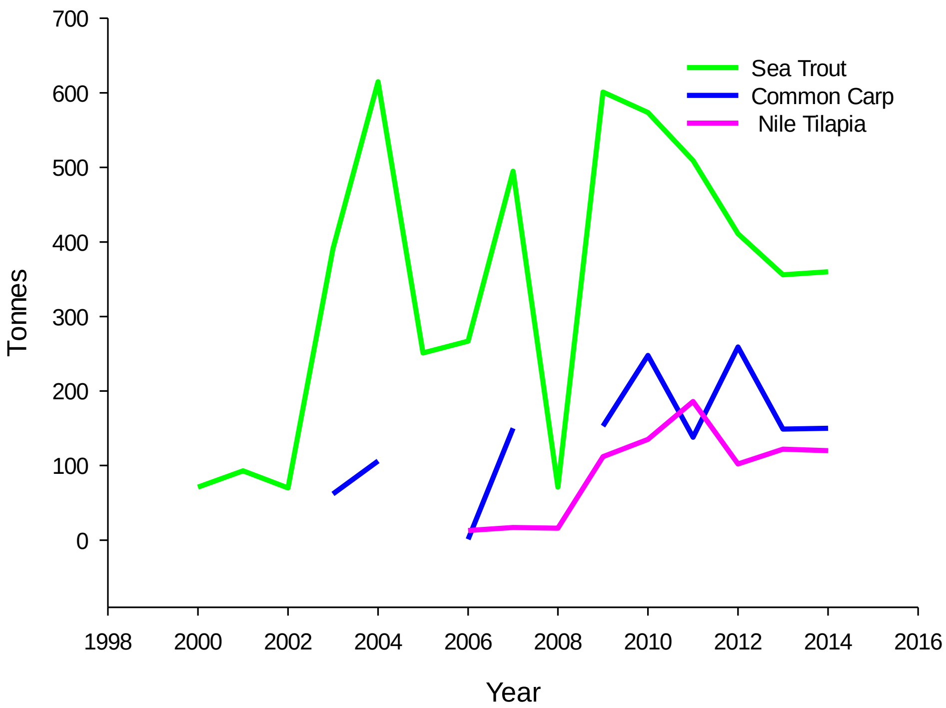


Figure 2. UK aquaculture production: freshwater production is dominated by rainbow trout

Data source: Marine Scotland Science (2016)

Note difference in scale bar between the two graphs

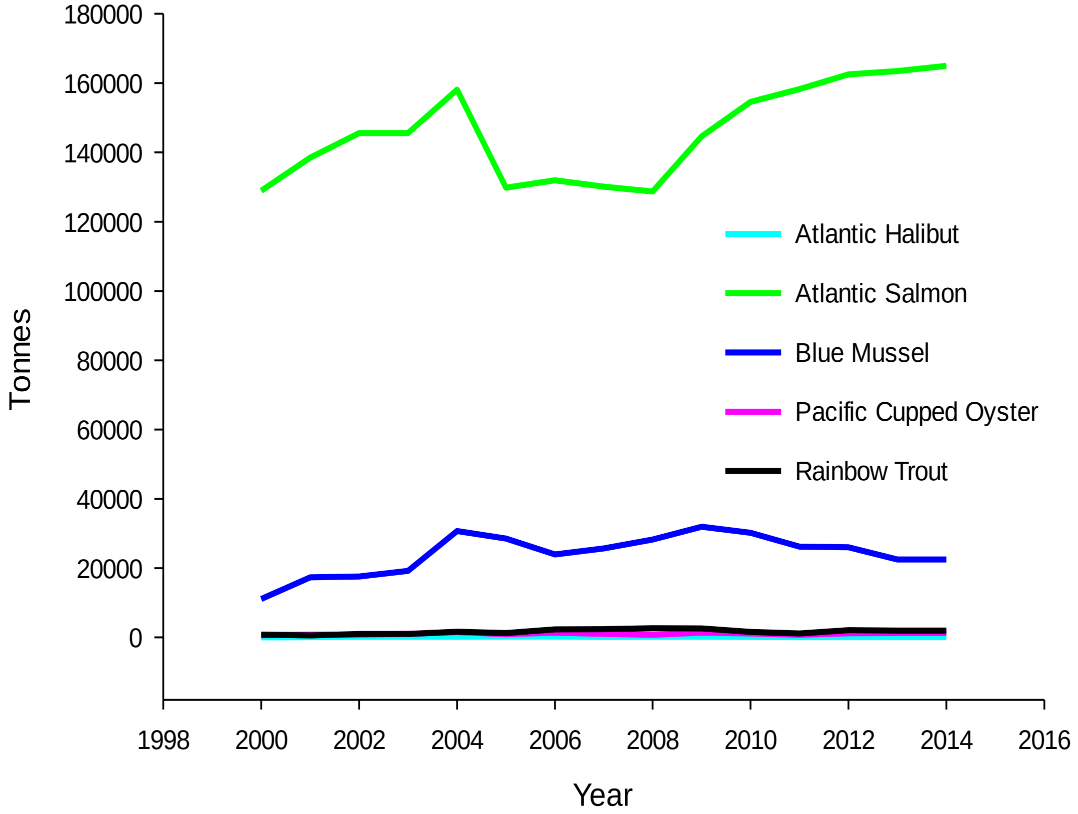


Figure 3. UK marine aquaculture production is dominated by Atlantic salmon and blue mussels

Data source: FAO (2016)

The English industry is predominantly re-laid in intertidal bays but considerable expansion of suspended mussel production in England is proposed (e.g. Offshore Shellfish Ltd, n.d.). There are no marine finfish farms in England and Wales but other marine farms do exist on land. Emerging offshore technology from Norway and Scotland, together with investment from a suitable industrial partner, may make offshore fish farming in England and Wales feasible in the future. A very useful and practical Toolbox has recently been released by Seafish (2017), which provides a detailed and comprehensive inventory of the regulatory requirements with respect to the whole range of aquaculture types in England. Seaweed culture is at the pilot stage in the UK with very small volumes of several species produced for experimental use and for speciality food ingredients (Capuzzo and McKie 2016). An assessment of the potential for aquaculture development in Wales (The Welsh Government 2015) indicates several future opportunities for a variety of aquaculture types, although the conclusions are heavily caveated. Aquaculture in Northern Ireland is dominated by marine shellfish production and considerable effort has been made to determine the carrying capacity of the NI Loughs (e.g. the AFBI Sustainable Mariculture in northern Irish Sea Lough Ecosystems (SMILE) project).

As well as culture in the open environment, a limited amount of fish production takes place in recirculating aquaculture systems (RAS), which are contained systems on land. This technology has the potential to deliver fish very close to markets but would require considerable further innovation before being able to compete in non-niche sectors (e.g. salmon) (Murray et al. 2014). RAS are presently a marginal economic activity (Jeffery et al. 2011) but is increasing as a method of salmon smolt production in Scotland (Fishupdate 2014). Aquaponics (the combination of fish culture and hydroponic plant culture), a specialised form of RAS, is attracting interest as a method of efficient food production, often in urban areas (Goddek et al. 2015).

Of the British Overseas Territories (BOT), the Falkland Islands is the only one registered in the UN Food and Agriculture Organization (FAO) FishStat database (FAO 2011–2017) as having had any aquaculture production. Minor production of shellfish in the mid-2000s is recorded, but none from 2009 to 2014 despite a project funded by the Falklands Development Department (Fishupdate 2009). It is very likely that other BOTs such as Anguilla, Bermuda and the British Virgin Islands will have some potential to develop aquaculture production in line with other small island states due to their large Exclusive Economic Zones and diverse marine resources (Hughes et al. 2016).

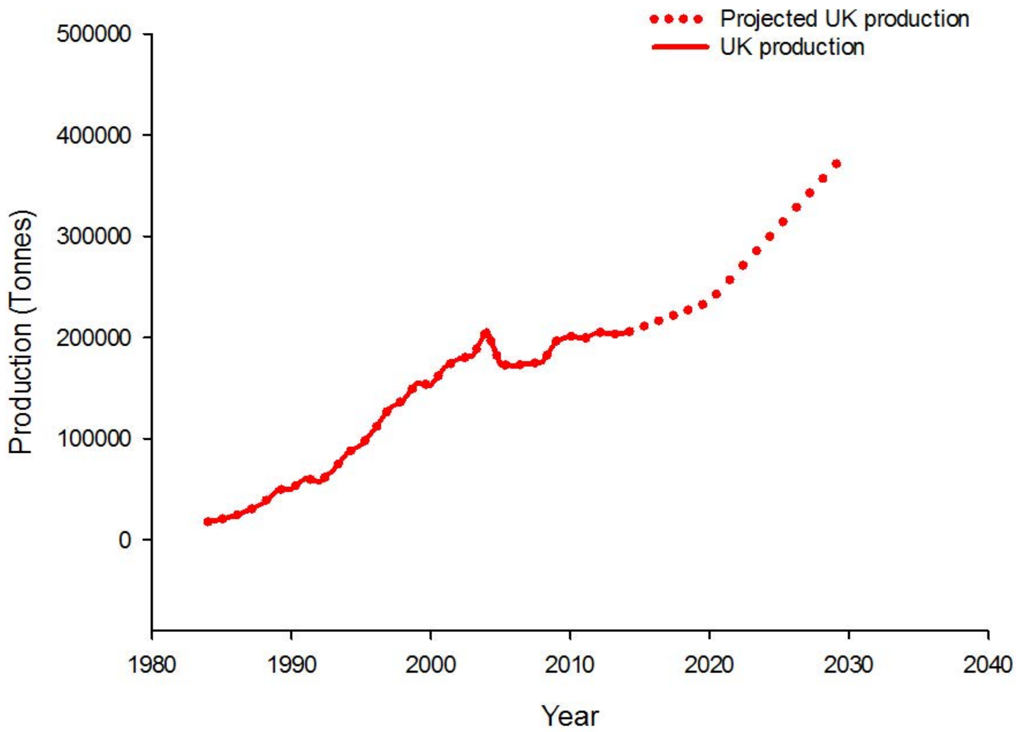
1.2 The Potential and Current Limitations for UK Aquaculture Growth

The UK fish and seafood market is currently dominated by imports (43 per cent) and capture fisheries (40 per cent) with aquaculture making up only 17 per cent of domestic supply (Jennings et al. 2016). The main export markets for UK salmon are the USA (34 per cent), France (23 per cent) and China (12 per cent). However, there are plans for the UK salmon production to increase significantly. The Scottish aquaculture industry, supported by the Scottish Government, has clearly articulated highly ambitious targets for the development of the industry over the short to medium term: 300–400 kt of fish and 21 kt of shellfish are proposed 2030 targets (Scotland Food and Drink 2016). Challenges to achieving these targets have been examined in detail (Gatward et al. 2017). In contrast, UK aquaculture outside of Scotland has been stagnant or declining for many years (Hambrey and Evans 2016) and, although there are some plans (DEFRA 2015), there is no published strategy for growth: a detailed, politically supported strategy is vital for the future development of aquaculture in England, Wales and Northern Ireland. If it is accepted that production within the rest of the UK will be static (it actually fell from 34 kt in 2010 to 21 kt in 2014 – Seafish 2014), then a total UK production of approximately 385 kt by 2030 could be expected, if these figures are met with the medium values for Scottish targets (Figure 4).

There is evidence to suggest that the shellfish targets are obtainable if all current sites were brought up to the production levels of the most-efficient farms. However, for the fish production there are a number of obstacles that would need to be addressed to reach these targets (see below). Although UK production has increased, its share of the global market peaked in 1999 at 0.4 per cent by volume and approximately 1 per cent by value. The World Bank predicts an increase in global aquaculture production of 3–4 per cent from 2010–2019, and then a growth rate of between 1–2 per cent from 2020–2029, whereas the UK will require an average growth rate of over 4 per cent if it is to meet the 2030 target laid out by Scottish industry (Fish to 2030) (Msangi et al. 2013).

The World Bank modelling (Msangi et al. 2013) predicts global production of salmon will be 3.6 Mt by 2030 – although this does not reflect Norwegian ambitions (production increasing to up to 3 Mt by 2030, see Case Study). On the basis of the World Bank model, UK is predicted to increase its share of the global farmed salmon market from 5.5 per cent (in 2008) to 9 per cent by 2030 (350kt). However, the reality is that Norway and Chile will likely expand faster than Scotland and the emergence of new producers such as Iceland could also erode the UK market’s share of salmon. In addition to this increase in market share, it is also predicted that

(a)



(b)

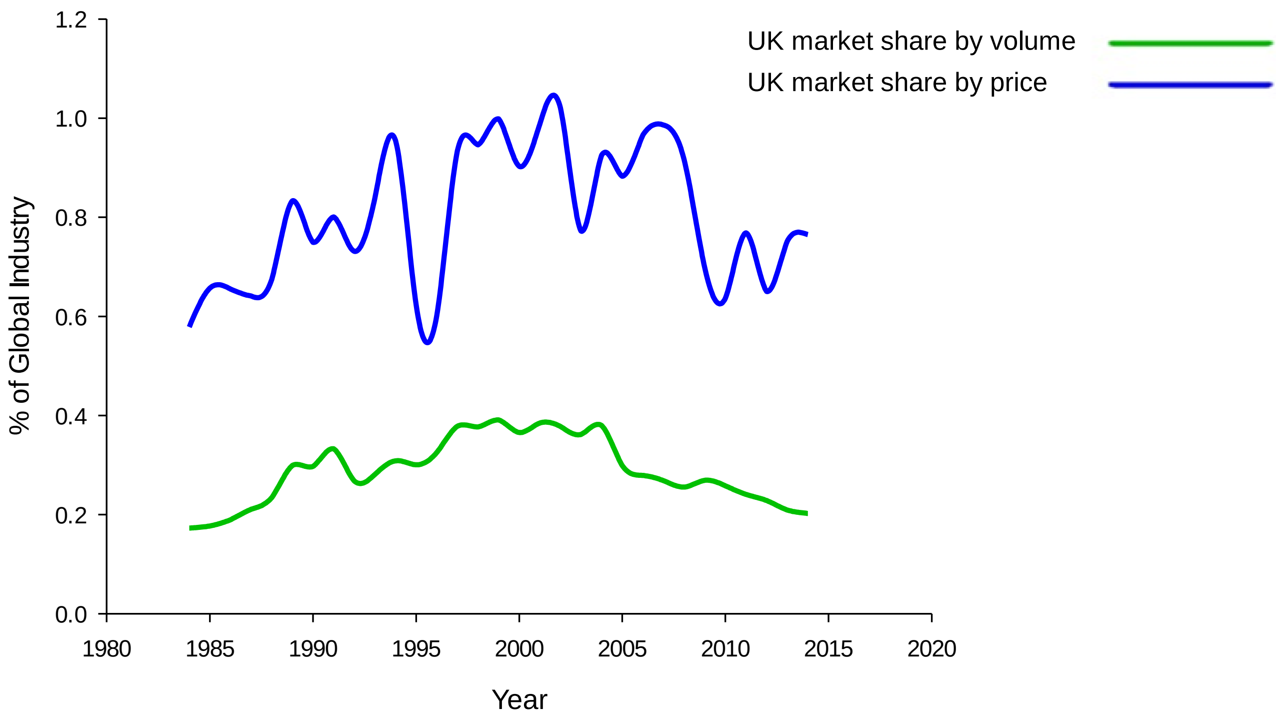


Figure 4. Current and articulated industry targets:

(a) UK production of aquaculture products; (b) global market share

Data source: FAO (2016)

the price will rise by 7.5 per cent in real terms between 2010 and 2030, with the main import markets for salmon being China (accounting for 55 per cent of the market), North America and Japan. This may have major implications for the price and availability of farmed salmon to the UK domestic market. If Chinese consumers shift towards high-value fish driven by demographic change, urbanisation and higher levels of income, the modelling predicts that the demand for salmon in China could double and account for 77 per cent of the world consumption (Msangi et al. 2013) (see Case Study).

To reach their 2030 targets, Scottish industry is preparing for modest expansion at existing nearshore sites and considerable expansion of production at existing and new exposed sites. This is supported by current political and regulatory proposals whereby the present arbitrary cap on farm size will be lifted under Scottish Environment Protection Agency proposals, which will be consulted on in 2017.

Looking beyond the 2030 targets for the main UK species requires consideration of future technologies to deliver increased production without compromising the environment. It is reasonable to assume that Atlantic salmon will continue to dominate UK production over the foreseeable future, especially if rapid progress can be made to deal with the lice issue. This is because salmon is a very easy fish to cultivate, with big eggs, robust physiology and excellent feed conversion – better even than chicken (Torrissen et al. 2011) – and few bones, which gives it wider consumer appeal than bonier fish species. Industry is already looking towards truly offshore production technologies (SeafoodSource 2016) that would massively increase the availability of space for expansion, although this is not expected in the next 10 years. In addition, for more inshore sites, floating closed-containment systems are already in development. These allow most wastes to be captured and processed and should make fish escapes and lice transmission completely controllable. They have many of the benefits of RAS systems but lower costs.

If these new technologies are successfully developed – and the industry in Norway is already investing in these (Undercurrent news 2016) – space will essentially be removed as a limiting factor, together with many of the negative environmental and societal impacts.

2. Projected Key Drivers

2.1 Economic Variability

Consumers are sensitive to the price of commodities when making purchasing decisions, but this varies between different commodities (Lockshin et al. 2006). Globally, the relative price differential between aquaculture and fishery products converged between 2006 and 2010. The FAO Fish Price Index for aquaculture products dipped below that for capture fisheries but it has since converged again (Tveterås et al. 2012). Compared to other commodities such as poultry, beef and pork, fish is relatively insensitive to price fluctuations (Lockshin et al. 2006), and in fact in the UK from 2006/07 to 2010/11, when there was a small reduction in the relative price of fish, there was also a reduction in consumption (Griffith et al., 2015). However, if we look at the relative price of two UK fish products, farmed salmon and UK landed cod, it can be seen that there are significant differences in their price trends. Looking at data going back to 1984, the price of farmed salmon has fluctuated greatly but there is no evidence for a long-term trend in an increase of price over this period (Figure 5). In contrast, wild caught cod has shown a strong positive price trend. Currently the export value of salmon per kilo is higher than the export value per kilo of cod (£4.62 vs £3.44 respectively in 2015 – Seafish 2015). In the absence of robust predictions, it is the authors' opinion that the reduction in price of aquaculture products relative to wild caught products will continue in the long term (with short-term price fluctuations) and will be a further driver for UK aquaculture development.

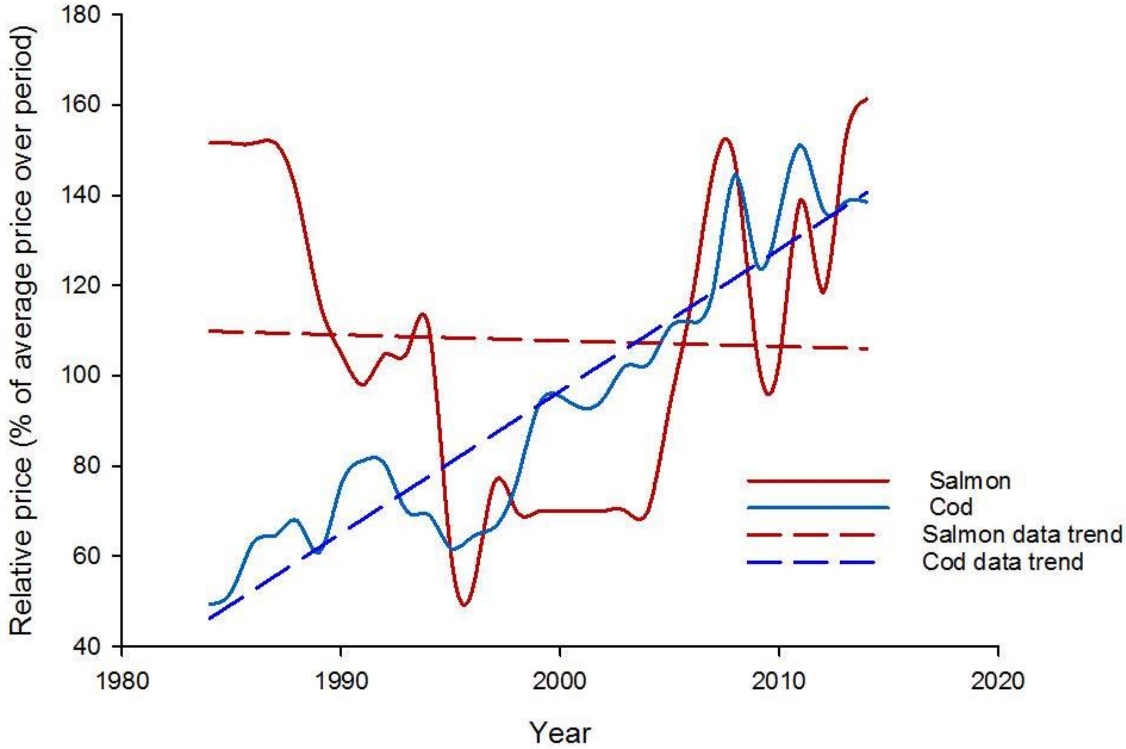


Figure 5. The relative price of wild cod and farmed salmon produced in the UK since 1984
The price for each species has been normalised against the average price during this period

Data source: FAO (2011–2017) and MMO (2017)

2.2 Funding and Stakeholder Acceptance

In some cases, there is significant opposition to development applications from non-local stakeholder groups that are committed to opposing aquaculture (Hambrey and Evans 2016) through the planning system. As a relatively new sector in the UK, aquaculture developments may be judged by different standards than sectors perceived as more traditional such as fisheries even though these sectors may in fact be highly industrial and have significant ecological-social impacts (Schlag and Ystgaard 2013). As well as regulatory barriers, financing of aquaculture development can be difficult for small business, particularly in the shellfish sector, owing to the long production cycle (2–3 years for mussels).

2.3 Climate Change

Climate change is likely to be a primary driver for change in the UK aquaculture industry over the next 50 years. These impacts will be multifaceted and have been extensively reviewed (Callaway et al. 2012). An outline of potential impacts are included below, and are summarised in Table 2.

Table 2. The potential effects of climate change on UK aquaculture sectors
Based on the Marine Climate Change Impacts Partnership report card on aquaculture (MCCIP 2012) and Callaway et al. (2012), with interpretation of impacts by the authors

Species	Temperature	Ocean Acidification	Extreme Weather	Disease and Harmful Algae Species
Finfish production at sea	Minor	Minor	Significant	Significant
Finfish on land	Moderate	Minor	Moderate	Significant
Finfish in recirculation	Minor	Minor	Minor	Minor
Mussels	Minor	Major	Significant	Significant
Oysters	Minor (positive)	Major	Significant	Significant

2.3.1 Sea Surface Temperature Increase

The predicted increase in sea surface temperature (SST) is not uniform around the UK. There is a much greater predicted increase in SST in the southern North Sea, the Channel and the Celtic Sea (Figure 6).

Salmonids (Atlantic salmon and trout) have a preferred temperature range of 5–19°C with the optimum being 13–17°C (Callaway et al. 2012). Based on predictions for the west coast of Scotland where the majority of the industry is based (and is likely to remain), the 2070 SST projections show that the average summer temperatures are likely to remain below or around this 17°C threshold. However, it is likely that peak surface temperatures in sheltered waters will go beyond these threshold values, which will be more important in terms of detrimental effects than the average values, meaning that some sites may have to be relocated to more dynamic water bodies. Even if the temperatures are within lethal limits, it is likely that food conversion ratios will be affected as temperature rise causes an increase in metabolic activity, but this may be balanced by shortened growth cycles. In mitigation, it is likely that selective breeding could allow for some adaptation of farmed stocks to this increase in temperature.

Temperature increases will also impact the existing shellfish aquaculture industry in the UK. There is modelling evidence to suggest that a 1°C increase in temperature could see a 50 per cent reduction in the productivity of mussel aquaculture, but the mechanism of this decline is not documented. However, although mussels are an intertidal organism, its aquaculture production is normally subtidal, so the predicted increases in temperatures are well within the lethal tolerance of this species. Warming SSTs are also likely to offer opportunities for the development of new species for UK aquaculture in the southern UK such as sea bass (*Dicentrarchus labrax*) (Callaway et al. 2012).

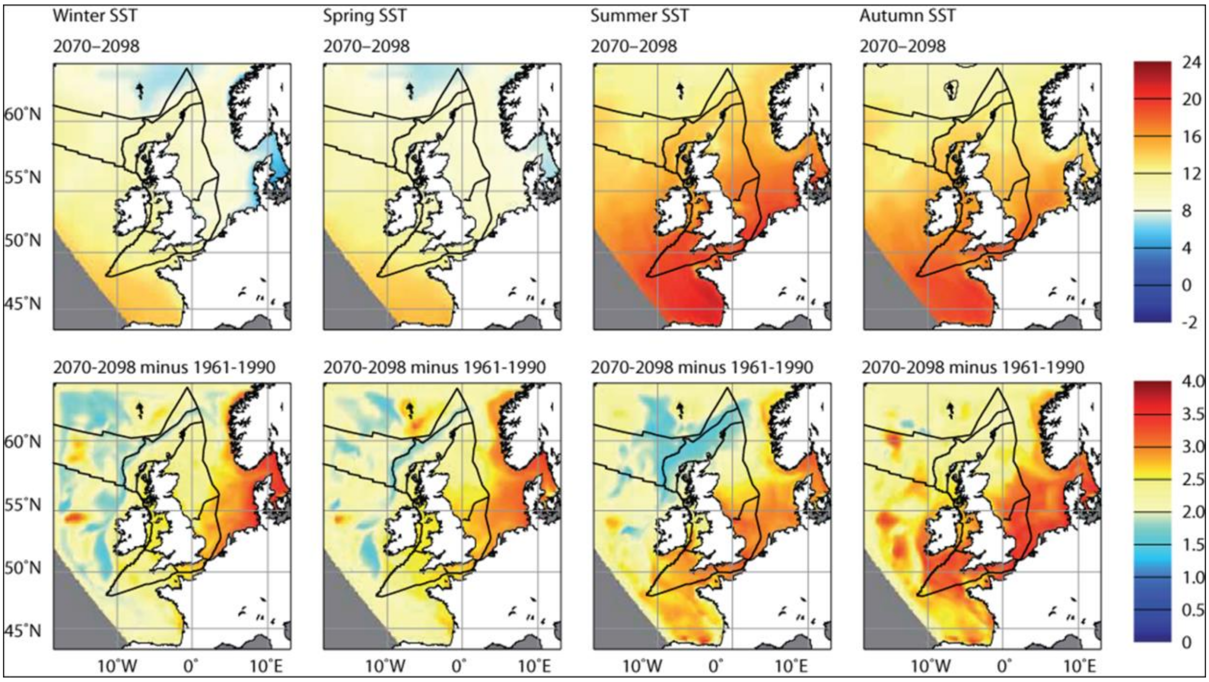


Figure 6. Seasonal mean sea surface temperature (SST) 2070–2098 relative to 1961–1990
Top row: Seasonal mean SST for 2070–2098 (°C)
Bottom row: Change in seasonal mean SST, relative to modelled 1961–1990 conditions; black lines depict 'Charting Progress' regional borders
From Dye et al. (2013), adapted from UKCP09, Lowe et al. (2009)

2.3.2 Ocean Acidification

There is a recognised lack of evidence regarding the impacts of ocean acidification on fish (Wittmann and Pörtner 2013) but it is thought that the larval stages would be most impacted. For aquaculture species these stages occur under close environmental control in hatcheries, so there would be limited impact. The effects on shellfish from ocean acidification are likely more pronounced as they form their shells from dissolved calcium carbonate. Both the larval stages and the adults are affected by ocean acidification. In mussels, the impacts of acidification on the larvae can be extreme, with a significant reduction in the number of larvae surviving to settlement (Gazeau et al. 2010). The influences on adult shellfish are less pronounced as the mussels are better able to up-regulate calcification genes and dedicate more energy towards calcification (Lannig et al. 2010). However, this redirection of energy may further reduce reproductive output and growth. These impacts on commercial mussel production can be reduced through the production of mussel juveniles in a hatchery as opposed to relying on natural spat.

2.3.3 Extreme Weather

Two patterns of extreme weather are likely to impact on UK aquaculture. The occurrence of extreme precipitation events in UK winter, spring and autumn are set to increase by up to 30 per cent (Fowler and Ekstrom, 2009). Extreme precipitation events and their associated flooding are associated with significant nutrient pulses to the nearshore environment. These pulses of nutrients can trigger microalgal blooms (Hallegraeff, 2010) and are often associated with increase in sediment loading from terrestrial run off. These events may have negative impacts through reduced water oxygen content or increases of harmful algal species, but may also have benefits for shellfish species from increasing food availability for filter feeding species. The second major impact from increased extreme weather events is from storms, which are predicted to increase in frequency in the UK (Slingo et al. 2014). Most of UK aquaculture production is vulnerable to storm events. Structural damage to farm infrastructure is the main risk and may cause fish escapes or mortality. The value of lost stock in Scotland has been estimated as about £1.5 million for 2009 (Jackson et al. 2015).

2.3.4 Disease and Harmful Algae Species

Because of the interaction of multiple environmental drivers, it is difficult to predict the impacts of climate change on the occurrence of disease and harmful algae blooms (HABs) in relation to aquaculture production. Disease is a major risk for the current industry and is likely to remain so in the future. In the case of HABs, predictions are again difficult, but an increase in SST may promote the establishment of new harmful algal species in UK waters and alter algal toxicity (Bresnan et al., 2013).

2.4 The Cost of Energy

Although impossible to predict over the timescales considered within this report, the relative cost of energy will have a very large impact on how aquaculture develops. In broad terms it can be supposed that if relative energy prices reduce then those aquaculture production systems which are energy intensive will become more economically viable and vice versa.

Most of the energy costs of aquaculture are embedded in the feed (raw ingredients production/capture, processing, shipping, distribution) and so those aquaculture products which require no feed, such as shellfish, would be expected to be advantaged (although if a hatchery phase is involved then this effect will be lessened due to the energy costs involved). RAS are highly energy dependent. For fish species that rely on feed like salmon, recirculation aquaculture will become more economically competitive in a cheaper energy world. Due to its environmental advantages, if energy becomes sufficiently cheap then it is expected that RAS will rapidly increase (Table 3).

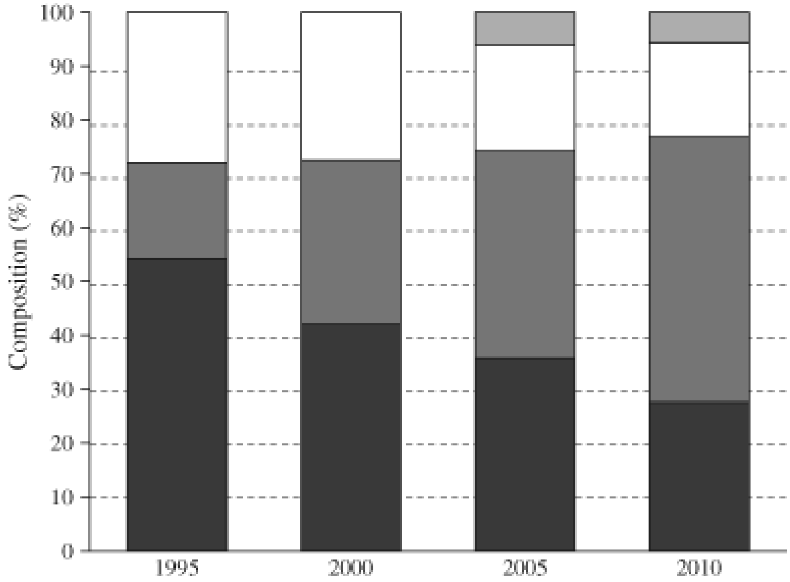
Table 3. The energy expenditure associated with different aquaculture production systems and the likely impact of changes in the energy price (authors' interpretation)

Aquaculture production system	Energy consumption (MJ) cost per kg of live weight product	Expected production in a cheap energy world	Expected production in an expensive energy world
Shellfish	3–4 (Winther et al. 2009)	No difference	Increase
Sea cage finfish	28–48 (Winther et al. 2009; Pelletier et al. 2009)	No difference	Increase
On land finfish flow-through	78–98 (Aubin et al. 2009; Ayer and Tyedmers, 2009)	Increase	Reduce
Recirculating finfish	291–353 (Ayer and Tyedmers, 2009)	Increase	Reduce

2.5 The Cost and Availability of Raw Material

Aquaculture feeds typically represent 50–60 per cent of the operating costs of a finfish production business. These feeds are formulated to promote rapid growth and fish health and welfare. They have traditionally been a mix of marine proteins (fish meal) marine oils (fish oil) and a carbohydrate (such as wheat starch). The marine ingredients are expensive and finite (in terms of the wild stock of forage fish from which they are in the main obtained), and to date there has been a pronounced substitution of these ingredients with terrestrial proteins and oils to try to eke out the available marine supplies (Figure 7). Fishmeal is expected to double in price by 2030, while fish oil is likely to increase by over 70 per cent in real terms (Msangi et al. 2013) so reducing the amount of these ingredients in fish feed will continue to be of prime industry interest.

Current technology permits the entire replacement of marine ingredients in salmon food, but this leads to reduced growth and raises issues of consumer acceptance and public health. The quantity of beneficial omega-3 polyunsaturated fatty acids in farmed salmon fillets has halved from 2006 to 2013 (Sprague et al., 2016). However, there are already several alternate sources of lipids and proteins that have the potential to mature into economically viable replacements of fish meal and oil. New protein sources include field bean and insect meals. The replacement of fish oils may be more contentious. Genetically modified (GM) seed oils have already been produced that have a high contents of long-chain omega-3 fatty acids similar to fish oils. Early trials in Atlantic salmon have been successful and these seed oils may become a good alternative to fish oils, depending on the public acceptance of GM technology (Betancor et al., 2015).



■ fishmeal; ■ alternative proteins and starch; □ fish oil; ■ vegetable oil

Figure 7. The changes in composition of Norwegian *Salmo salar* feed over the period 1995–2010 Source: N. Alsted, personal communication (2010)

2.6 Social Acceptance of Aquaculture and Associated Technological Developments

Social acceptance of aquaculture and the adoption of new technologies into the food production sector will have a major impact on how aquaculture develops in the UK. At present, a large proportion of the UK population were born before the extensive development of aquaculture in the UK, but by 2060 most of the population will have grown up with aquaculture. There has been a shift in both public perceptions and media coverage of aquaculture with time and demographic change (Verbeke et al. 2007; Fernández-Polanco and Luna 2012), and an increasing social acceptance of aquaculture may be expected. There is also evidence to suggest that consumer acceptance of GM is increasing within Europe and the UK (Lucht 2015) and attitudes within the timeframe considered within this report could have dramatically shifted towards a more general acceptance of this technology. Public perceptions to GM and fish grown on terrestrial ingredients will be key to the direction of development within the UK aquaculture industry. It is likely in the relatively short term (10–15 years) that the supply of marine proteins and oils will continue to be a major constraint on the global industry. However, global consumer acceptance of GM terrestrial alternatives could significantly ease supply of marine ingredients to the UK. There is an interesting scenario where the UK aquaculture industry chooses to position itself within the premium product market sector (where it is currently positioned), and eschews the increased use of terrestrial and GM ingredients for their feed. In this case the use of these technologies by other producers reducing market demand for marine ingredients combined with the market premium obtained may be sufficient to support a small, high-price UK industry based on a higher percentage of marine ingredients than the average for the international market.

2.7 Changes in Other Food Production Segments

2.7.1 Fisheries

It is predicted that capture fisheries will stagnate over the next 10 years, although projections to 2050 suggest through effective fisheries management and technological adaptation they could ensure the global supply (including forage species for fishmeal/oil production). However, ineffective management and rising fishmeal prices are a significant threat. In addition, the South American fisheries, which are a major source of fishmeal (43 per cent of global production, Msangi et al. 2013), are subjected to periodic collapses due to climate events and may be highly susceptible to impacts from climate change (Fréon et al. 2014). Aquaculture is reducing its dependence on marine ingredients (see previous section) and the increase use of European-sourced fish meal and oil, both from direct fisheries and from fishery by-products and discards will reduce the UK dependence on the South American fisheries over time. Given this background it would be expected that aquaculture will continue to increase its proportion of total seafood production. Though fluctuations in the price of fish meal and fish oil from wild fisheries will continue to impact on aquaculture, the increasing decoupling of capture fisheries and aquaculture will reduce this impact over time.

2.7.2 Oil Seed Crops

Oil seed crops deliver both vegetable oils and protein meals and will become important components of aqua feed in the future. It is predicted that supply of these will keep pace with demand and as such little change in their interaction with aquaculture is foreseen (Shepherd et al. 2017).

2.8 Geopolitical Situation

Seafood is a globally traded product and relies on globally sourced raw materials and services. This situation is unlikely to change and so UK aquaculture production will continue to be vulnerable to geopolitical upheaval. These are intrinsically unpredictable, but there is clear evidence that China will continue to increase its demand for seafood due to population increase and economic development. Under this scenario, China will both increase its seafood exports and imports. Salmon produced in the UK is currently seen as a premium product on the international market and export demand is likely to increase. Farmed salmon is also one of the main fish consumed in the UK. Depending on the size and strength of the export market it is foreseeable that there may be competition between domestic and export markets, with the possibility of reduced availability/increased prices for UK consumers.

3. Scenarios for the Future Development of Aquaculture in the UK

It is assumed that the world will become more populous (United Nations 2017) and wealthier (Shorrocks et al. 2016), and that there will be increased pressure on natural resources to provide appetising food of high quality. However, it appears that fish consumption is sensitive to economic conditions, as the post-2007 financial crisis has resulted in a trend of reducing per capita UK consumption (Figure 8; Seafish, 2014). The DEFRA food report (2014) attributed the drop in consumption of fish (and other expensive food items) to high prices, and thus it can be assumed that increasing global affluence is a prerequisite to increased consumption of relatively expensive aquaculture products.

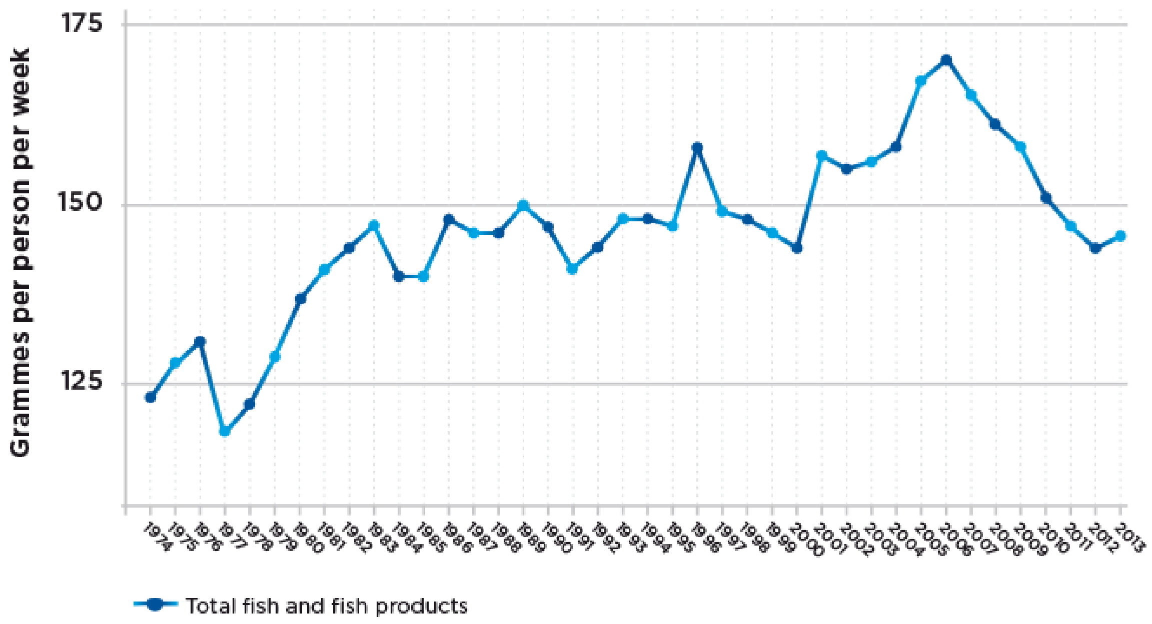


Figure 8. The decreasing trend in UK fish consumption since the 2007 financial crisis
Source: Seafish (2014) using data from DEFRA food report (2013)

When forecasting how the UK aquaculture industry will develop, it is crucial to understand which of the drivers previously described are likely to have the largest impact, and also which are likely to undergo the largest shift from the current position. In predicting these it is necessary to use a degree of judgement, supported by the available evidence. In the absence of robust predictions, it is the authors' opinion that the most important drivers for aquaculture development in the UK over the next 50 years will be two, as follows.

3.1 Social Acceptance

Public perceptions of aquaculture, including consumer preferences, stakeholder attitudes and political support, are expected to co-vary to some extent over the timescales of interest. There are presently different levels of regulatory support for the aquaculture industry among the UK administrations. The English regulatory framework has been described as appearing "fragmented, overlapping, inconsistent and complex. For some businesses this may act as a barrier both to effective compliance with their environmental obligations and to growth" (DEFRA

2015). A move to a more Scottish level of political support is envisaged. Within this category, increased social acceptance is to also be associated with an increase in acceptance of GM organisms.

3.2 Energy Costs

These have been shown to be highly variable over the last 50 years and there is evidence to suggest that this variability is increasing (Kilian 2008). As the energy price will impact every aspect of the value chain it is likely to have a large impact on the development of aquaculture. As such, when considering scenarios with a higher relative energy cost, it will be reflected in higher feed, transportation, infrastructure and fabrication costs.

Four scenarios have been developed against binary changes in these two key drivers (either increasing or decreasing), and mapped on to seven metrics or descriptors of the aquaculture industry (see Table 4). These scenarios represent end points that can be used to illustrate the more probable space between these extremes. The general response of the metric is given in the table/infographic (Table 5), with a narrative description to accompany each scenario.

Table 4. Explanation of the metrics or descriptors used for the presented scenarios

Metric or descriptor	Explanation
Cost	The farm gate price
Volume	The total UK production volume
Onshore	The production volume from land-based aquaculture such as freshwater flow-through systems or recirculation systems
Nearshore	The production volume <2 km from shore (the present marine industry)
Offshore	The production volume from systems >2 km from shore
Diversity of species	The total number of species that are cultured
Trophic level	The average trophic level of species produced through aquaculture (e.g. seaweed =1, mussels =2, salmon =3)

Table 5. Response of the descriptors to variation in the key drivers for the UK aquaculture sector

		Social Acceptance	
		Lower Social Acceptance	**Greater Social Acceptance**
Energy Costs	**Reduced**	**Scenario 1** Cost: Lower Volume: Moderate increase Onshore: Increased Nearshore: Static Offshore: Increased Diversity of species: Increased Trophic Level of species: Unchanged	**Scenario2** Cost: Lowest Volume: Greatest Onshore: Increased Nearshore: Increased Offshore: Increased Diversity of species: Increased Trophic Level of species: Unchanged
	Increased	**Scenario 3** Cost: Highest Volume: Lowest Onshore: Reduced Nearshore: Static or reduced Offshore: Increased Diversity of species: Increased Trophic Level of species: Lower	**Scenario 4** Cost: High Volume: Increased Onshore: Static Nearshore: Increased Offshore: Static Diversity of species: Increased Trophic Level of species: Lower

3.2.1 Scenario 1

A future where there is low social acceptance of aquaculture in the UK and the global energy price is lower in real terms.

Due to lower energy prices and difficulties in obtaining new marine consents, there would be an increase in land-based recirculation systems that are energy intensive in terms of pumping and heating water. This expansion would be UK-wide, in England building on the trout industry already present. Expansion in RAS combined with cheaper energy costs would lead to a proliferation of species cultured. These species would develop high-value niche markets, probably based on warm-water exotic species such as shrimp. This development would be further facilitated if development can be tied to sources of waste heat. Expansion of the current nearshore salmon industry will be limited, but it is envisaged that the combination of reduced transportation, fabrication and feed costs and high public pressure is likely to move aquaculture further offshore.

3.2.2 Scenario 2

A future where there is greater social acceptance of aquaculture in the UK and the global energy price is lower in real terms.

This scenario represents the most favourable scenario for the development of the UK aquaculture industry. Under these circumstances UK production could keep pace with global growth and retain its current market share. There would be an increase in aquaculture in all sectors across the UK. This could include the development of a nearshore finfish industry across England, Wales and Northern Ireland. In addition there would be the development of onshore aquaculture, probably for niche-market high-value warm-water species. This scenario would also allow the rapid expansion of offshore salmon culture.

3.2.3 Scenario 3

A future where there is lower social acceptance of aquaculture in the UK and the global energy price is higher in real terms.

In this scenario, there will be the least growth of the UK aquaculture industry. Most of the production would remain in Scotland and be limited to the existing nearshore infrastructure. There could however, be an increase in shellfish production fostered both by better consumer acceptance of this low impact aquaculture, and the lower embedded energy in the products. Although public perceptions may act as a driver to move aquaculture offshore, the added cost would make this an unattractive option to the industry. It is also unlikely there would be any substantive growth of onshore aquaculture.

3.2.4 Scenario 4

A future where there is greater social acceptance of aquaculture in the UK and the global energy price is higher in real terms.

There would be significant growth across the UK aquaculture industry under this scenario, most pronounced within the nearshore industry, possibly with the development of sites across the whole of the UK. These new developments would include a significant proportion of shellfish due to its economic advantage under high energy prices. It is also likely that there could be significant adoption of GM for feed ingredients and (possibly GMO fish) to increase production efficiency.

Case Study

Norway (population 5.3 M) is an intensely maritime nation – much more so than the UK, and its rugged coastline provides enormous capacity for aquaculture. It is the biggest salmon producer in the world (1.26 Mt, + ~ 70 kt of rainbow trout in 2014; FAO 2016). A Norwegian expert working group (Olafsen et al. 2012) estimated that salmonid (salmon plus rainbow trout) production may grow to 3 Mt in 2030 and 5 Mt in 2050 i.e. a growth of about 5.5 per cent to 2013 and then 3 per cent to 2050. If the UK had similar growth for its salmon sector, then it would yield about 390 kt in 2030 and 700 kt in 2050, (cf. 171 kt in 2015 for UK salmon – Marine Scotland Science 2016), i.e. greater than present targets. The Norwegian aquaculture industry has for many years benefited from strong, strategic government support for what it regards as a key sector (along with oil and gas, fisheries and the maritime sectors). “The Norwegian Minister for Fisheries and Coastal Affairs has made it clear that it is Norway’s aim to become the world’s leading seafood producer” (Olafsen et al. 2012): it is presently the world’s second-largest seafood exporter. Norway hosts the most advanced aquaculture research and development facilities in the world and many of the largest aquaculture companies have strong Norwegian interests. In contrast to Norway, the UK has a less sheltered coastline and a complex regulatory system. Consequently planning is a much longer process with lower certainty of outcome (EC 2013). When offshore methods of aquaculture are developed, the geographical differences both between Scotland and the rest of the UK and between the UK and Norway may diminish in importance.

China (population 1.4 B) is perhaps the home of aquaculture, with records dating back to 400 BC. It is by far the world’s largest aquaculture producer with 26 Mt of freshwater fish production, 1.2 Mt of marine fish (i.e. slightly less than Norway), 13.4 Mt of molluscs and 4 Mt of crustaceans (45.5 Mt, 62 per cent of global production in 2014 (FAO 2016), not including seaweeds – an additional 13.3 Mt). China is the world’s largest seafood exporter but is also a major importer – for example, the UK exports farmed salmon to China (£54 million in 2015; SSPO, 2014), which is seen as an important growing market. China has a highly diverse aquaculture production with 27 major taxa of freshwater fish and 13 major taxa of marine fish listed in the FAO FishstatJ database in 2014, and 92 species listed (including invertebrates), and an average growth for total production of 5.5 per cent from 2000 to 2014. A recent review has predicted that China will continue to dominate freshwater aquaculture production and in future will have a greater focus on environmental quality through, for example, increasing the quality of feeds (Wang et al. 2015). Hitherto, the rapid expansion of China's industry has not followed the environmental and societal norms present, for example, in the UK, and has relied on a somewhat empirical approach to management. Due to its key global role in both production and consumption of aquaculture products, China's policy and economic future will have a significant impact on the global industry. The UK is unlikely to be able to develop aquaculture to a scale approaching that within China as the fundamental change to landscapes and seascapes would be completely unacceptable to UK society in general and to a range of existing stakeholders, e.g. fisheries, in particular.

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