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1 Future availability of raw materials for salmon feeds and supply chain
2 implications: the case of Scottish farmed salmon

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4 C. Jonathan Shepherd^a, Oscar Monroig^{b*}, Douglas R. Tocher^b

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6 ^a Bluetail Consulting Ltd., Richmond, Surrey TW9 3NL, UK

7 ^b Institute of Aquaculture, School of Natural Sciences, University of Stirling, Stirling FK9 4LA, UK

8
9 * Corresponding author: oscar.monroig@stir.ac.uk

10

11 **Abstract**

12 The current range of Scottish salmon feeds is adapted to a differentiated supply of salmon products,
13 including differing omega-3 content, differing content of marine raw materials, etc. The progressive
14 replacement of marine feed ingredients by plant proteins and oils is reducing the content of omega-3
15 long-chain polyunsaturated fatty acids (LC-PUFA). However the benefits are a more secure and less
16 volatile raw material supply, together with environmental feed contaminants at low or undetectable
17 levels in the resulting salmon product. There is widespread adoption of standards and certification
18 schemes by Scottish salmon farmers and feed suppliers in order to demonstrate environmental
19 sustainability. This has focused in particular on use of certified ingredients from sustainable supply
20 sources ('responsible sourcing'). Future volume estimates of Scottish salmon production, hence feed
21 requirements, are insufficient to threaten raw material supply compared with global markets,
22 although it is argued this is likely to involve greater use of locally grown plant proteins and an
23 increased proportion of fishmeal manufactured from by-product trimmings (derived from processing
24 fish for human consumption). However, UK retail chains will remain reluctant to allow salmon
25 suppliers to utilise land animal by-products due to negative consumer perceptions, with resulting
26 implications for formulation cost and flexibility. Given its world-wide scarcity, the main strategic
27 concern relates to future availability of sufficient omega-3 LC-PUFA, in particular eicosapentaenoic
28 acid (EPA) and docosahexaenoic acid (DHA), in order to maintain the healthy image of Scottish
29 salmon. To maintain its longer-term reputation and product benefits, the Scottish industry may need
30 to consider adopting a more flexible attitude to using new alternatives to fish oil (e.g. EPA and DHA
31 derived from transgenic oil seed crops, when commercially available). It is concluded that Scottish
32 salmon farming is a successful example of sustainable feed development and the industry can be
33 confident that the changing raw material base will support continuing production of high quality,
34 healthy farmed salmon, but the long-term security of supply of omega-3 LC-PUFA remains an issue.

35

36

37 Keywords: Atlantic salmon; sustainable feeds; fishmeal; fish oil; alternative proteins; alternative oils;
38 omega-3; EPA; DHA; supply chains

39 **1. Introduction to Scottish salmon feeds**

40

41 *1.1 Study aims and methodology*

42 Farmed Scottish salmon has a distinct market position, which has implications for feed
43 requirements. The purpose of this study was to consider trends in the change in composition of
44 Scottish salmon feeds with regard to the availability and use of key feed ingredients, and to consider
45 the resulting implications for farmed salmon supply chains. In particular the study aim was to identify
46 the nutritional, ethical, marketing, and sustainability issues surrounding reduced reliance of the
47 salmon farming industry on marine ingredients. In order to achieve this, over the period from April
48 2014 to March 2015, meetings and telephone interviews were conducted with industry experts and
49 stakeholders in the UK, Norway, Denmark, France, Ireland, and the USA.

50

51 *1.2 Global farmed salmon industry and the differentiated supply of Scottish salmon and feeds*

52 Salmon farming is the most highly developed form of large-scale intensive aquaculture owing to its
53 productivity growth and technological change since the industry started in the 1970's in Norway and
54 Scotland; it represents a highly efficient mechanism for transforming marine resources into high
55 quality food that is available on a year round basis (Hognes et al., 2011; Ytrestøyl et al., 2011).
56 Estimated global production of farmed Atlantic salmon in 2013 was approx. 1.8 million tonnes and is
57 dominated by Norway with 1.1 million tonnes (Kontali, 2013). The much smaller Scottish industry
58 (163,234 tonnes in 2013, Table 1) closely parallels Norway in terms of farming technology and is now
59 mainly in Norwegian ownership. The compound annual growth rate (CAGR) for farmed Atlantic
60 salmon was 6 % on a global basis from 2003 – 2013, but is now decreasing (Marine Harvest, 2014). In
61 both Scotland and Norway the growth in salmon farming has resulted in year-round availability of
62 cost-efficient, affordable salmon products on a greatly increased scale, while creating wealth and
63 sustainable employment, including to remote rural locations; the industry therefore demonstrates
64 clear economic and social benefits (Asche and Bjørndal, 2011).

65 Table 1 compares Scottish with Norwegian farmed salmon production, feed supply, and feed
66 conversion rate (FCR) for 2013 and 2014. At c. 13% of combined Scottish and Norwegian production
67 volume in 2014, it is clear that Scottish production is relatively small. Also the Scottish Government's
68 target for sustainable growth of marine finfish is 210,000 tonnes by 2020. It should be noted that
69 2014 Scottish salmon production was boosted by premature 4th quarter harvesting for health reasons;
70 as a consequence an FCR of 1.23 appears unrealistically low and industry sources indicate it was close
71 to the 2013 value at c. 1.3. Feed costs dominate production costs for farmed salmon with the 2013
72 cost of salmon feed in Norway and Scotland for Marine Harvest (the largest global salmon producer)

73 estimated at 50 % and 46 % respectively of production costs; the corresponding figures of 41 % and
74 43 % respectively for Canada and Chile are mainly due to lower feed costs linked to use of land animal
75 by-products (Marine Harvest, 2014).

76 Despite being relatively small in volume compared with Norway and Chile, the Scottish salmon
77 industry holds a distinctive position in world markets. Whereas the Norwegian salmon farming
78 industry is the leading world producer and exporter of farmed salmon as a standardised commodity
79 product, including to the UK market, the Scottish industry, lacking comparable economies of scale,
80 supplies more differentiated products at higher unit value to offset potentially higher production
81 costs. These range from standard to high performance products¹, including bespoke supply for niche
82 markets in the UK and overseas (mainly to the USA and France). Scottish production therefore relies
83 on a variety of different feed products, including specialist formulations to support a premium salmon
84 segment, i.e. higher price salmon products with quality characteristics, including label claims on
85 Scottish provenance, the content of omega-3 LC-PUFA in regard to EU intake recommendations, and
86 others (e.g. compliance with responsible farming standards).

87

88 **2. Changing salmon feed composition**

89 *2.1 Historical picture and trends*

90 Historically the two most important ingredients in salmon feed have been fishmeal and fish oil, having
91 favourable nutrient compositions and reflecting a major food item for a carnivorous species like
92 salmon (NRC, 2011). Apart from a need for low levels of essential fatty acids for salmon growth,
93 supplied via small quantities of (the oil present in) fishmeal or via fish oil, fishmeal itself is not an
94 essential feed ingredient for aquaculture *per se*, but it provides a near optimal complete feed in a
95 convenient, cost-effective, and highly digestible product form (Tacon and Metian, 2008). However,
96 the pattern of stagnating wild fisheries and the fast growth of aquaculture risked over-dependence on
97 a limited range of feed ingredients, especially fishmeal and fish oil, while the issues involved in
98 replacement by alternative proteins and oils were soon recognised (Sargent and Tacon, 1999; Naylor
99 et al., 2000). For reasons of cost reduction and security of supply, cheaper alternative ingredients (e.g.
100 soyabean meal; rapeseed oil) have therefore been researched and progressively substituted in
101 commercial feed formulations, where technically and economically feasible, and after further

¹ 'high performance diets' are defined as diets with high nutrient density, typically containing relatively high levels of energy and digestible protein

102 processing as required (NRC, 2011). At the same time increasingly higher inclusion of oil has been
103 made possible by extruded feed technology and driven by the protein sparing effect of oil promoting
104 growth (NRC, 2011).

105

106 *2.2 Salmon feed composition in Scotland and Norway*

107 Information about salmon feed formulation is more widely available in Norway than Scotland due
108 to reporting requirements and policy issues. However, until recently the same three fish feed
109 companies dominated feed manufacture in both countries (i.e. BioMar, Ewos and Skretting, although
110 Marine Harvest has now also entered feed manufacture in Norway). Therefore, the two salmon
111 farming industries are similar with some key differences in response to UK market focus, e.g. on
112 omega-3. Thus feed formulation trends are broadly comparable between the two countries, with
113 Scottish salmon feeds being more conservative in terms of rate of change and more varied in
114 reflecting bespoke customer requirements. Fig. 1 shows the large changes in composition of
115 Norwegian salmon feed since 1990 when c. 90 % of the diet came from marine ingredients compared
116 with 29.2 % in 2013 (Ytrestøyl et al., 2014, 2015).

117 The feed comparison between Scotland and Norway is complicated by the proliferation of bespoke
118 diets in Scotland, some of which are driven by external standards (e.g. Organic, Label Rouge etc.), but
119 mostly by farm customer requirements linked in turn to retail requirements. Although the
120 consultation revealed average Scottish salmon diets for 2013/14 comprised approximately 60 % plant
121 and 40 % marine ingredients, this obscures the large range of different Scottish formulations; for
122 instance in 2014 c. 7,000 tonnes (4 %) of salmon production was made for export to the Label Rouge
123 salmon specification with a marine feed content of 51 %, whereas there is also significant salmon
124 volume being produced approximating to lower Norwegian diet specifications. At the same time there
125 has been a move in Scotland during 2013/2014 towards use of high performance diets of variable
126 specification, but generally higher use of fishmeal. The consultation also revealed that nearly all
127 Scottish feeds are being currently formulated to give not less than 22 MJ/kg in order to achieve faster
128 growth and improved feed conversion. Typically this entails diets with 37 % lipid and 36 % protein
129 (with 11% carbohydrate/fibre, 9% ash and 7% moisture), with high salmon prices allowing farmers to
130 invest in higher specification diets at higher cost in order to yield higher marginal productivity. As a
131 consequence the overall average marine protein and oil content of Scottish salmon diets is probably
132 around 25 % and 15 %, respectively, (c.f. around 20 % and 10 %, respectively in Norway), and with

133 higher average eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3)
134 required for Scottish farmed salmon. In Scotland (and Norway) there is no use of land animal by-
135 products, which account for over 20 % dietary inclusion in Chile and Canada, or of genetically
136 modified (GM) ingredients (e.g. Chile and Canada use GM soya).

137 The following ingredients are commonly used in Scottish salmon feeds: soy protein concentrate (SPC);
138 rapeseed oil; fishmeal; wheat starch; fish oil; wheat gluten; sunflower meal; faba beans; pea starch;
139 maize; pea protein concentrate; and other ingredients have been used in minor proportions, e.g.
140 rapeseed protein concentrate, palm oil, tapioca starch etc., with usage based on least cost
141 formulation in order to optimise recipe cost. The volatility of ingredient costs is illustrated by the
142 pattern of changing ingredient prices for five key raw materials in salmon feed during the period from
143 2006 to 2013, with a rising trend for fishmeal, fish oil, and soya, compared with more stable prices for
144 rapeseed oil and wheat (Fig. 2).

145 146 *2.3 Effect of reduced marine ingredient inclusion on feed sustainability*

147 The replacement of finite marine feed resources by plant-based ingredients (and fishery by-
148 products), is enabling salmon farming to achieve net fish protein production and possibly net marine
149 oil production (Crampton et al., 2010; Bendiksen et al., 2011; Sanden et al., 2011). This continuing
150 trend towards substitution of marine ingredients, together with increasing evidence that reduction
151 fisheries are not being overexploited, contradicts the traditional view that salmon farming relies on
152 the unsustainable use of marine ingredients (Shepherd and Little, 2014). For global 'fed' aquaculture,
153 there is an overall plateau in fishmeal and fish oil use despite increasing aquaculture production (Fig.
154 3), which has not been restricted by, at best, a static supply of marine ingredients since 2009. Rising
155 demand for fish feed ingredients has not therefore increased pressure on wild fish resources because
156 of increased use of plant resources. At the same time there is no evidence that plant resources are
157 inherently more sustainable for farming salmon, provided marine feed ingredients are sourced from
158 sustainably managed stocks (or from fishery by-products); hence an increased utilisation of plant
159 ingredients may not be as sustainable as generally assumed (Torrissen et al., 2011). However, all
160 marine ingredients supplied to the Scottish salmon feed industry are required by the supply chains to
161 show that they are responsibly managed and renewable (see section 6).

162 163 *2.4 Effect of reduced marine ingredient inclusion on salmon nutrition and welfare*

164 If the available EPA and DHA for global salmon feed falls below 4 % of the total dietary oil fraction
165 (equivalent to c. 1.2 % of total feed), this then approaches the 1 % risk area for essential fatty acid
166 deficiency in salmon and could predispose to health problems or reduced performance (Ruyter et al.,
167 2000a,b). This risk is likely to be exacerbated by the increased use of higher performance diets and
168 resulting higher growth rates (NRC, 2011). The implications of falling omega-3 LC-PUFA levels for
169 salmon consumers are considered in section 4. In the case of increased plant protein usage, it is well
170 recognised that the risks relate to the need to supplement with certain amino acids (e.g. lysine and
171 methionine), whereas the presence of anti-nutritional compounds requires prior processing of the
172 raw materials (e.g. by concentration or heat treatment) (Gatlin III et al., 2007). As regards
173 micronutrients, increased plant protein levels may lead to suboptimal levels of certain minerals (e.g.
174 selenium, iodine) and vitamins (e.g. vitamins A, D, and some B vitamins) (NRC, 2011).

175 176 *2.5 Effect of reduced marine ingredient inclusion on contaminant levels*

177 The Norwegian Scientific Committee for Food Safety concluded that the benefits of eating fish
178 clearly outweigh the negligible risk presented by current levels of contaminants and other known
179 undesirable substances (VKM, 2014). As regards farmed salmon, concentrations of dioxins and dioxin-
180 like polychlorinated biphenyls (PCBs), as well as of mercury, have decreased by about 30 % and 50 %,
181 respectively, compared with the corresponding levels in 2006, due to replacement of marine feed
182 ingredients by plant ingredients. New fish feed contaminants, such as the pesticide endosulfan,
183 polyaromatic hydrocarbons (PAHs), and mycotoxins are unlikely to be a safety issue, since the
184 concentrations are very low and not detectable with sensitive analytical methods (VKM, 2014). The
185 health risk associated with brominated flame-retardants (PBDEs) is low. In contrast to their earlier
186 conclusions, VKM stated that there is now no reason for specific dietary limitations on fatty fish
187 consumption for pregnant women. It is likely that the contaminants picture in Scottish salmon feed
188 closely parallels the Norwegian experience, with the main differences due to local UK sourcing of
189 fishery by-products, the slower rate of replacement of marine ingredients in Scottish diets, and the
190 greater use of bespoke salmon diets in Scotland with higher marine content. The switch from marine
191 to predominately plant-based diets will not mean a greater risk of pesticide contamination of the
192 feed, since any such contamination is unlikely to penetrate through the hull, which is normally
193 discarded from oil seeds during processing.

194

195 **3. Global supply and local demand for proteins and oils**

196 *3.1 Marine ingredients*

197 Fishmeal and fish oil are globally traded commodities similar to other raw materials or primary
198 agricultural products that have long been produced and marketed; aquaculture grew to become the
199 biggest customer for these marine resources (Jackson and Shepherd, 2012). Figs. 4 and 5 detail annual
200 world fishmeal and fish oil production, respectively, by producing region from 2006 to 2015, with Peru
201 the dominant world supplier followed by Chile. There may be a decreasing trend for marine
202 ingredient production (e.g. fishmeal production in 2012 and 2013 was around 12 % less than the 11
203 year mean at 4.56 and 4.68 million tonnes, respectively (IFFO, 2014)). Production is subject to
204 environmental influences and, whereas the potential impact of climate change is not well understood
205 (Callaway et al., 2012), acute phenomena, such as El Niño, have well-known consequences, especially
206 for the Peruvian anchovy fishery (Shepherd and Jackson, 2013). Given these supply uncertainties in
207 the dominant southern Pacific anchovy fishery, compounded by increased regulatory focus on
208 precautionary catch quotas, continuing growth by major users of marine ingredients (including
209 salmon farming) has only been possible by the increased substitution in feeds by other ingredients.

210 Based on a 2014 Scottish salmon feed volume of c. 220,000 tonnes, the corresponding estimated
211 usage of marine ingredients at 40 % of feed is 88,000 tonnes (i.e. requirements for fishmeal at 25 %
212 being 55,000 tonnes and for fish oil at 15 % being 33,000 tonnes). UK and Irish production of fishmeal
213 in 2014 was c. 39,000 tonnes (T. Parker, United Fish Products, personal communication), but in
214 practice at least 50 % of fishmeal requirements need to be imported as some of this domestic
215 production is from salmon processing offal and therefore cannot be fed back to salmon. Logistics
216 favour Scottish fishmeal imports from Iceland and Norway, while fish oil is also imported from Peru
217 and Chile to obtain higher levels of EPA and DHA than would be available from fisheries in the North
218 East Atlantic.

219

220 *3.2 Plant ingredients*

221 *3.2.1 Plant proteins*

222 US World Agricultural Supply and Demand Estimates (October 2015) have updated 2015/2016
223 global crop estimates, as follows: wheat - 732.8 million tonnes; corn - 988 million tonnes (based on
224 38,898 million bushels); and soybeans - 320.5 million tonnes (USDA, 2015).

225 The requirement for feeds with a high nutrient density ordinarily favours using plant protein
226 concentrates. These are most readily available from oilseeds, including rapeseed and sunflower seed,
227 but the most widely used is SPC. Although their global availability as bulk commodities is not a
228 constraint on fish feed (e.g. 2015/2016 estimated global supply of oilseeds is 531 million tonnes;
229 USDA, 2015), the availability of protein concentrates is less.

230 Norway's salmon industry requirements for non-GM soy (as SPC) were 365,000 tonnes in 2013
231 (Ytrestøyl et al., 2014) and current plant protein requirements for Scotland are estimated at 77,000
232 tonnes, over 50,000 tonnes as SPC. Although estimated global production of soybeans for 2015/2106
233 is 320.5 million tonnes, this is mostly GM material, whereas European salmon feed uses only non-GM
234 soya products (see 6.1). Currently 5.5 million tonnes of non-GM soya are being grown, mainly in
235 Brazil, and supplied to world markets at a price premium of US\$80 – US\$100 or c. 10 % over GM soya
236 (C. Meinich, Chr. Holtermann ANS, personal communication). Given that GM soya is used in Chilean
237 and North American salmon feeds, requirement for non-GM soy for Scottish salmon feed is c. 1 % of
238 global supply and totals only 7.5 % for combined Norwegian and Scottish salmon production;
239 however, these are underestimates as the yield of concentrates is c. 61.5 % of harvested soya. Despite
240 it being a niche product and all imported mainly from Brazil, there are no indications or reasons to
241 suspect that availability of non-GM soya will decline in the short to medium term.

242

243 3.2.2 Plant oils

244 Plant oils are incorporated into salmon feeds to provide energy and blended with sufficient fish oil
245 of the appropriate quality to give the required content of EPA and DHA. The preferred ingredient is
246 rapeseed oil, which is grown in the EU (including the UK), but mainly in North America. Rapeseed has
247 been cross-bred to reduce levels of erucic acid and glucosinolates and is safe for human consumption
248 (e.g. Canola). Global production of rapeseed oil for 2014/15 was 26.98 million metric tons and
249 availability of non-GM rapeseed oil is not a constraint, including from UK crop material (Statista,
250 2015). Other plant oils, including soya oil and palm oil, have been used at low levels (e.g. to help pellet
251 integrity).

252

253 **4. Omega-3 LC-PUFA scarcity**

254 *4.1 Introduction*

255 World usage of fish oil from 2003 to 2013 is given in Fig. 6, with increasing demand from direct
256 human consumption (so-called 'nutraceuticals') appearing to be at the expense of aquaculture.
257 Aquaculture use averaged around 800,000 tonnes per annum until 2012, but declined to just below
258 700,000 tonnes per annum in 2013. Therefore around 75 % of total global supply was used in
259 aquaculture, with 21 % going for direct human consumption in 2013. Around 83 % of fish oil used in
260 aquaculture feeds in 2013 was consumed by salmonids (60 %, mainly salmon) and marine fish (23 %)
261 (Fig. 7).

262 Although prices for fish oil and rapeseed oil were broadly similar a decade ago, demand for fish oil
263 is now largely a derived demand for omega-3 LC-PUFA. This is shown in Fig. 2, which indicates that the
264 fish oil price has been at an increasing premium over rapeseed oil since 2009 which is directly linked
265 to its content of EPA and DHA (Shepherd and Bachis, 2014). Thus rapeseed oil, which has no EPA and
266 DHA, is included as a more cost-effective source of dietary oil for energy purposes only.

267

268 *4.2 Acute shortage in 2014/2015 and likely recovery*

269 As a result of Peru's industrial fleet being given low anchovy fishing quotas in 2014, the fleet caught
270 only 2.25 million tonnes in 2014, which is around 1/3 of the catch in recent years (Reuters, 2015). This
271 severely impacted on the global availability of EPA and DHA resulting in record price levels reaching
272 US\$2,500 - US\$3,000/tonne for high omega-3 Peruvian fish oil delivered into Europe (IFFO,
273 unpublished). Table 2a indicates 2014 global production was only 140,000 tonnes of combined EPA
274 and DHA (compared with a 'normal' year of up to c. 200,000 tonnes) giving total availability of
275 170,000 tonnes including year-end stock carry-over (after Meinich, 2014). Table 2b indicates total
276 consumption of combined EPA and DHA for salmon feed in 2014 was c. 50,000 tonnes, equating to an
277 inclusion rate in the oil fraction of global salmon feed of around 6 % after taking account of
278 consumption by non-salmonid aquaculture, direct human nutrition, and technical uses (after Meinich,
279 2014).

280 Although the total Peruvian anchovy catch increased to 3.69 million tonnes in 2015 (E. Bachis,
281 IFFO, personal communication), the anchovy were leaner with a lower oil yield than 2014 due to the
282 El Niño effect; therefore it is considered that the current anchovy oil scarcity is continuing and global
283 EPA and DHA supplies in 2015 or early 2016 may be no more than in 2014 (E. Bachis, IFFO, personal
284 communication).

285 Due to high fish oil prices, non-traditional sources are now appearing on world markets, e.g.
286 *Sardinella* spp from north-west Africa (C. Meinich, Chr. Holtermann ANS, personal communication),
287 although such sources are unlikely to be satisfactory in regard to certification requirements for UK
288 salmon feed use (see 5.1). High prices will tend to dampen demand from price sensitive segments.
289 Demand growth for human nutrition and non-salmon aquaculture would be expected to be around
290 2.5 % - 5 % per annum; however, human nutrition growth has stalled since 2013 (A. Ismail, GOED,
291 personal communication) and fish oil inclusion in non-salmonid feeds can be expected to fall at
292 current prices.

293 Historical precedent provides confidence of a likely strong rebound in Peruvian anchovy stocks
294 following the current oceanic conditions of El Niño, with a recovery now likely during 2016, in which
295 case annual global fish oil supply will then increase towards more 'normal' annual production levels
296 approaching c. 1 million tonnes of crude fish oil (corresponding to up to a maximum of 200,000
297 tonnes of combined EPA and DHA). History also suggests that such 'normal' levels will be sustained
298 until the next El Niño event, which is unlikely to occur before 2020. Assuming a 2.5% compound
299 annual growth rate (CAGR) for both direct human nutrition and salmon farming and 5% CAGR for non-
300 salmon aquaculture from 2016, this will permit *pro-rata* growth in EPA and DHA demand, with total
301 consumption of 170,000 tonnes in 2016 increasing to 192,000 tonnes in 2020 (including 55,000
302 tonnes for salmon but with spare capacity to increase to 63,000 tonnes). If another El Niño occurs
303 soon after 2020, by then the resulting scarcity could possibly be offset by an increased supply of EPA
304 and DHA from novel sources (see 4.6)

305 306 *4.3 Market significance of changing EPA and DHA content of salmon*

307 Onozaka et al. (2012) surveyed the position of farmed salmon in five European countries (including
308 the UK) and found that consumers regard salmon as superior in healthiness compared to other meats.
309 Certain UK retailers reported that their customers take health benefits of salmon into account in their
310 purchasing decisions, hence negative publicity on the health benefits of farmed salmon might reduce
311 demand. However, the health benefits of farmed salmon consumption are not restricted to its
312 content of omega-3 LC-PUFA (Galli and Risé, 2009; Tocher, 2009). Salmon comprises highly digestible
313 protein and essential amino acids and marine lipids, as well as vitamins and minerals, so consumption
314 of salmon is more nutritious compared with consuming omega-3 supplements alone.

315 The Global Organisation for EPA and DHA (GOED) summarized the international recommendations
316 for EPA and DHA intake (GOED, 2014), while Shepherd and Bachis (2014) showed that, as a result of
317 the combined EPA and DHA content of added oil in Norwegian feeds falling from 20 % in 2002 to 7.2
318 % in 2012, the number of days recommended requirement met by one portion of Norwegian salmon
319 had fallen proportionately to approximately 6 days (EFSA at 250 mg/day), 3.4 days (SACN at 450
320 mg/day), and 3 days (ISSFAL at 500 mg/day). The average UK consumer eats less fish than Norwegians
321 and a UK survey showed that, for oily fish, average consumption was well below the recommended
322 one (140 g) portion per week in all age groups, with men and women aged 19 to 64 eating just 52 g
323 and 54 g/week of oily fish, respectively (HM Government, 2014).

324 In a recent study of different farmed and wild salmon products available during 2013 in retail
325 outlets in Scotland, Henriques et al. (2014) showed that, although wild salmon products had higher
326 relative values of EPA and DHA, farmed salmon products generally delivered a higher dose of EPA and
327 DHA compared to the wild salmon products, due to their higher lipid content, and were therefore
328 better able to deliver recommended dietary intake levels than the wild salmon products; the study
329 also confirmed the elevated levels of omega-6 PUFA, specifically linoleic acid (18:2n-6), but concluded
330 that 18:2n-6 does not have a major impact on the nutritional quality of farmed salmon and does not
331 outweigh the benefits of the high omega-3 LC-PUFA levels recorded.

332

333 *4.4 Omega-3 LC-PUFA differentiation by UK retailers*

334 The consultation revealed there is clear segmentation in UK farmed salmon supply between those
335 retailers willing to claim that one portion provides the weekly required intake ('formulated to deliver
336 high levels of healthy omega-3 long-chain fatty acids' or similar wording) and those simply stating
337 'variable omega-3 content' or similar wording. Currently four (out of nine) UK retailers (so-called
338 'premium suppliers') claim on the pack of some or all of their products that consuming the stated
339 portions will deliver the internationally recommended intake of EPA and DHA, for which EFSA would
340 appear to be the (minimum) target reference of choice. For these premium suppliers/products, there
341 is a clear link being made between the content of omega-3 LC-PUFA on offer and the health of the
342 consumer, with the premium suppliers specifying Scottish farmed provenance, i.e. omega-3 has
343 become something of a Unique Selling Point (USP) linked to Scottish production. This differentiation is
344 used as a competitive tool by retailers, but raises related questions, such as:

- 345 • The term 'omega-3 fatty acids' may justifiably include more than EPA and DHA, e.g.
346 docosapentaenoic acid (DPA). In evaluating competing product claims, care must be taken to
347 ensure like-for-like comparisons, since using total omega-3 LC-PUFA content gives higher flesh
348 values than only EPA and DHA.
- 349 • There is no indication whether premium salmon is formulated with an overage of omega-3 LC-
350 PUFA to take account of the reduction in levels due to cooking the product (which will vary
351 with cooking method and fat loss, etc.), while intake recommendation levels are based on an
352 assumption of what is actually consumed.
- 353 • There is no reference to omega-6 fatty acid levels that have increased in farmed salmon due to
354 vegetable oil inclusion levels.

355

356 *4.5 The challenge to feed formulation*

357 The existence of a range of bespoke salmon products in response to retail market differentiation
358 represents a complex challenge for farms and feed suppliers. From the consultation it appears that UK
359 feed mills add between 6.5 % and 8.5 % of combined EPA and DHA in the oil fraction of the feed to
360 achieve 1.75 g in a 130 g fillet portion of salmon (EFSA target), depending on salmon bodyweight and
361 fat level (or proportionately more assuming a 100 g portion). The lower end of the Scottish farmed
362 range is in the normal range of standard Norwegian practice during 2014 and is claimed to be typical
363 of current UK imports of Norwegian salmon (supplying an estimated 60 % of the UK market). At these
364 lower levels there is no certainty that the EFSA claim will be met consistently (unless consumers eat
365 more salmon each week) and this lower range corresponds to the majority of UK (non-premium)
366 salmon volume labelled on the basis of 'variable omega-3 levels'.

367 *4.6 Future availability of LC-PUFA sources*

368 GM sources of LC-PUFA (EPA and DHA), such as EPA-containing GM yeast, are being used in Chilean
369 salmon feeds; 'Verlasso salmon' (<http://www.verlasso.com/>). In addition, commercial production of
370 EPA and DHA from GM oilseeds could be a reality by around 2020 (section 8.2.2) (Tocher, 2015). Other
371 potential sources of LC-PUFA are:

372 *4.6.1 Fishery and aquaculture by-products*

373 Increasing use of fishing industry by-products will continue to supply marine ingredients,
374 including fish oil. The recycling of salmon oil for salmon production, which is prohibited by
375 some codes of practice, is being used in aquaculture feeds (e.g. for gilthead bream, *Sparus*

376 *aurata*) and could potentially supply c. 150,000 tonnes of global salmon oil. With 70 %
377 vegetable origin it would contain a maximum 10,000 tonnes of EPA and DHA, but its use
378 would reduce the total demand from non-salmonid aquaculture, making more EPA and DHA
379 available for salmon. In conclusion, increased EPA and DHA from fishery and aquaculture
380 sources is unlikely to have major volume significance in the short to medium term (Tocher,
381 2015).

382 4.6.2 Whole cell DHA-rich algal biomass

383 'DHA Gold' (<http://www.dhagold.com/>) is a dry biomass sold by DSM as a non-GM feed
384 product approved for sale in the EU.

385 4.6.3 Microalgal DHA

386 Fermentation of heterotrophic organisms (e.g. *Schizochytrium*) (Tocher, 2015) requires
387 fermentation use of energy-dependent organic substrates (e.g. sugar), with current
388 commercial developments by DSM, ADM, Alltech, etc. The potential applicability of DHA to
389 salmon feed is by blending fish oil to achieve a similar 1:1 ratio of EPA to DHA as seen in
390 wild Atlantic salmon. As Peruvian anchovy has an 18:12 ratio of EPA to DHA, DHA can be
391 added to anchovy oil to achieve a 1:1 EPA to DHA ratio, before balancing the blend with
392 rapeseed oil; hence 25-30 % of the resulting 'fish oil' can come from microalgal DHA but still
393 remain in the natural range of fish oil composition of wild Atlantic salmon.

394 4.6.4 Longer term options

395 In the long term it is recognised that cultivation of autotrophic/phototrophic algae using
396 photosynthesis is the most efficient solution, but it is proving highly complex and difficult to
397 scale up (Tocher, 2015).

398

399 4.7 Options and implications for the Scottish salmon industry

400 The current shortage of marine sources of LC-PUFA (EPA and DHA) (section 4.2) should start to
401 reverse soon and supplies are likely to become normal during 2016 and thereafter until the next El
402 Niño occurs around 2020, by when alternative novel sources of EPA and DHA may be available from
403 GM and non-GM sources; otherwise the current acute shortage becomes a chronic shortage. Total
404 2015 supply of fish oil (including farmed salmon oil) is estimated at 834,800 tonnes (E. Bachis, IFFO,
405 personal communication) and the expectation is that average salmon feed inclusion will have
406 remained close to 6 % combined EPA and DHA level in feed oil, corresponding to the bare minimum

407 needed to meet EFSA weekly intake recommendation. The main difficulty for the Scottish industry
408 from the current shortage is if the premium segment needs to reassess its claim about one portion of
409 fish meeting weekly recommended requirements for omega-3 LC-PUFA; if product relabelling
410 becomes necessary, this could negatively impact salmon's image as a healthy product.

411 It is relevant for the industry to consider the marginal cost of additional EPA and DHA in Scottish
412 feed. For example, assuming the replacement cost of anchovy oil (c. 26 % combined EPA and DHA) is
413 US\$3,000/tonne and it is necessary to add 7 % of the oil fraction of the feed as EPA and DHA to
414 reliably meet the EFSA claim, this is equivalent at 30 % oil inclusion to 2.1 % of the total feed, hence
415 costing US\$240/tonne. On this basis should the market be supplying only 5 % of the oil fraction of the
416 feed to conserve material, the additional 2 % to regain scope for the EFSA claim would cost c.
417 US\$69/tonne (or US\$34.50 for each percent inclusion of combined EPA and DHA), which may be
418 viewed as a minor cost premium set against the reputational cost and risks of doing otherwise. On the
419 same basis, if current salmon feed cost/tonne is c. US\$1,250/tonne, an additional 2 % of combined
420 EPA and DHA at US\$69/tonne would increase feed cost by 5.5 %. Note (i) calculations should take into
421 account the inclusion of fishmeal, which contains 9 % oil with high levels of EPA and DHA; (ii) if some
422 producers are using more EPA and DHA, others will have to use less due to scarcity limits.

423

424 **5. Role of certification and standards in responsible sourcing**

425 *5.1. Demonstrating responsible sourcing of marine feed ingredients*

426 Standards and certification schemes have become important tools to manage concern issues, such as
427 economic, social and environmental sustainability (e.g. Gail Smith, 2008). The main focus for Scottish
428 salmon is long-term sustainability from an environmental standpoint, especially use of marine feed
429 ingredients. An overview of the sustainability of reduction fisheries is published annually (Sustainable
430 Fisheries Partnership, 2015) and there are well-established food chain standards controlling process
431 quality, food safety, and a particular focus on fish welfare in Scotland (Munro and Wallace, 2015).

432 In developing a consensus approach to responsible practice, the Code of Good Practice for Scottish
433 finfish aquaculture (CoGP) seeks 'to enhance the industry's reputation for respecting the environment
434 through adoption of best practice and greener technologies and reducing the impact on wild fisheries
435 by increasing use of alternative feed sources' (CoGP, 2015). In addition to recommendations on feed
436 formulation and use, the CoGP requires that fish-catch supplies used in fishmeal manufacture are
437 from fisheries which are responsibly managed, either by reference to the FAO (Food and Agriculture

438 Organisation of the United Nations) Code of Conduct for Responsible Fisheries (FAO-CRF; FAO, 2015)
439 or the Marine Ingredients Organisation (IFFO) RS scheme (IFFO, 2015), or by another globally
440 recognised standard. The CoGP also makes fish welfare provisions, which are influenced by husbandry
441 conditions, including use of suitable feeds and feeding methods.

442 To demonstrate responsible sourcing, the use of certified ingredients has been adopted by Scottish
443 feed suppliers and farmers (SSPO, 2013). For marine feed ingredients used in aquaculture there are
444 six commonly used standards; GlobalGap is more focused on food safety, while the other five claim to
445 be based on the key principles underlying the FAO-CRF (FAO, 2015). They are Aquaculture Stewardship
446 Council (ASC) (<http://www.asc-aqua.org>), Best Aquaculture Practice (GAA BAP)
447 (<http://www.gaalliance.org/bap/standards.php>), Friend of the Sea (<http://www.friendofthesea.org/>),
448 IFFO RS, and Marine Stewardship Council (MSC) (<http://www.msc.org>). For marine ingredients, IFFO
449 RS certification is probably universal in Scotland providing evidence of traceability back to responsibly
450 managed fish stocks, avoidance of illegal, unreported, and unregulated fish (IUU), and control of by-
451 product raw material, with an associated chain of custody. For sourcing of fishmeal and fish oil, the
452 following were required for the processors and retailers interviewed during this study:

- 453 • Traceability to species and country of origin
- 454 • No endangered species used, as defined by the International Union for Conservation of Nature
455 (IUCN) 'Red List' (IUCN, 2015)
- 456 • Preference for feed manufacturers to provide evidence of responsible sourcing
- 457 • Avoidance of IUU fish

458

459 *5.2 Demonstrating responsible sourcing of plant feed ingredients*

460 Three standards are currently used for plant ingredients for Scottish salmon feeds:

- 461 • The Roundtable on Responsible Soy (RTRS) Association approved its Standard for Responsible
462 Soy Production versions in 2010 (RTRS, 2011)
- 463 • The new ProTerra Foundation Standard Version became effective in January 2015 and includes
464 soya (ProTerra, 2015).
- 465 • Cert ID is focused on Non-GMO certification and has become the benchmark for Non-GMO
466 identity preservation (Cert ID Europe Ltd., 2015).

467 The use of these three schemes for fish feed, primarily for soya, is seen as work in progress. Given the
468 growing recognition of potential environmental problems (e.g. rain forest degradation associated with

469 uncontrolled soya production, especially in South America), it is perhaps surprising that
470 environmentalist pressure has focused on use of marine ingredients in aquaculture and largely
471 ignored plant ingredients until recently.

472

473 *5.3 UK supply chain perspective - salmon farmers and feed manufacturers*

474 It was clear from the consultation that sustainability issues are a strategic concern for the owners of
475 the three principal UK salmon feed companies and lie at the heart of their day-to-day operations,
476 including raw materials purchase; also that salmon purchasing firms increasingly oblige their suppliers
477 to provide evidence demonstrating responsible management and use of renewable resources. The
478 salmon farm and feed-related certifications used currently by Scottish salmon farms and their
479 associated supply chains are given in Supplementary File 1. Key findings include the following:

- 480 (i) Over 90 % of Scottish salmon farms are members of the Scottish Salmon Producers
481 Organisation (SSPO) and subscribe to the CoGP.
- 482 (ii) Widespread adoption of 'Freedom Food'/'RSPCA Assured' certification
483 (<http://www.freedomfood.co.uk/>) is an international differentiator specifying 'sustainable
484 feed' and IFFO RS certification of marine ingredients
- 485 (iii) The most widely (but not exclusively) used Scottish salmon farming certification is
486 GlobalGap (http://www.globalgap.org/uk_en/), which is focused on food safety and feed
487 assurance.
- 488 (iv) The ASC salmon standard (<http://www.asc-aqua.org/index.cfm?lng=1>) has received global
489 endorsement by Marine Harvest with two Scottish salmon farms now certified. ASC is likely
490 to be adopted by other Scottish producers
- 491 (v) IFFO RS certification is currently only accepted in a chain of custody role by the ASC salmon
492 standard.
- 493 (vi) The GAA BAP certification is not currently adopted by any Scottish producers despite its
494 leading position in North and South American aquaculture ([http://gaalliance.org/what-we-
495 do/bap-certification/](http://gaalliance.org/what-we-do/bap-certification/)).
- 496 (vii) Greater harmonisation between different standards would be beneficial; the Global
497 Sustainable Seafood Initiative plans to benchmark them to facilitate sourcing decisions
498 (<http://sustainableseafoodcoalition.org/news/new-gssi-website-launches>).

499

500 *5.4 UK supply chain perspective - salmon processors and retailers*

501 To discover salmon sourcing policies of leading multiple retailers and processors, eight of the nine
502 major UK retailers and two leading UK seafood processors were consulted. This confirmed that UK
503 retail salmon standards are a complex set of competing codes aimed at increasing retailers' control
504 over the supply chain. Aquaculture focus on sustainable feed issues is partly driven by competing UK
505 retailers and is influenced by pressure from environmental NGOs, which often compete for support
506 from consumers and supply chains. The existence of different private standards can cause confusion
507 (e.g. to retail fish buyers) and is poorly understood by consumers. It appears sustainability issues are
508 being used as a competitive tool by firms highlighting responsible sourcing credentials, so salmon
509 farming and feed standards continue to be driven up; however, this has implications in restricting
510 choice among different raw material sources.

511

512 *5.5 Relevance of input/output indices for marine resource use*

513 Although the main driver for replacement of marine ingredients by plant raw materials has been the
514 combination of nutritional innovation and market forces in the face of fluctuating supply and highly
515 volatile price, replacement has impacted on the different indicators used to relate marine ingredient
516 input to farmed salmon output. These 'marine sustainability indicators' include fish-in fish-out ratio
517 (FIFO), marine protein dependency ratio (MPDR), forage fish dependency ratio (FFDR), etc., and their
518 use has been reviewed by various authors (e.g. Ytrestøyl et al., 2015). Although FIFO and FFDR have
519 been used as a proxy for sustainability, it is not clear why this should be since sustainability must be
520 based on responsible harvesting of fish that are used for fishmeal and fish oil according to
521 international regulations (backed up by private standards if necessary). Nor has the FIFO ratio any
522 obvious nutritional basis and it is not therefore a measure of production efficiency (Tocher, 2015).

523 As one of its indicators ASC has included FFDR, calculated as the quantity of forage fish required to
524 produce the amount of fishmeal and fish oil to produce a unit of farmed fish. For 2013 the
525 corresponding FFDRs for Norwegian salmon were 1.54 and 0.69 for fish oil and meal, respectively,
526 well within the ASC standards of < 2.95 for fish oil and < 1.35 for fishmeal (Ytrestøyl et al, 2014); by
527 comparison the equivalent (unpublished) values for one Scottish producer in 2013 of 2.09 for fish oil
528 and 0.76 for fishmeal were higher than Norway, but well within the ASC permitted range.

529

530 *5.6 Effect of changing raw materials on salmon farming sustainability*

531 As regards protein retention, Torstensen et al. (2008) and Bendiksen et al. (2011) have found similar
532 levels in Atlantic salmon fed either mainly marine diets or mainly plant-based diets, explaining why
533 salmon can be produced with feeds containing high inclusions of plant ingredients and only low
534 inclusions of marine ingredients. Changing the salmon diet composition from 88 % marine ingredients
535 to 85 % plant ingredients resulted in almost the same carbon footprint (Ytrestøyl et al., 2011), which
536 supports the view of Torrissen et al. (2011) that increased utilisation of plant ingredients may not
537 provide an increase in sustainability as often claimed. The increased use of fishery by-products
538 influences sustainability; although they have little, if any, alternative use, the effect on dietary carbon
539 footprint will depend on whether the life cycle analysis (LCA) calculation adopts economic or mass
540 allocation. As stated by Ytrestøyl et al. (2015), several methods must be used to evaluate eco-
541 efficiency and sustainability of salmon production as no single method is sufficiently robust.

542

543 **6. Scope for alternative feed ingredients, including land animal products, genetically modified, and** 544 **fermentation products**

545 Considerable research has been performed to assess a large range of alternative protein and oil/fat
546 sources as ingredients for aquaculture feeds, including salmon (Gatlin III et al., 2007; Turchini et al.,
547 2011). Focus here will be on alternative current and emerging protein and oil ingredients that have
548 large-scale potential in Scottish salmon farming, but where there are supply chain concerns about
549 their use or the technical basis is not sufficiently established. For alternative protein feed ingredients
550 found to be suitable and cost-effective, it is important to be able to concentrate the protein in order
551 for it to replace SPC in practical feed manufacture.

552

553 *6.1 Land animal by-products (LAPs)*

554 6.1.1 Current status and availability of LAPs in Europe

555 Before year 2000 animal proteins were widely used in fish feeds, but due to Bovine Spongiform
556 Encephalopathy (BSE), most animal proteins were banned from terrestrial and aquatic animal feeds.
557 From June 2013, due to improved testing methods, use of non-ruminant Processed Animal Protein
558 (PAP) has been approved for use in aquaculture in the EU (Regulation 56/2013). The following are the
559 main non-ruminant PAP products in the UK and EU now legally available for inclusion in aquaculture
560 feeds: Poultry PAP; Feather meal PAP; Porcine PAP; Porcine blood meal PAP; and Porcine blood
561 products. EU production of poultry-derived PAP and of porcine PAP and blood products in 2013 was

562 365,000 tonnes and 275,000 tonnes, respectively (Woodgate, 2014). To ensure lack of ruminant
563 protein contamination, segregation, security, and traceability of 'Category 3' animal by-products is the
564 subject of detailed controls at the slaughterhouse and downstream.

565

566 6.1.2. Current use of LAPs in salmon feed

567 Despite the legal relaxation, since 2001 no LAPs have been used in salmon feeds in Europe, with a
568 marked reluctance by supply chains to incorporate animal by-products in feed for farmed salmon (see
569 6.1.4), despite technical benefits (e.g. blood meal's histidine content preventing cataracts). The
570 situation outside Europe with fewer BSE-related problems is very different (e.g. current Chilean
571 salmon diet formulations with 3 % poultry oil and 19 % LAPs).

572 A voluntary ban on use of LAPs in salmon feed in UK (and Norway) is reinforced by the CoGP
573 prohibiting use of LAPs in Scottish salmon. This strict policy appears contradictory in view of retail
574 supply of imported farmed warm water prawns (*Penaeus* spp.), 'River Cobbler' (*Pangasius* spp.), and
575 Pacific salmon (*Oncorhynchus* spp.) from enhancement programmes, which may all have been fed
576 LAPs. The rationale of the ban is fear of negative consumer reaction, variously linked to: BSE
577 concerns, the horsemeat contamination issue, the supposed 'unnaturalness' of such ingredients, and
578 associations of animal by-products with use of waste material otherwise destined for landfill disposal.
579 The retailers consulted pointed out this is not a food safety issue and would give access to global
580 salmon production, but accept their customers do not wish the policy to change. All respondents
581 referred to the constraints of halal and kosher requirements, which prohibit use of porcine material
582 (e.g. pig blood), hence further supply chain segregation. In practice this means that use could only be
583 made of poultry products, such as poultry offal meal, feather meal and poultry oil. The non-
584 governmental organisations (NGOs) consulted supported the use of LAPs in salmon feed as
585 representing a sustainable solution; also the ASC salmon farming standard supports the use of LAPs.

586

587 6.1.3 Conclusions and implications for LAPs/PAP

588 Consultation, especially with retailers, showed strong resistance to using LAPs in salmon feed by UK
589 and continental European consumers. It is therefore not under consideration in Scotland and this is
590 unlikely to change in the foreseeable future, despite the EU having removed legal obstacles for PAP
591 use. If this is reconsidered in the future, robust source assurance guarantees would be required and
592 porcine material would need to be excluded. As regards cost savings from an open salmon feed

593 formulation with poultry by-products, estimates from feed companies consulted were in the range of
594 £60 - £80/tonne (i.e. up to 10 % of feed cost), depending on feed size and specification.

595

596 *6.2. Use of genetically modified feed ingredients*

597 6.2.1 Scope for GM protein ingredients

598 6.2.1.1 UK use in land animal feeds versus salmon feeds

599 Following supply concerns about non-GM soybeans in 2013, all but one of the eight UK retailers
600 consulted changed their sourcing policies to permit the inclusion of GM plant ingredients in terrestrial
601 livestock feeds, especially for chicken. Although inclusion of approved GM feed ingredients is legally
602 permissible in the UK, currently salmon producers and feed companies have a strict non-GM policy.
603 This appears to reflect the following:

- 604 (i) Negative consumer attitudes to GM in Europe, especially in France, Germany, Austria and
605 Italy, with potentially severe export implications for Scottish salmon.
- 606 (ii) The current lack of a clear commercial disadvantage to sourcing non-GM ingredients, such
607 as reduced availability and substantially increased cost for non-GM SPC.
- 608 (iii) The current consensus to maintaining non-GM fed salmon status in Scotland being shared
609 by the SSPO, some NGOs, and the Scottish Government, as part of a 'green and clean'
610 stance (while English and Welsh Government policies on GM are more flexible).
- 611 (iv) The Norwegian salmon farming industry has a non-GM policy.

612 However, seven of the eight UK retail respondents consulted were willing to consider adopting a more
613 flexible GM feed policy if market circumstances changed. They accepted that UK consumer attitudes
614 were becoming less hostile to GM, but the largest supply chain concern relates to the risk of losing
615 key export markets, especially France.

616

617 6.2.1.2 Availability of non-GM proteins

618 As shown in 3.2.1, although the 5.5 million tonnes of non-GM soy protein is less than 3 % of global
619 soya supplies, dominated by GM material, there is no current threat to availability, or sufficient of a
620 price driver for switching to GM SPC in salmon feeds. Discussions in Norway about whether it is
621 logistically possible to supply GM and non-GM feed at the same time by using different mills
622 concluded this is more a matter of policy and additional cost than logistics, but it would be more
623 difficult (but possible) to segregate the resulting fish streams post-harvest. This is not seen as being

624 feasible in Scotland and any move to abandon the non-GM policy would need to be agreed jointly by
625 all three UK feed producers.

626

627 6.2.2 Scope for GM oil containing EPA and DHA

628 Commercial production of so-called 'Verlasso' salmon in Chile involves the use of yeast, which has
629 been genetically modified to produce EPA (Xue et al., 2013). The transgenic yeast cells are produced
630 by fermentation using glucose and killed before the whole dead cells are added to salmon feed as a
631 partial replacement for fish oil (Hatlen et al., 2012; Berge et al., 2013).

632 Camelina oil (from the oilseed crop False Flax, *Camelina sativa*) has been suggested as commercially
633 suitable for salmon feeds since it contains about 30 % α -linolenic acid (a precursor of EPA and DHA),
634 with relatively low levels of omega-6 PUFA, and has been used experimentally to replace fish oil in
635 salmon diets (Hixson et al., 2014). However, it is the recent success in producing EPA and DHA at
636 levels equivalent to those in fish oil by inserting algal DNA into *Camelina* that has aroused most
637 interest (Ruiz-Lopez et al., 2014) (<http://www.rothamsted.ac.uk/camelina>). It has been estimated that
638 1 hectare of the new transgenic crop would produce about 750 kg of oil containing around 12 % EPA
639 and 8 % DHA and it should be highly scalable, hence 1 million hectares could produce 750,000 tonnes
640 of oil or 150,000 tonnes of EPA and DHA (Ruiz-Lopez et al., 2014). Oil from transgenic Camelina has
641 been demonstrated to successfully replace fish oil in feeds for Atlantic salmon (Betancor et al.,
642 2015a,b). Although the European Parliament agreed in January 2015 to allow individual member
643 states to determine their GM policy, regulatory approval for growing the transgenic crop would be
644 simpler outside the EU (e.g. in Canada or USA). Transgenic oil might become available in the UK (and
645 Norway via its EU agreements) by around 2020, subject to commercial agreements and to regulatory
646 approval in the country where the crop is grown and in the EU as a GM feed additive. A similar
647 timescale seems likely for the production of EPA and DHA from transgenic canola (rapeseed) by a joint
648 venture between BASF and Cargill. In Australia the focus on transgenic canola is mainly on DHA
649 (Kitessa et al., 2014) with claims that commercial supply could be available by 2017 (CSIRO, 2013). The
650 existence of an entire logistical system for handling oilseed products means that the supply chain is
651 already present and GM oil's production cost need be no higher than conventional oilseeds. The
652 continuing decline in EPA and DHA levels is a potential driver for change if GM oil becomes
653 commercially available and the lack of any cellular material, protein, or nucleic acid in oil may help
654 market acceptance.

655

656 6.2.3 Conclusions and implications for GM feed ingredients

657 Unless non-GM protein becomes less competitive in terms of supply and price, given the current
658 premium for non-GM SPC (used at 20 % - 30 % of the diet) is under 10 %, there is little commercial
659 incentive for the Scottish industry to change policy today. The position with omega-3 LC-PUFA is
660 different as the potential commercial availability of GM oilseed crop sources by around 2020 offers a
661 potential technical solution to a chronic shortage, which might otherwise undermine the healthy
662 profile of Scottish farmed salmon. A switch to using GM oil might be seen as worthwhile to avoid the
663 risk of fish oil supply interruptions, if and when transgenic oils become commercially available. If the
664 next El Niño causes a repeat of the current acute scarcity, and consumer attitudes continue to soften,
665 it might become appropriate for policy-makers and the industry in Scotland to review current policy,
666 but the potential risk to salmon export markets, especially France, from using GM feed ingredients is
667 likely to be a key commercial consideration.

668

669 *6.3 Use of novel non-GM feed ingredients*

670 6.3.1 Insect-based feed ingredients

671 Since wild salmon eat insects during the freshwater stage, there is current R&D investment on the
672 potential of using insects as safe and healthy ingredients for salmon feed. Makkar et al. (2014)
673 reviewed existing research on five major insect species that are claimed to have potential for animal
674 feed concluding that black soldier fly larvae have most promise for replacing soybean meal in pig and
675 poultry diets. The recent 'Aquafly' project in Norway is exploring the potential to tailor insect nutrient
676 profile to meet salmon nutritional requirements ([http://nifes.no/en/counting-insects-future-fish-
677 feeds/](http://nifes.no/en/counting-insects-future-fish-feeds/)). It is claimed that many insect species are highly nutritious and their production has less
678 environmental impact compared with traditional sources of animal protein. At an EU level, EFSA has
679 been commissioned to review available safety evidence around insect protein, while the Commission
680 is funding the PROteINSECT project to investigate quality, safety, processes, and human acceptance
681 around the use of insects in animal feed (<http://www.proteinsect.eu>). In addition to salmon
682 nutritional studies, there is a need for cost-effective mass insect-rearing facilities and a regulatory
683 framework and sanitary procedures for the safe use of bio-wastes (including managing the risks of
684 diseases, heavy metals and pesticides, etc.). The scope for insect use as a potential protein
685 replacement in salmon feeds is clearly at an early stage of evaluation.

686

687 6.3.2 Fermentation products

688 As an alternative to DHA-rich algal biomass produced by fermentation of non-GM heterotrophic
689 organisms, the current low cost of energy has renewed interest in natural proprietary fermentation as
690 a means of producing microbial protein based on methane as the main source of carbon and energy.
691 In particular *Methylococcus capsulatus*, a naturally occurring single cell organism, is now being used
692 to produce a stable powder or dry pelleted product with 71 % protein, 10 % fat, and <1 % fibre, and a
693 shelf life of over a year. The resulting product ('FeedKind'TM) is already approved for use in the EU and
694 it is claimed that it will be released commercially in 2018 and prove a superior alternative to fishmeal
695 and soy in aquaculture diets (<http://calystanutrition.com/feedkind-protein/>). Assuming the product
696 proves cost-effective in use, this has some clear advantages to conventional protein sources in salmon
697 feeds. It remains to be seen if the product will remain feasible in practice if and when energy costs
698 escalate once more, although the manufacturers claim they could switch to alternative feedstocks,
699 such as biogas.

700

701 7. Projected forward requirements for salmon feed ingredients

702 7.1 Future farming and feed requirements

703 The Scottish Government's farmed salmon target of 210,000 tonnes by 2020, (see 1.2) represents a
704 realistic CAGR of c. 2.5 %, provided new production sites are available, etc. This is also in line with
705 global salmon projections where annual growth rate has recently diminished, resulting in a projected
706 3 % CAGR from 2013 to 2020 (Kontali, 2013). If the overall FCR in 2013/2014 was c. 1.3 (see 1.2), and
707 annual salmon harvest volume is expected to increase from c. 165,000 tonnes to 210,000 tonnes in
708 2020, it seems not unreasonable to assume an improved FCR within the range of 1.1 - 1.2,
709 corresponding to a 2020 Scottish salmon feed requirement in the range of 231,000 - 252,000 tonnes.

710

711 7.2 Forward supply of marine ingredients

712 OECD-FAO (2013) constructed an annual global forecast from 2013 to 2022 of total fishmeal and fish
713 oil production, production from whole fish, consumption, variation in stocks, and price. Using the
714 OECD-FAO fish model for 2022, FAO (2014) projected total fishery production, aquaculture, fishmeal
715 and fish oil production assuming that about 16 % of capture fishery production will be reduced to
716 fishmeal and fish oil (down 7 % on the 2010-2012 average, the base period), but total 'baseline' 2022

717 production will be 7.02 million tonnes and 1.08 million tonnes, respectively (i.e. up 15 % and 10 % on
718 the base period, with almost 95 % of the additional gain for fishmeal coming from improved use of
719 fish waste, cuttings and trimmings) (Table 3). OECD-FAO estimate that fishmeal from by-products
720 should represent 49 % of total fishmeal production in 2022 and that, with global demand stronger
721 than supply, prices of fishmeal and fish oil will increase by 6 % and 23 %, respectively, in nominal
722 terms by 2022 (OECD-FAO, 2013). Although the OECD-FAO model is the best available, this is no
723 guarantee of its predictive ability, especially if there is a possibility that the base period may be
724 somewhat overstated. For instance IFFO data give lower estimates for the 2010 – 2012 base period
725 than FAO with 4.92 million tonnes of fishmeal as the 2010 – 2012 year average versus 6.10 million
726 tonnes from FAO (due mainly to lower assumptions on Chinese production by IFFO), while IFFO data
727 for fish oil is close at 0.96 million tonnes versus 0.98 million tonnes for the same 3-year average (IFFO,
728 2014). Also IFFO data are suggestive of a recent downward trend in fishmeal production most likely
729 linked to more precautionary fishing (Fig. 4). Although this is less evident in the data on fish oil
730 production, the trend will be for less fish oil being available for aquaculture due to competition from
731 the human nutrition sector (Figs. 5 and 6).

732 Supply and demand forecasts for fishmeal and fish oil need to take into account *inter alia* demand
733 for pelagic fish for direct human consumption, the effect on reduction fisheries of increased
734 regulatory curbs, climatic events (e.g. El Niño), increased exploitation of fish processing wastes for
735 reduction purposes, etc. At the same time demand for fishmeal and fish oil is a function of price and
736 availability of alternative proteins and alternative oils, particularly novel sources of omega-3 LC-PUFA,
737 as well as the rate of growth, not only of fed aquaculture species, but also of young pigs and day-old
738 chicks (Shepherd and Jackson, 2013). This is in turn influenced by innovation of feed formulators,
739 plant protein processors, and geneticists, as they seek to reduce fishmeal inclusion rates to save on
740 scarce, fluctuating, and costly ingredients, and also by the efforts of civic society (e.g. NGOs) to
741 discourage use of marine ingredients on alleged sustainability grounds. Since fish oil demand has
742 become a derived demand for EPA and DHA, salmon feed buyers compete strongly with the human
743 nutrition market, while supply is linked to that of its co-product fishmeal, with both products subject
744 to the volatility of the dominant Peruvian catch due to El Niño. However, Olsen and Hasan (2012)
745 concluded that the limited supply of pelagic fishmeal will not be a major obstacle for a continued
746 moderate growth in global aquaculture production; it is reasonable to make the same conclusion in
747 regard to global salmon production.

748 On the somewhat conservative assumption of a 30 % marine/70 % plant content of feed ingredients
749 (lower in marine content than today's Scottish average, but the same as current Norwegian feeds),
750 231,000 - 252,000 tonnes of salmon feed for Scotland in 2020 would require annually 69,000 - 76,000
751 tonnes of marine ingredients and 162,000 - 176,000 tonnes of plant ingredients. On this basis the
752 reduced fishmeal inclusion rate projected for 2020 will more than offset the increased feed
753 production. If the UK annual fishmeal requirement in 2020 is 45,000 - 50,000 tonnes (compared with
754 c. 55,000 tonnes demand and 39,000 tonnes supply in 2014, – see 3.1) and domestic supply is likely to
755 rise over time, most, if not all, fishmeal requirements could be sourced locally if desired. However,
756 salmon by-products could not be recycled (3.1) and sourcing criteria for farm certification (e.g. by
757 ASC), may become more exacting over time (5.2), restricting raw material.

758

759 *7.3 Forward plant protein and oil supply*

760 OECD and FAO secretariats analysed the price ratios of aquaculture species relative to oilseed
761 products and concluded that tight supplies of fishmeal and fish oil are likely to contribute to an
762 increased price ratio between fish and oilseed products over the medium term due to continuing
763 demand from early rearing of pigs and salmon farming and from continuing omega-3 demand (OECD-
764 FAO, 2013). They recognised the price ratios will be exacerbated in El Niño years, further constraining
765 supply and supporting higher prices. Also they project a 26 % increase in world production of oilseeds
766 and a switch in distribution of land from coarse grains to oilseeds. Global protein meal output is
767 projected to increase by 25 % or 67 million tonnes by 2022; this envisages consumption growth of
768 protein meal slowing somewhat due to slower absolute growth in global livestock production and
769 slower growth in the relative use of protein meal in feed rations. The overall availability and price of
770 terrestrial ingredients will also depend on factors such as freshwater availability.

771 In the short-term, demand from Scottish and global salmon production for the principal plant feed
772 ingredient, non-GM soy (as SPC) is only c. 1 % or 7.5 %, respectively, of global supply, suggesting
773 security of supply is not an issue. The European salmon industry imports non-GM soya mainly from
774 Brazil as already crushed concentrate (see 3.2.1), paying a premium which may increase over time.
775 Hence the strategic logic of avoiding over-reliance on imported soya products by greater focus on
776 locally grown protein substitutes, including legumes, beans and peas, as well as focusing on novel
777 sources of EPA and DHA, especially from algal fermentation and transgenic oilseed crops. If microbial

778 protein (e.g. FeedKind™) is shown to be cost-effective and available on a large scale, this could
779 potentially start to replace fishmeal and SPC in salmon feeds from as early as 2018.

780

781 **8. Overall conclusions**

782 8.1 The Scottish salmon farming industry occupies a distinctive international market position
783 supplying a differentiated product range to offset potentially higher production costs compared with
784 the much larger and more standardised Norwegian industry. Scottish production therefore relies on a
785 variety of feed products, including specialist formulations with a higher than standard content of
786 marine ingredients and omega-3 LC-PUFA, etc. Despite its recognised economic and social benefits,
787 this has raised questions about the industry's environmental sustainability in regard to salmon feed.

788

789 8.2 Finite marine feed resources are now being replaced by plant-based ingredients in salmon feed,
790 hence enabling salmon farming to achieve net fish protein production. Although it is continuing to fall,
791 the relatively higher marine content of some Scottish feeds (averaging around 40 % marine and 60 %
792 plant ingredients) compared with Norwegian farmed salmon reinforces a 'healthy and natural'
793 reputation and may be seen as a necessary trade-off against increased feed costs.

794

795 8.3 There is no evidence that terrestrial agricultural animal and plant feed resources are more
796 sustainable for farming salmon than using feed ingredients based on wild-caught marine resources,
797 provided they are sourced from sustainably managed stocks (or from the growing proportion of fish
798 processing by-products, which currently represent 25 – 30 % of marine ingredients); hence an
799 increased utilisation of plant ingredients in salmon feed may not be more environmentally
800 sustainable.

801

802 8.4 The Scottish salmon industry has sought to adopt best farming practice in response to its producer
803 organisation and to supply chain pressures, including responsible sourcing. Scottish certification focus
804 on sustainable raw materials has helped to counter claims of an unsustainable use of marine
805 ingredients, hence the growing recognition that sustainability issues for farmed Scottish salmon are
806 now more related to sea lice rather than feed ingredients. Certified evidence on use of renewable
807 feed ingredients is underpinned by third party auditing. Retailers require suppliers to comply with
808 external certification schemes as well as their in-house standards, with the result that farming

809 standards are demanding and continue to be driven up. The recent ASC certification of two farm sites
810 in Scotland suggests that this may become a future benchmark of responsible practice. In addition the
811 Scottish ethical commitment to fish welfare (via Freedom Food/RSPCA Assured status) demonstrates
812 the industry's willingness to step beyond traditional boundaries of best practice.

813

814 8.5 Increased demand for fish oil from aquaculture and the human nutrition industry has coincided
815 with acute scarcity due to El Niño conditions affecting the anchovy fishery in Peru and Chile. In the
816 short-term this issue will temporarily resolve itself in Peru as the anchovy fishery recovers. In the
817 medium-term interim solutions are needed to manage this situation cost-effectively and DHA from
818 algal fermentation is now available albeit at relatively high cost and being studied as one solution. In
819 the longer term, in view of the food security and consumer health implications, it is appropriate for
820 the Scottish industry to consider reviewing its policy on GM feed ingredients for when new transgenic
821 plant sources of EPA and DHA become available. However, it is recognised that, use of GM feed
822 ingredients at the present time would risk lost sales to France, which is the second most valuable
823 export market for Scottish salmon.

824

825 8.6 There is evidence some consumers take into account the health benefits when choosing to buy
826 salmon and some UK retail packs indicate that eating a product portion will allow the consumer to
827 meet international recommendations for weekly consumption of omega-3 LC-PUFA. This creates a risk
828 for Scottish salmon since the content of EPA and DHA has fallen because of increasing replacement of
829 fish oil by plant oils in salmon feed. In current scarcity conditions fish oil supplementation of feed to
830 meet the label claim is costly and difficult, but may be necessary to maintain industry and brand
831 reputations. At the same time the health attributes of Scottish salmon are not solely based on EPA
832 and DHA, but could take more account of the content of amino acids, vitamins and minerals, etc., as
833 well as extremely low levels of environmental contaminants due to replacing marine by plant
834 ingredients.

835

836 8.7 Despite its potential benefits (e.g. cost savings and formulation flexibility), and its widespread use
837 in salmon farming in the Americas, there is strong supply chain resistance to incorporating terrestrial
838 by-products into salmon feeds in the UK. EU approval has been granted for use of PAP in aquaculture
839 feeds, although in commercial practice this would mean poultry material as porcine by-products are

840 problematic for religious and cultural reasons. However, UK retailers are currently unwilling to accept
841 the high risk of a negative customer reaction. It is recognised that this policy restricts sourcing and
842 runs counter to sustainability options, but is unlikely to change in the near future. The potential for
843 insect-based ingredients has yet to be evaluated and developed, but could meet similar consumer
844 objections.

845

846 8.8 As regards the use of GM feed ingredients, a similar embargo exists today in European salmon
847 farming. This is despite their use in UK chicken feeds, signs of a weakening in UK consumer hostility to
848 the GM issue, and a more flexible approach by the EU and the English and Welsh governments. Given
849 the availability of non-GM soya at a relatively small price premium today, there is no current incentive
850 to alter this policy on grounds of protein availability, although this situation could change in the
851 future. The position with omega-3 LC-PUFA is different as the likely commercial availability of GM
852 oilseed crop sources by around 2020 from outside Europe offers a possible solution to a chronic
853 shortage. Avoiding GM could mean that the Scottish industry is accused of supplying a less healthy
854 product than in those countries using GM feed ingredients. It does not appear to be logistically
855 feasible for the UK fish feed and fish farming industries to maintain both GM fed and non-GM fed
856 supply lines at the same time.

857

858 8.9 Although forward supply of proteins is not seen as a major issue, there should be continuing focus
859 on cost-effective local alternatives to non-GM SPC in particular. Provided it becomes available on
860 schedule and remains cost-effective, the development of microbial protein is of strategic interest,
861 offering a novel alternative to fishmeal and SPC of strategic interest.

862

863 8.10 As regards research bottlenecks, continuing focus is required on how best to maintain EPA and
864 DHA levels in farmed salmon given the increased price and reduced availability of fish oil of
865 appropriate certification status and lack of contaminants. The most feasible alternative source may be
866 GM oil by 2020, but algal and microbial sources should be kept under review and interim solutions are
867 required to manage this situation cost-effectively. Although alternative plant protein feed ingredients
868 (e.g. beans and peas) are being studied, especially those that can be grown in the UK, it is important
869 to be able to concentrate the protein in order for it to replace SPC. The technical process and
870 associated logistics therefore need to be defined and offer a cost-effective solution.

871 **Acknowledgements**

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873 healthy farmed salmon (*Salmo salar*) from a changing raw material base, with special reference to a
874 sustainable Scottish industry’ (Shepherd et al., 2015). We acknowledge the support of the Scottish
875 Aquaculture Research Forum (SARF), which commissioned this study (Project SP007), and a full list of
876 all individuals and stakeholder organisations to whom we are grateful is included in the original study
877 report (Shepherd et al., 2015).

878

879

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1033

1034 **Tables**

1035

1036 Table 1. Comparison of farmed salmon production (tonnes), feed supply volume (tonnes), and
 1037 corresponding feed conversion ratio (FCR) for Scotland and Norway in years 2013 and 2014 (source:
 1038 Kontali AS).

1039

	2013		2014	
	<u>Scotland</u>	<u>Norway</u>	<u>Scotland</u>	<u>Norway</u>
Farmed salmon production as whole fish equivalent	163,234	1,143,500	179,022	1,198,900
Salmon feed supply	214,000	1,487,600	221,000	1,598,800
Feed Conversion Ratio	1.31	1.30	1.23	1.33

1040

1041 Table 2. Estimated global production (a) and consumption (b) of combined EPA and DHA (tonnes) in 2014 (after
 1042 Meinich, 2014).

1043 Table 2a

Estimated global production of crude fish oil	800,000
Estimated global production of EPA + DHA	140,000
Estimated global year-end carryover of EPA + DHA	30,000
Estimated global availability of EPA + DHA	170,000

1044

1045 Table 2b

Estimated global consumption of EPA + DHA in salmon feed	50,000
Estimated global consumption of EPA + DHA by non-salmon aquaculture	50,000
Estimated global consumption of EPA + DHA for direct human consumption	61,000
Estimated technical usage of EPA + DHA (e.g. hardening, tanning, energy)	9,000

1046

1047

1048 Table 3. FAO fish model: overall trends to 2022 for world (million tonnes in live weight equivalent) (FAO, 2014).

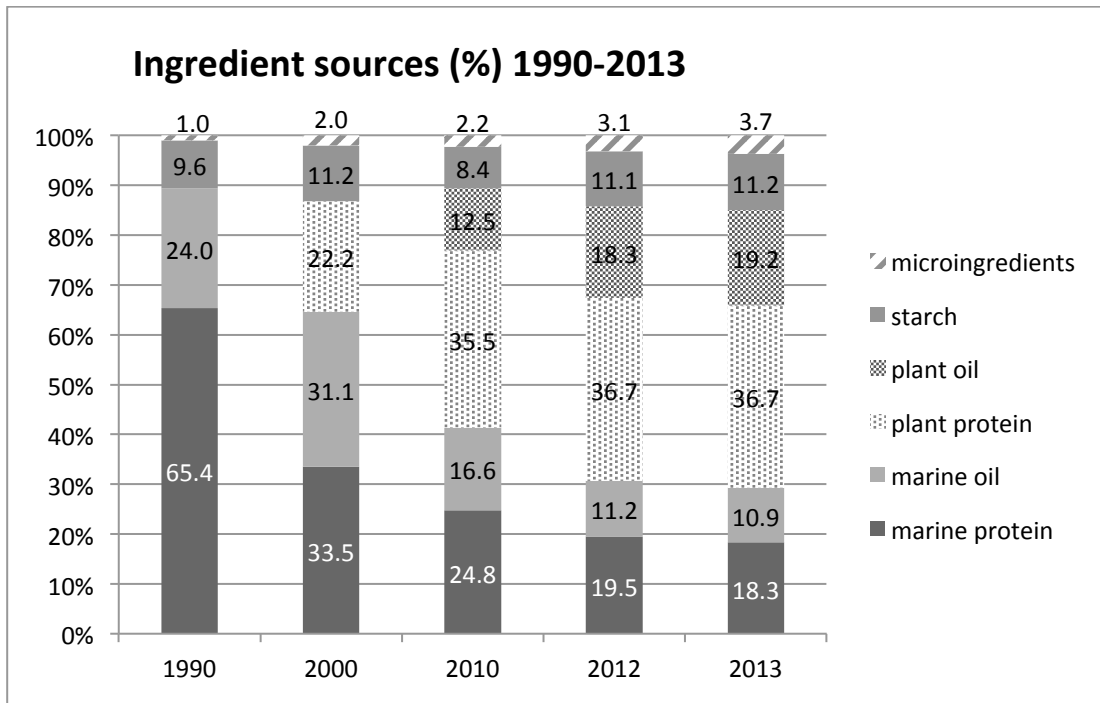
	Base period 2010 - 2012	2022 scenarios			
		Baseline	Intermediate	Optimistic	Mixed
Total fishery production (World)	153.940	181.070	188.093	194.800	194.792
Aquaculture	62.924	85.124	92.402	99.330	99.330
Capture	91.016	95.946	95.692	95.474	95.462
Fishmeal production (<i>product weight</i>)	6.103	7.021	7.358	7.679	7.734
Fish oil production (<i>product weight</i>)	0.980	1.079	1.087	1.094	1.088
Fish trade for human consumption	36.994	45.082	45.566	46.237	46.566
Fish supply for human consumption	131.741	160.514	167.397	173.969	174.032
Per capita apparent fish consumption (<i>kg</i>)	18.9	20.7	21.6	22.4	22.4

1049

1050

1051 **Figures**

1052

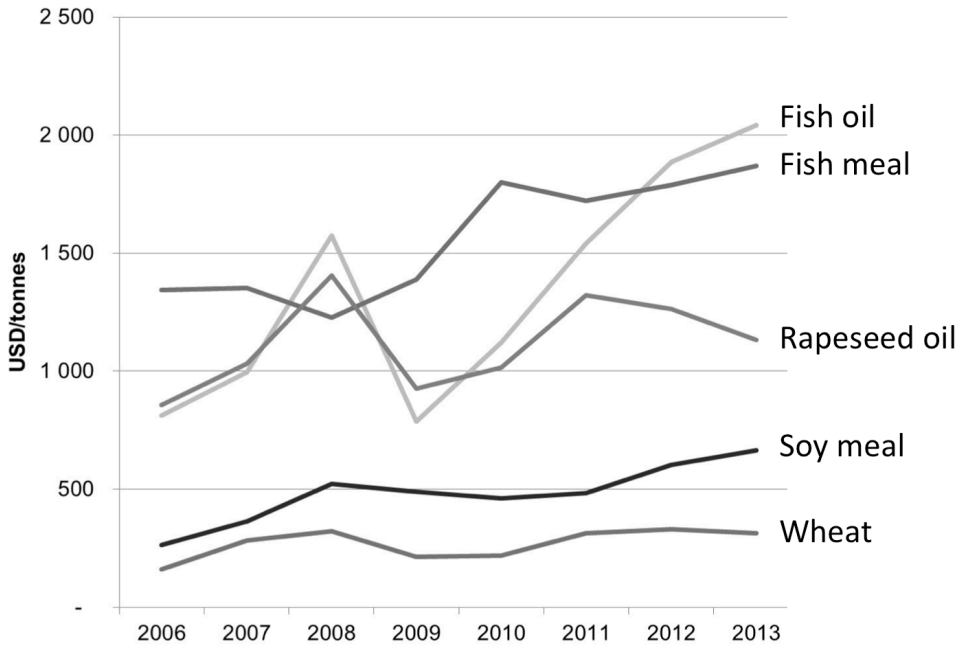


1053

1054 Fig. 1. Nutrient sources in Norwegian salmon farming from 1990 to 2013. Each ingredient type is shown as its
1055 percentage of the total diet (Ytrestøl et al., 2015).

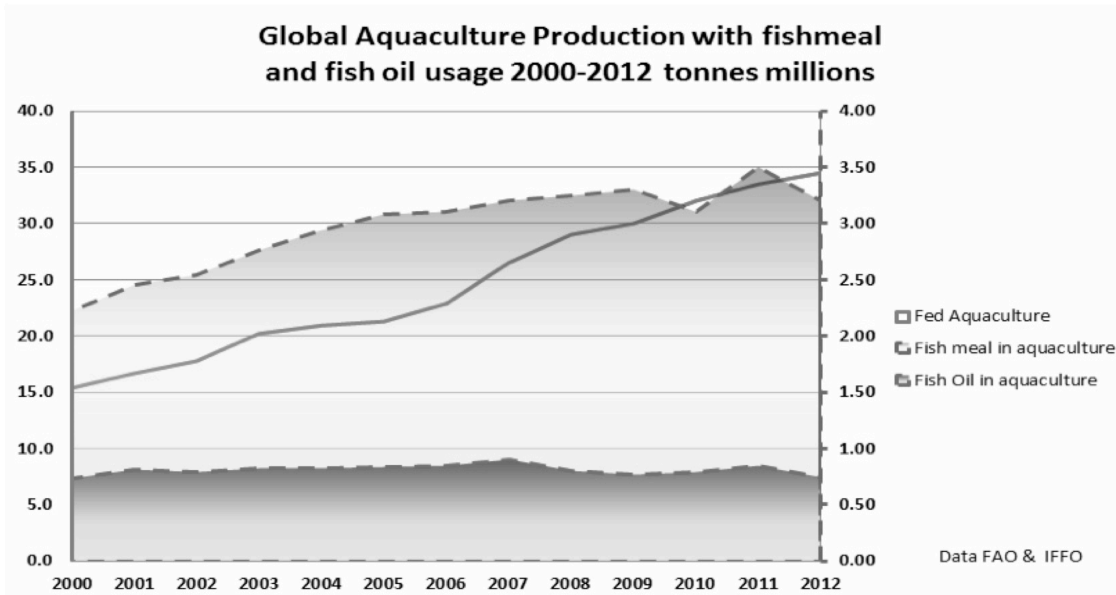
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1058

1059 Fig. 2. Prices of fishmeal, fish oil, rapeseed oil, soy meal and wheat delivered Europe, from 2006 to 2013
 1060 (source: Marine Harvest, 2014, after Chr. Holtermann).



1061

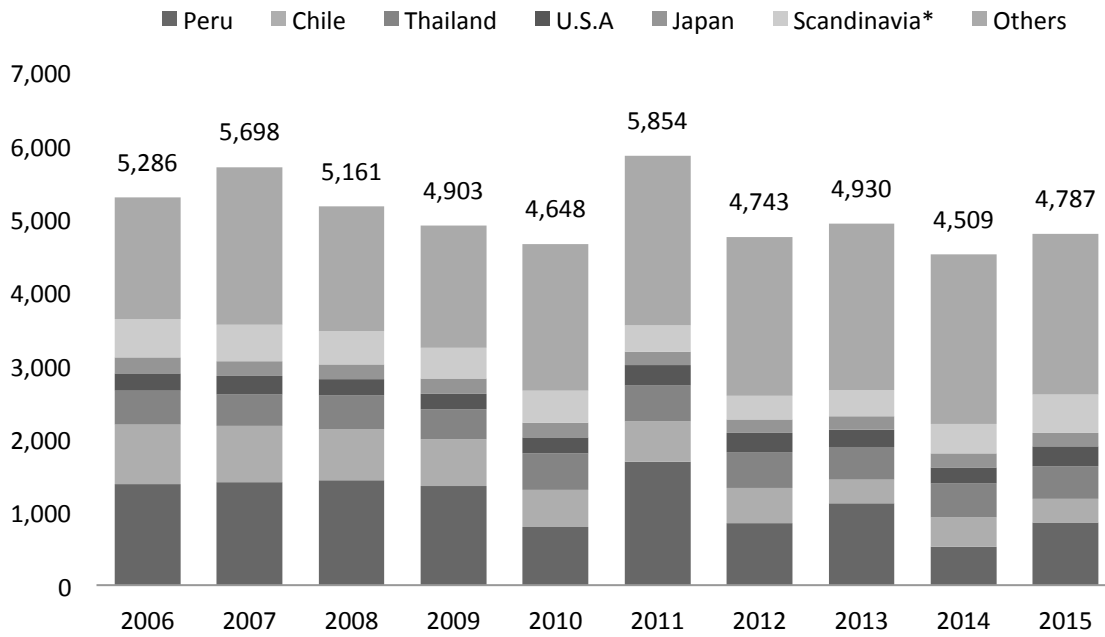
1062 Fig. 3. World fishmeal and fish oil consumption by aquaculture (right axis) (---) compared with growth in 'fed'
 1063 aquaculture (left hand axis) (—) 2000 – 2012 (million tonnes) (sources: IFFO data and FAO, 2014).

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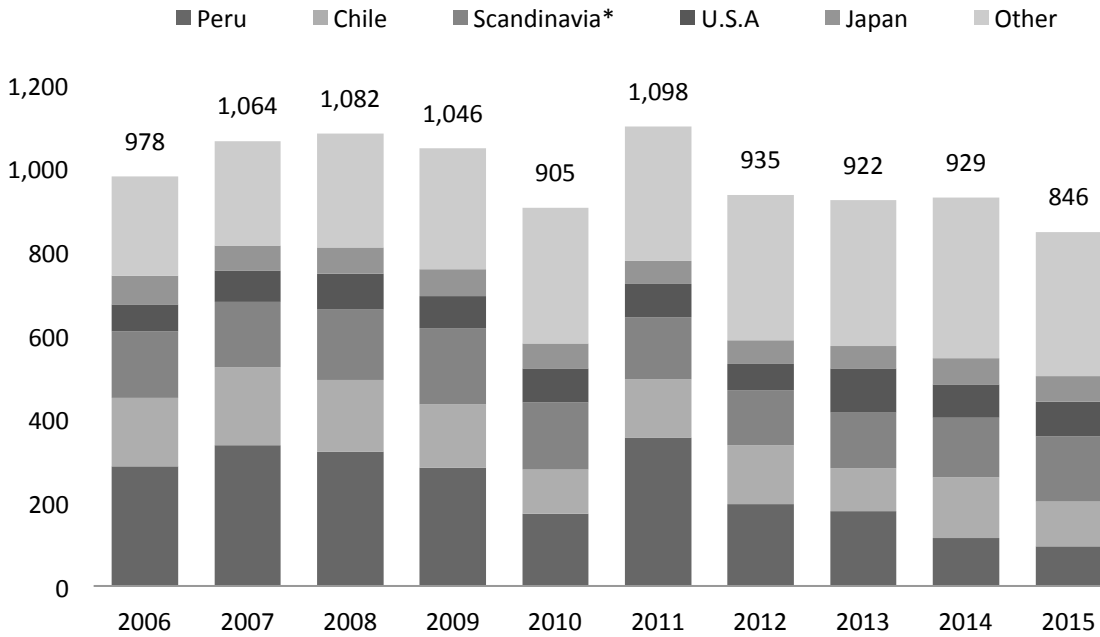


*Includes Denmark and Norway
source: IFFO and ISTA Mielke GmbH, OIL WORLD

1068

1069 Fig. 4. Annual world fishmeal production by major national producer from 2006 to 2015 (tonnes x 1000).

1070

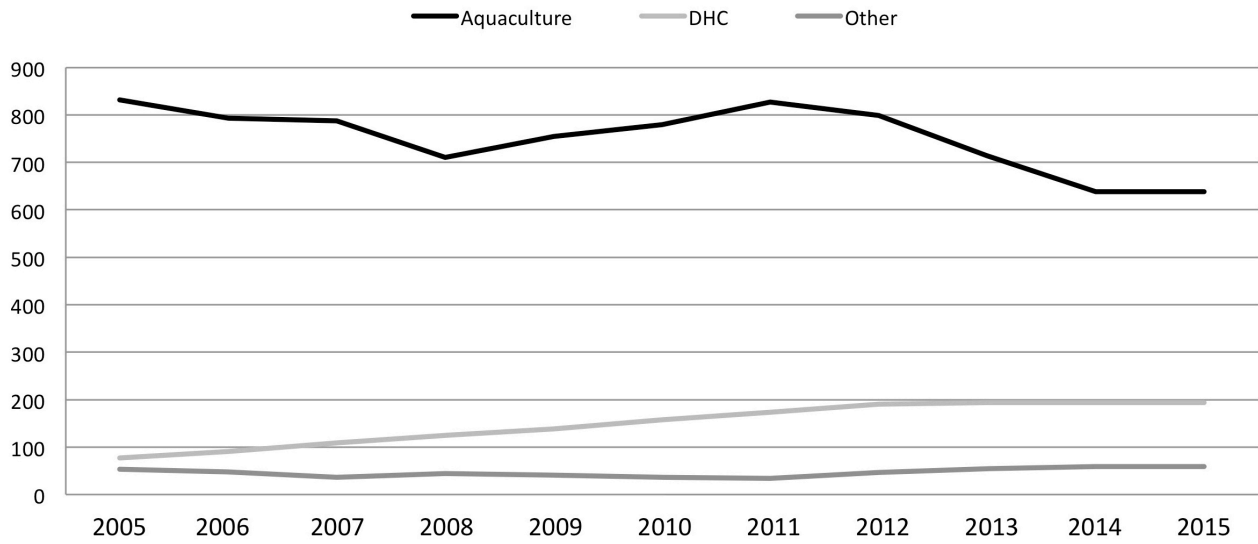


* Includes Denmark, Norway & Iceland
source: IFFO and ISTA Mielke GmbH, OIL WORLD

1071

1072 Fig. 5. Annual world fish oil production by major national producer from 2006 to 2015 (tonnes x 1000).

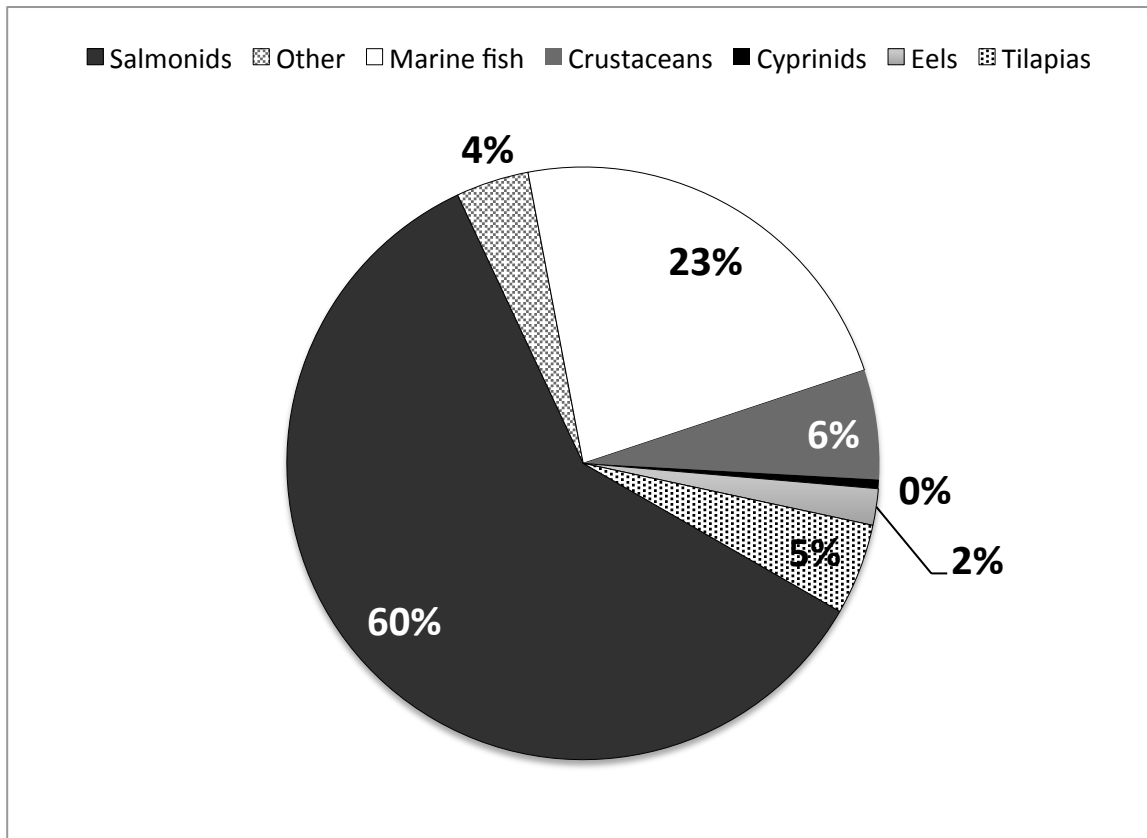
Trends of Use for Fish Oil ('000 mt)



sourced: IFFO

1073

1074 Fig. 6. World fish oil consumption (tonnes x 1000) by aquaculture, direct human consumption (DHC), and other
1075 uses from 2005 to 2015 (source: IFFO).



1076

1077 Fig. 7. Use (% of total aquaculture use) of fish oil by different categories of farmed fish and crustaceans in 2013
1078 (source: IFFO).