A Nuffield Farming Scholarships Trust Report

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How can retail and supply chains support demand for more sustainable aquaculture feed?

Aisla Jones

September 2023

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Nuffield (UK) Farming Scholarships Trust Report

Date of report: September 2023

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	How can retail and supply chains support demand for more sustainable aquaculture feed?
Scholar	Aisla Jones
Sponsor	The Richard Lawes Foundation
Objectives of Study Tour	1. Gain a holistic understanding of the sustainability challenges and opportunities during production of aquaculture feed ingredients through supply chain visits, stakeholder interviews and existing literature. 2. Identify opportunities for retailers and seafood supply chains to encourage best practice and support initiatives to lower the environmental impacts of aquaculture feed baskets.
Countries Visited	Brazil, Norway, Singapore, Thailand, UK and the USA
Messages	• All feed ingredients have environmental challenges and opportunities, these are context specific. • Sustainability can be improved in all feed ingredients- there are examples of improvement efforts globally. • Most aquafeed data collection and certification is currently focused on 'known risks' i.e., environmental impacts of marine ingredients and soy. • Data collection on workers in feed supply chains is limited. • There are opportunities for aquafeed stakeholders i.e., those in aquafeed and aquaculture supply chains to better support feed sustainability initiatives. • Of stakeholders interviewed, future aquafeed priorities included finding sustainable alternative ingredients, improving feed traceability and holistic risk assessment of feed ingredients.

Executive summary

Background

A constraint to the potential growth and long-term sustainability of global aquaculture in the coming decades, is the availability and sustainability of aquafeed (Naylor *et al*., 2021). Aquafeed ingredients may account for up to 90% of the environmental impacts and carbon footprint of farmed fish production (Little *et al*., 2018). In the last few years, many UK retailers and seafood companies have set ambitious carbon emissions targets as well as having broad responsible sourcing policies which include seafood. Scottish Salmon is the UK's largest food export and a popular domestic product (Seafish, 2021). In addition, UK consumers enjoy a range of imported farmed fish species e.g., farmed prawns, seabass and pangasius. These species rely on feed made up of a range of globally sourced ingredients which contributes to the carbon and environmental footprint of the product.

This project aimed to explore the environmental impacts of traditional and 'alternative' aquafeed ingredients and identify opportunities for retailers and seafood supply chains to support more sustainable feed ingredient production and use.

Methods

As part of the Nuffield study tour, six countries were visited: Brazil, Norway, Singapore, Thailand, USA and the UK. Visits and meetings were carried out with a range of aquaculture feed stakeholders including feed ingredient producers, feed manufacturers, fish farmers, researchers, seafood processors, seafood companies and retailers; a sample also participated in in-depth interviews.

Results

Through the study tour, examples of aquaculture feed sustainability initiatives were observed which may mitigate some of the environmental impacts of aquaculture feed production. Aquafeed data collection and certification was largely focused on 'known risks' i.e., environmental impacts of marine ingredients and soy. Stakeholders suggested that feed companies are currently leading work on feed sustainability. Limitations to working more on feed sustainability was largely lack of information and data regarding feed production and sustainability challenges. Finding sustainable alternative ingredients was agreed to be the main priority for future aquafeed sustainability.

Discussion and conclusions

Retailers and suppliers can support more sustainable aquaculture feed through:

- Managing risks e.g., using data and certification; responsible sourcing policies
- Supporting improvement efforts e.g., supply chain engagement, advocacy, and investment

Although there are existing data and certification tools available to the supply chain, supply chains should advocate for improved traceability and transparency of feed ingredients to allow better understanding of feed ingredient production and associated environmental and social risks.

An opportunity to support best practice and drive sustainability could be the creation of an independent holistic risk assessment tools focused on feed ingredients and in a format readily accessible to non-feed experts. More clear and consistent asks from aquaculture supply chains could encourage feed companies to prioritise feed sustainability when formulating feed. Collaboratively addressing responsible sourcing of aquaculture feed ingredients could support the long-term sustainability and availability of feed ingredients for the aquaculture sector.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body.

Please note that the content of this report is up to date and believed to be correct as at the date shown on the front cover.

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Nuffield Farming Scholars are available to speak to NFU Branches, Agricultural Discussion Groups and similar organisations.

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Personal introduction

I grew up in coastal North Wales with a passion for the outdoors and the environment and subsequently studied a BSc in Zoology and MSc in Marine Biology. Having spent time carrying out ecological fieldwork in various countries, I had visions of going to work on a tropical beach after my masters. However, after an insightful lecture series on tropical shrimp aquaculture, I realised I could combine my interests of science, travel and food in a fast-paced environment by working in the seafood industry. I was offered a timely job as a research assistant at Bangor University after I graduated working on a knowledge exchange project on the environmental impacts of aquaculture.

Subsequently, I worked for several years in research and for environmental NGOs in the UK and abroad before entering the world of UK retail as the Fisheries & Aquaculture Manager for Co-op. There I was responsible for creating and updating responsible sourcing policies for seafood and working in collaboration with Co-op suppliers and the seafood industry on various sustainability initiative. During this time, I realised that retailers can either be a help or a hinderance to improving the sustainability of seafood supply chains and there is opportunity to leverage the power of retailers more effectively.

An area I became particularly interested in through my experiences was aquaculture feed however, my questions list on the topic became far too extensive to answer during my day-to-day role. A conversation with a previous Nuffield scholar introduced me to the Nuffield programme which provided a fantastic opportunity to explore the topic of aquaculture feed and supply chain action more thoroughly. To my delight, I was accepted as part of the 2021-year group in the midst of the global Covid 19 pandemic. It's proved to be an invaluable experience and I'm looking forward to seeing where it takes me.

Chapter 1 - Introduction

1.1 Aquaculture feed

Overview

Aquaculture is the fastest growing protein sector globally (FA0 2022). Farmed fish are vital to meet future global protein needs which, based on current trends, will rise 70% by 2050 (Ninnes, 2021). A constraint to the potential growth and long-term sustainability of global aquaculture in the coming decades, is the availability and sustainability of aquafeed (Naylor *et al*., 2021). For the industry to reach its projected volumes, enough nutritionally viable, economical, and sustainable feed ingredients need to be available for use by the sector (Tacon, 2020).

Scottish Salmon is the UK's largest food export and a popular domestic product (Seafish, 2021). In addition, the UK imports a range of farmed seafood species such as shrimp, pangasius and seabass (Seafish, 2021), all of which rely on feed. Although this project focuses on aquaculture feed, there are many commonalities with terrestrial agriculture systems.

This Nuffield project will explore the environmental sustainability of existing and alternative aquafeed ingredients and investigate opportunities for retailers and seafood supply chains to support more sustainable aquafeed supply chains.

1.1.2 What ingredients make up the aquaculture feed basket?

Demand for aquaculture feed is projected to reach 73.15 million tonnes by 2025 as global aquaculture production increases (Tacon, 2020) and compound feed is utilised by 70% of global aquaculture (FAO 2020).

Aquaculture feed is made up of a variety of ingredients which may be sourced from a global commodity market (Cargill, 2022; Skretting 2022; Table 1). Aquafeed is often sourced far from aquaculture farms and the aquafeed industry is increasingly globalised (Tacon *et al*., 2011; Figure 1).

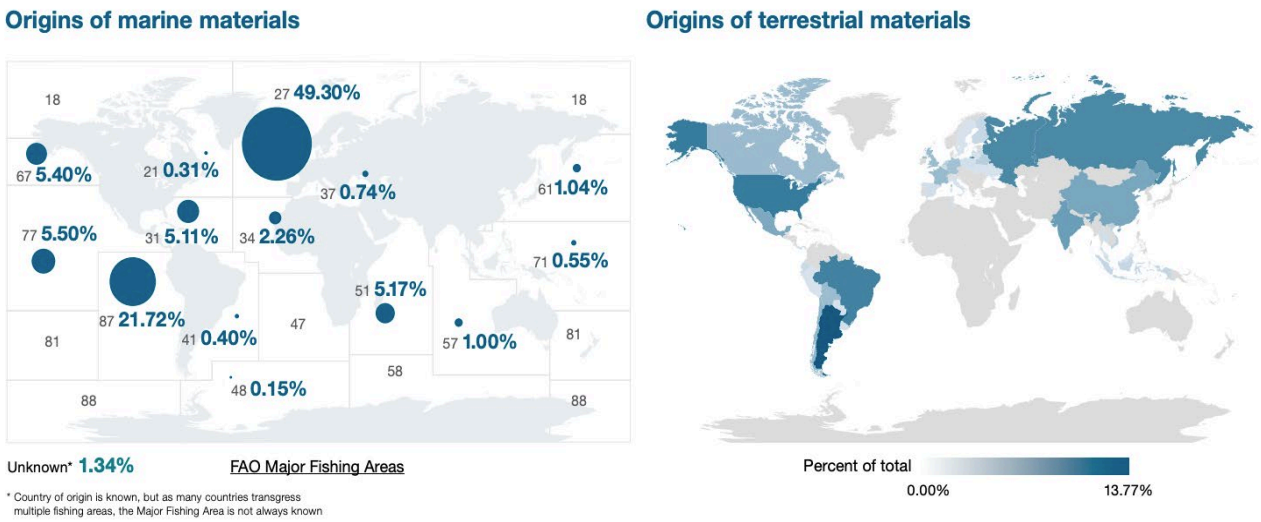


Figure 1: Origins of marine (left) and terrestrial (right) Cargill aquafeed ingredients for global aquaculture feeds. (Cargill, 2022

Table 1: Overview of ingredients included in Skretting aquaculture feeds for Salmon, seabass& sea bream, shrimp and tilapia with average inclusion percentages (Skretting, 2022).

	Primary raw material	Ingredient group	Typical examples	Salmon	Sea bass & Sea bream	Shrimp[2]	Tilapia	Average Skretting
				average % inclusion in feed				
Protein	Wild capture and farmed fish and crustaceans	marine proteins	fish meal, crustacean meal	13.2	19.8	11.3	1.2	**12.6**
	By-products from farmed land animals	land animal proteins[1]	poultry meal	13.3	21.8	4.5	9.6	**10.2**
	Agricultural crops	vegetable proteins	wheat gluten, corn gluten, soybean meal, soy protein concentrate, rapeseed meal, sunflower meal, lupin, faba	33.3	29.5	43.1	41.6	**35.4**
Fat	Wild capture, algae, farmed fish and crustaceans	fish oil, algal oil	fish oil, algal oil	9.7	3.2	1.5	0.3	**5.7**
	Agricultural crops	vegetable oils	rapeseed oil, soybean oil, camelina oil	18.1	3.8	2.6	0.2	**9.0**
	By-products from farmed land animals	land animal oils[1]	poultry oil	1.5	1.4	0.0	0.0	**0.9**
Carbohydrates	Agricultural crops	starch raw materials	wheat	9.0	19.2	29.5	42.2	**19.5**
Micronutrients	Various	vitamins minerals pigments	vitamin premixes, mineral premixes, pigments	1.9	1.3	7.5	4.9	**6.7**

1 Use of land animal by-products will depend upon market acceptance and legislation

2 Level of starch raw materials will be different in extruded and pelleted feed

1.2 Factors affecting the sustainability of aquafeed ingredients.

Improving the feed conversion ratio (FCR) of farmed fish is often the focus when looking to improve efficiency and sustainability in aquaculture production. However, aquafeed ingredients may account for more than 90% of the environmental impacts of aquaculture production (Little *et al*., 2018). Therefore, UK seafood supply chains may well take a keen interest in the sustainable production of aquafeed ingredients.

1.2.1 Declining inclusion of marine ingredients

The opening gambit to many studies cites marine ingredients as the highest risk ingredient in aquaculture feed due to the use of wild capture fisheries which may be overfished and not managed responsibly (Hansen *et al*., 2019). Fishmeal and fish oil (FMFO) historically made up a large proportion of the diet of carnivorous aquaculture species diets, which rely on marine ingredients to provide essential omega 3 fatty acids, which plant oils may not be able to deliver (Sprague *et al*., 2016).

FMFO inclusion has drastically declined over recent decades and in 2021, made up around 25% of Scottish salmon diets (Skretting 2021). Globally, marine ingredients made up 7% of aquafeed ingredients (Fry *et al*., 2016; Figure 2). Fish-in-Fish-out (FIFO) ratio is used to measure the volume of fish fed to aquaculture to ensure the sector is not depleting wild fish stocks (Kok *et al*., 2020). Forage fish dependency ratio for fishmeal and fish oil is also used to calculate the volume of wild fish converted to farmed fish (Naylor *et al*., 2021).

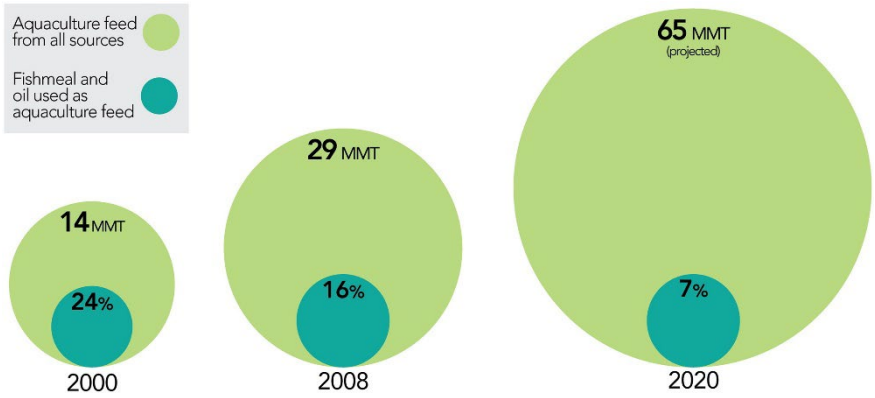


Figure 2: Expansion of global compound aquaculture feed. From 2000- 2020, fishmeal and fish oil use volumes remain static but their proportion of overall feed volume declines (from Fry et al., 2016 using data from Tacon& Metian, 2015 and Tacon *et al*., 2011).

1.2.2 Shifting the problem: 'Alternative' feed ingredients.

Marine ingredients are increasingly being fully or partly replaced by terrestrial crops and other ingredients (Table 1; Mitra, 2021; Naylor et al 2021). Some refer to these ingredients as 'alternative' or 'novel' ingredients, although there is no agreed industry definition.

There is growing concern that increasing use of terrestrial ingredients could shift environmental impacts onto land rather than the sea (Malcorps *et al*., 2019). Of particular concern is the production of soy, especially in Brazil where areas of high conservation value in the Amazon and Cerrado, have been used for soy plantations causing high rates of carbon emissions due to deforestation and land conversion (Fry *et al.,* 2016; WWF, 2019). A range of other plant ingredients are used in aquaculture diets as an oil or protein source such as rapeseed, corn, wheat, sunflower oil and guar meal (Skretting, 2022).

1.2.3 'Novel' ingredients

Novel ingredients such as single celled proteins, insects and algae have been hailed as having potential to alleviate the impacts of high-risk marine and terrestrial ingredients (Malcorps *et al*., 2019). Some algae have high levels of omega 3, making them suitable to replace fish oil whilst still delivering health benefits to consumers (Turchini *et al*., 2010). However, most 'novels' need to achieve scale to be competitive with traditional ingredients (Naylor *et al*., 2021) and more data is needed to assess trade-offs.

1.2.4 Measuring aquafeed ingredient impact

Life cycle assessment (LCA) can be utilised to compare environmental impacts of aquafeed diets (Silva *et al*., 2018; Pelletier *et al*., 2018; Figure 3). Geographical origin and processing methods can cause a large amount of variation e.g., Brazil vs USA soy differed greatly in terms of land use and deforestation (Fry *et al*., 2016; Malcorps *et al*., 2019). There is little assessment of sustainability factors beyond environmental.

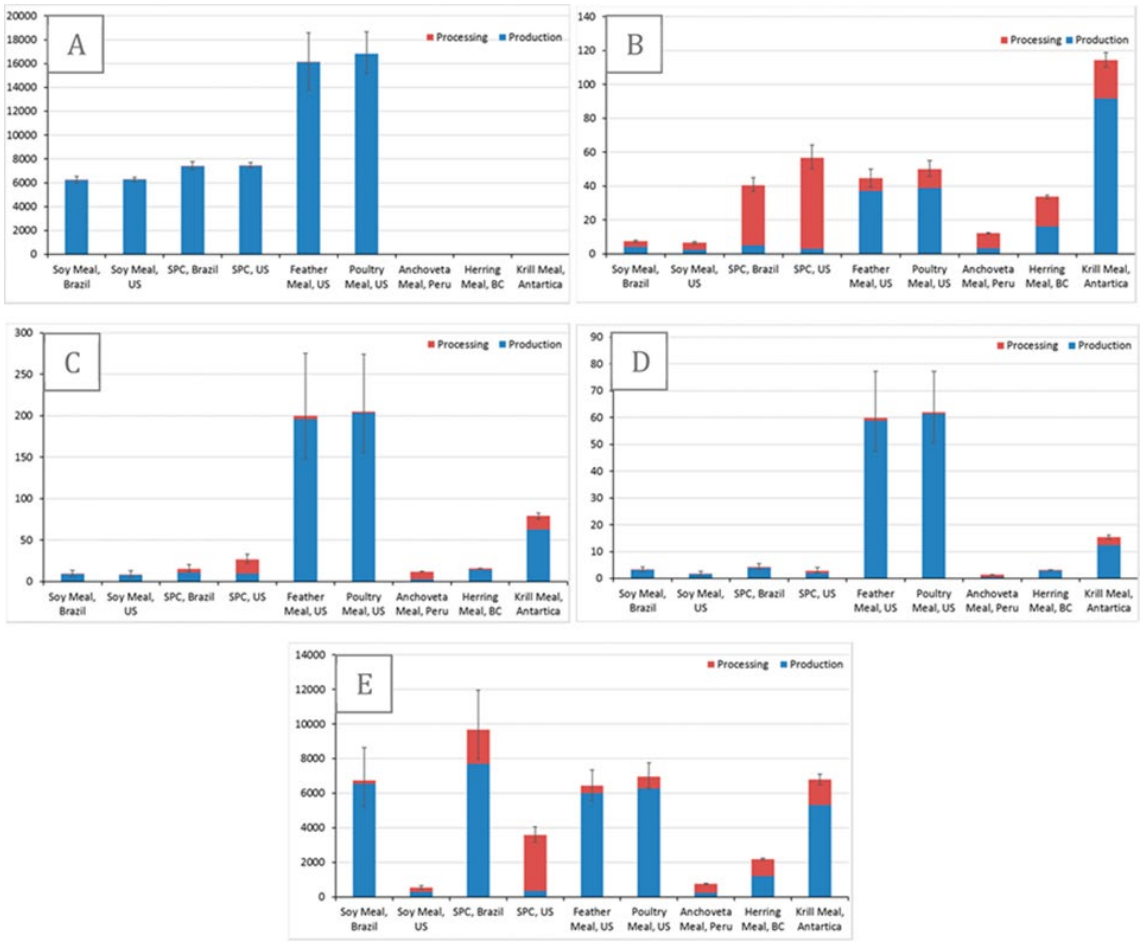


Figure 3: Estimated impacts of potential aquaculture ingredients on (A) land use (m3), (B) energy use (GL), (C) acidifying (kg SO_2-e), (D) eutrophying (kg P_2O_4-e), and (E) GHG (CO_2-e) emissions from source to feed mill using gross allocation LCA (ISO 14040 and 14044) from Pelletier *et al*., 2018.

Several areas have been omitted from this study due to word and time constraints i.e., live feed, GM material, terrestrial animal by-products, micronutrients, and feed for specialist systems e.g., Recirculating aquaculture systems. Each could be a Nuffield study in its own right.

1.3 Responsible sourcing of aquaculture feed

1.3.1 Aquafeed and the aquaculture value chain

Whilst some ingredients are sourced locally, some travel thousands of kilometres to reach feed mills where feed is formulated into pellets and may go through multiple companies on this journey (Skretting, 2022). Once feed is manufactured, there may be multiple players in multiple countries between feed producers and finished seafood products which in the UK are largely sold to consumers through retailers and food service outlets (Figure 4).

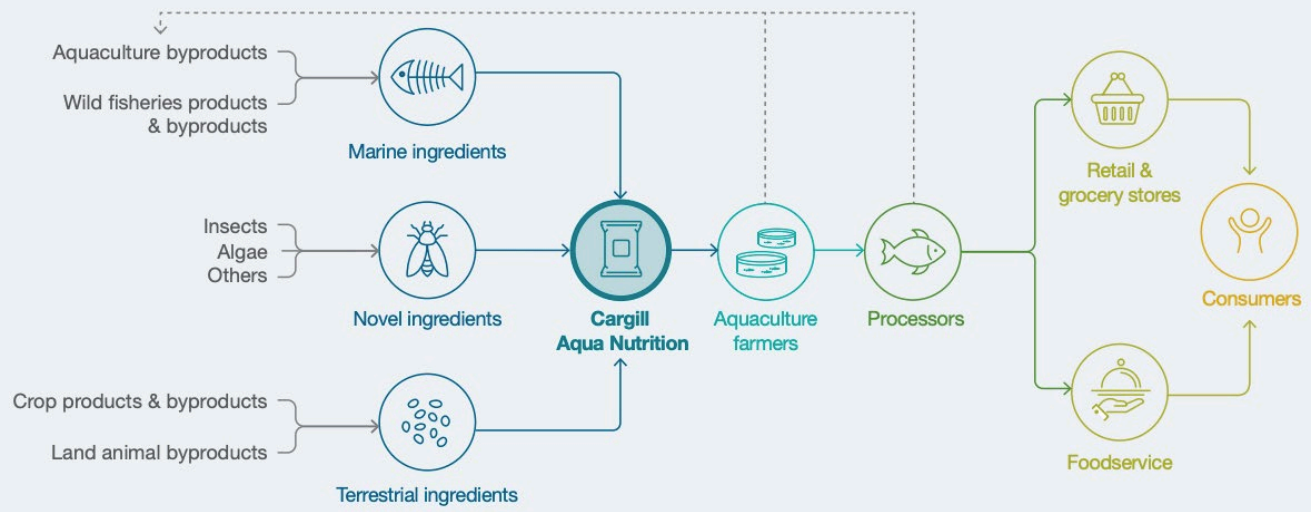


Figure 4: The main players in the aquaculture value chain from feed ingredients to consumer (NB. There may be more supply chain actors in between each stage). (Cargill, 2022)

1.3.2 Responsible sourcing tools available to retailers

Retailer and seafood company policies

Companies throughout supply chains can influence feed ingredient production through in-house policies and purchasing practices (Naylor *et al*., 2021). The Sustainable Seafood Coalition's voluntary codes for responsible sourcing of seafood guide the policies of most UK retailers along with seafood and food service companies. However, only marine feed ingredients are included in scope within the aquaculture sourcing guidelines (SSC, 2021).

Third party certification schemes and ratings tools

UK retailers heavily rely on third party environmental certification schemes to provide assurance and to manage supply chain risks (Osmundsen *et al*., 2020). The major aquaculture certification schemes (Aquaculture Stewardship Council (ASC), Best Aquaculture Practice (BAP) and Global Good Agricultural Practices (Global GAP) have historically focused on the sustainability credentials of marine ingredients to differing extents when assessing feed (Mariojouls *et al*., 2019). Despite increasing inclusion, terrestrial ingredients are given less consideration by aquaculture certification schemes and seafood ratings tools, with the focus on soy and palm oil (Table 2).

Table 2: Consideration of feed ingredients by seafood certification schemes and NGO seafood ratings tools.

Certification scheme	Version	Responsible sourcing scoring criteria- feed ingredients		
		Fishmeal and fish oil	Soy and palm oil	Other terrestrial ingredients
Aquaculture Stewardship Council (ASC)	Version 1.01, 2023	✓	✓	✓
Global Aquaculture Alliance, Best Aquaculture Practices (BAP)	Issue 3.0 June 2020	✓	✓	☒
Global GAP: Responsible operations standard add- on for compound feed manufacturers	Version 3.1, 2022	✓	✓	☒
Seafood ratings tool				
Marine Conservation Society: Good Fish Guide, Aquaculture Ratings Methodology Handbook	Version 4 2022	✓	✓	☒
Sustainable Fisheries Partnership: FishSource Aquaculture Scoring Methodology	Version 4, March 2018	✓	☒	☒
WWF: The Common Aquaculture Methodology	Version 2.3, April 2015	✓	✓	✓
Monterey Bay Aquarium, Seafood Watch: Standard for Aquaculture	Version A4.0, April 2020	✓	✓	✓

Several schemes certify individual feed ingredients and are utilised by retailer polices, third party certification schemes and NGO seafood risk rating tools. These include Marine Stewardship Council (MSC) and Marin Trust for marine ingredients supply chains and Round Table on Responsible Soy (RTRS) and ProTerra for soy. Within average global marine ingredients production, 49% was certified to the Marin Trust standard, 2019- 2023 (Marin Trust, 2023). WWF reported 77% of UK imported soy was from high-risk locations with only 2% of globally traded soy from sources meeting RTRS or ProTerra standards (WWF, 2019). 'Alternative' terrestrial and 'novel' ingredients are largely uncertified however, there are recent examples of algae and insect ingredients gaining third party accreditation e.g., Veramaris algal oil is accredited to the MSC/ASC Seaweed standard whilst InnovaFeed has achieved Naturland certification. The ASC feed standard accepts seventeen different third-party certification schemes to evidence environmental and/ or social risk mitigation in aquafeed ingredients (ASC, 2023).

1.3.3 Why should retailers care about feed?

In the last few years, UK retailers have been scrutinised for their sourcing policies for soy (WWF, 2022) and marine ingredients (Changing Markets, 2020). Studies have found varying levels of Omega 3 in Scottish salmon products of UK retailers reflecting the varied approaches to diet composition (Sprague *et al.,* 2016). In addition, retailers must consider consumer acceptance of potential feed ingredients such insect meal, poultry by-products and GM (Costello *et al*., 2019), although this is an understudied area.

More recently, several retailers e.g., Co-op and seafood companies have set ambitious scope 3 carbon emissions targets (i.e., emissions from value chains of food sourced and sold) and have broader targets on assessing the environmental impacts of food e.g., WWF basket metrics (Table 3). UK retailers have also set targets for specific feed ingredients as part of wider responsible sourcing policies e.g., deforestation and seafood (Table 3)

Table 3: Co-op Climate change and responsible sourcing policies with relevant targets for aquaculture feed ingredients (Co-op, 2022; Co-op, 2023)

Public facing commitment	Feed ingredient covered	Target
Co-op responsible sourcing policy: seafood	Marine ingredients	Preferred standards Marine Stewardship Council and/ or Marin Trust
Co-op Code of Practice: Soya	Soy	All soy used in Co-op products, including embedded in animal/ fish feed, must be deforestation and conversion free (with a cut-off date of 2020) and responsibly sourced by the end of 2025
Co-op climate plan	All	Reducing Scope 3 carbon emissions by 11% by 2025
WWF Basket	All	Halve the environmental impact of UK shopping basket by 2030

Farmed salmon (largely from Scotland and Norway) and imported farmed shrimp (SE Asia and Latin America) make up two of the top five seafood species consumed in the UK (Seafish, 2022). Along with the significance of aquaculture feed to the overall carbon and environmental footprint of seafood products, feed also represents the highest input costs in many farmed fish systems. These factors have been compounded by uncertainly created by geopolitical events such as Brexit and the Ukraine conflict. As a result, many retailers are looking to understand their seafood supply chains better to ensure surety of supply as well as meeting their ambitious sustainability targets.

Chapter 2 - Aims and Objectives

Aims:

Explore the environmental impacts of traditional and 'alternative' aquafeed ingredients and identify opportunities for retailers and seafood supply chains to support more sustainable feed ingredient production and use.

Objectives:

1. Gain a holistic understanding of the sustainability challenges and opportunities during production of aquaculture feed ingredients through supply chain visits, stakeholder interviews and existing literature.
2. Identify opportunities for retailers and seafood supply chains to encourage best practice and support initiatives to lower the environmental impacts of aquaculture feed baskets.

Chapter 3 - Materials and methods

To examine the impacts of the production of aquaculture feed ingredients and opportunities for aquaculture supply chains to support sustainable feed production, a combination of international site visits and interviews (in- person and virtual) of aquafeed stakeholders took place.

3.1 Nuffield scholarship international travel

Visits were carried out in six countries between August 2021 and October 2022, chosen based on their significance to aquaculture, aquafeed production and supply chains (Table 4). Countries visited were Brazil, Norway, Singapore, Thailand, UK and the USA. In addition, virtual meetings took place with stakeholders across multiple countries (due to the Sars Covid- 19 pandemic and resource constraints). These visits and meetings provided a comprehensive background to the study topic and provided context for the in-depth interviews.

Table 4: Countries visited during the Nuffield study tour with dates visited justification for country selection.

Country	Visited	Reason for visit
UK	Various 2021-2022	Salmon is the UKs largest food export; various innovative aquaculture and aquafeed operations
Norway	May 2022	The world's largest producer of farmed salmon; leading research and development in aquaculture and feed sectors.
Singapore	July 2022	A hub for aquaculture technology and start-ups. The country has ambitions to increase domestic food production.
Thailand	July 2022	89% of global aquaculture comes from the Asian continent from small to commercial scale. Thailand is a significant producer of farmed shrimp and marine ingredients for feed.
Brazil	October 2022	The world second largest exporter of soy for animal/ fish feed. Heavy media criticism in recent years for loss of the Amazon rainforest for crops e.g., soy and cattle grazing.
USA	October 2022	Home to one the world's largest land-based salmon farms as well as research into alternative seafood species and alternative feed ingredients.

3.2 Interviews with aquaculture and aquafeed stakeholders

3.2.1 Who was involved?

Visits and meetings were carried out with a range of sixteen stakeholders including feed ingredient producers, feed manufacturers, fish farmers, researchers, seafood processors, seafood companies and retailers. A sample of stakeholders were selected for in depth interviews (Table 5) to represent the breadth of industry perspectives.

Table 5: Feed and aquaculture industry stakeholders' visits or meetings (shaded box) and stakeholder interviews conducted (X in box) in each country. X may represent more than one stakeholder.

Country- supply chain actor visit/ meeting	Feed ingredient producer	Feed manufacturer	Aquaculture producers (Fish farmers)	Aquaculture/ feed stakeholder- seafood supply chain and researchers
UK	X			X
Norway	X	X	X	X
Singapore			X	X
Thailand		X		
Brazil	X		X	
USA	X			

3.2.2 Interview approach

Given the narrow focus of this study, it was decided to conduct in-depth interviews with experts in aquaculture and aquafeed to understand stakeholder approaches to responsible sourcing. Interview responses were collated using Aberystwyth University's online survey programme, Jisc and each participant agreed to the universities ethical policy before taking part in the interview (Aberystwyth University Assessment ID reference 22682). Interviews were recorded for verification purposes only. Data were stored using JISC to keep data secure.

3.2.3 Interview design

In depth interviews were carried out through structured one on one interviews, either in person or online.

A series of questions were put to interviewees (Appendix 2) addressing two areas:

1. Factors affecting the sustainability of aquafeed ingredients.
2. Responsible sourcing of feed and supply chain action

Three versions of the interview were used in which the questions were slightly different depending on the stakeholder group: 1) aquafeed ingredient producers, 2) aquafeed supply chain and 3) aquafeed stakeholders.

3.2.4 Analysis of results

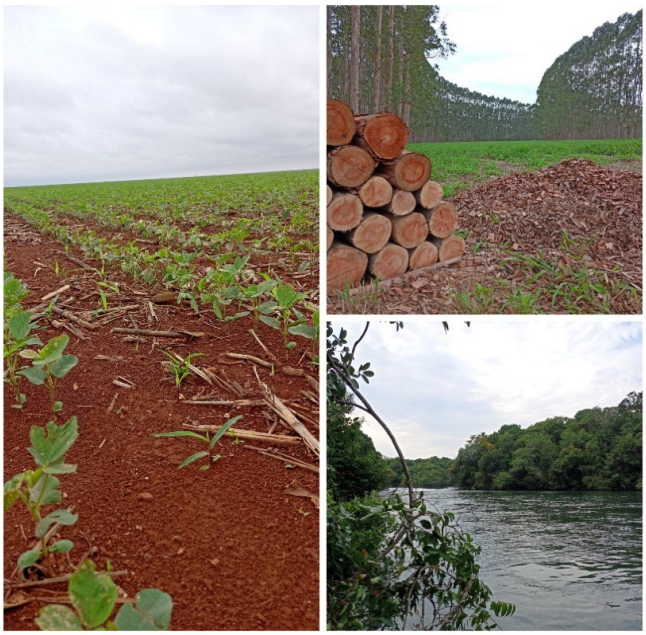
From the sixteen interviews, fourteen interview transcripts were analysed (two transcripts were of insufficient quality and/ or incomplete so were omitted).

Interviews were transcribed by hand from audio recordings then analysed using Thematic content analysis (TCA) of transcripts to identify themes and salient quotations (as described by Clark and Braun, 2017) for the questions where this analysis was deemed appropriate. Salient quotations were then grouped into raw data themes then clustered together to form first order themes or second order themes where appropriate.

Chapter 4 - Results

4.1 Part 1: Factors affecting the sustainability of aquafeed ingredients.

When considering the sustainability of any aquafeed ingredient, a range of advantages and challenges were identified by aquafeed stakeholders in addition to the published literature (Table 6). For example, although marine ingredients can come from overfished sources, there is increasing use of fishmeal and fish oil from trimmings from the seafood industry e.g., Norway pelagic fisheries (Appendix 1). Although many 'novel' ingredients may have fully traceable supply chains e.g., algal oil, the environmental impacts of the growth substrate (e.g., Brazil yeast production using sugar cane) also need to be considered.



Picture 1: A soy farm in Mato Grosso state, Brazil. Clockwise from left: Newly planted soy; Agroforestry project on the soy farm; Native vegetation is set aside on the farm, a legal requirement in Brazil.

Throughout Nuffield farming scholarship travel, interviews and discussions, a range of aquaculture feed sustainability initiatives were observed which may mitigate the environmental impacts of aquaculture feed production (Table 7). These included on farm practices such as regenerative farming principles e.g., Brazilian soy, utilisation of 'waste' products e.g., Singapore insects and use of third-party certification e.g., USA algal oil. Examples of collaborative stakeholder initiatives were also in place including stakeholders from fisheries through to retailers (Table 7 and Appendix 1).

Table 6: An overview of the challenges and advantages of marine and 'alternative' ingredients in aquaculture feed from the literature and evidence from Nuffield farming scholarship travels. Sources Bandara, 2018; Fry *et al*, 2016; Gasco *et al*., 2018; Hoegh-Guldberg *et al*. 2019; Kim *et al*., 2019; Malcorps et al., 2019; Osmond& Colombo, 2019; Newton & Little *et al*., 2017; Popoff *et al*. 2017; Shepherd *et al*., 2017; Ssepuuya *et al*., 2019; Tacon *et al*., 2011 adapted from Costello *et al*., 2019.

Ingredient category	Challenges	Advantages
Marine ingredients (fishmeal and fish oil)	Finite resource, some high risk sources- overfishing/ poor management, some sources may compete with human food, some sources have complex supply chains, nutritionally variable, may be high risk for workers, negative portrayal by media and some NGOs	Fish oil source of omega 3, can have lower greenhouse gas emissions than land based alternatives, third party certification utlised for feed supply chains (MSC, Marin Trust), 30- 70% of fish processing waste potentially available and added revenue from by-products, price competitive.
Terrestrial plant ingredients- protein and oil (e.g. soy, rapeseed, wheat, maize, groundnuts, guar)	Lower nutritional profile (e.g. omega 3), may need additives to make palletable, some high risk sources- water use, fertiliser/ pesticide use, land demand, potential for deforestation and land conversion e.g. Brazil soy= high carbon footprint, may be high risk for workers, poor traceability, negative portrayal by media and some NGOs (soy), competition with terrestrial agriculture supply	Price competitive, large volumes produced globally, variety of plants utilised, straightforward logistics, high nutrient density, some third party certification- soy (e.g. ProTerra, RTRS), palm oil (RSPO), potential for regenerative principles
Terrestrial animal by-products (e.g. poultry meal, feather meal, blood meal)	Varied nutritional quality, no omega 3, policy and regulation challenges (e.g. not used in Scottish salmon diets), possible consumer perception challenges, historic BSE challenges in UK, potentially high environmental impacts (e.g. carbon footprint) associated with primary protein production (e.g. poultry feed impacts)	Price competive, lower feed costs, large volumes produced globally, environmental impacts associated with primary protein production.
Single celled proteins (e.g. microalgae, yeast, bacteria)	High production cost, needs to achieve scale, growth medium (e.g. sugar cane) production impacts need to be assessed.	Some comparible nutritional profile to marine ingredients e.g. algae- omega 3, some may have lower greehouse gas emissions than land based alternatives,
Insects (e.g. black soldier fly)	Need to scale up, possible consumer perception challenges.	High protein content, realtive ease of production, can utilise waste from human food supply chains.

Table 7: Examples of sustainability initiatives related to aquafeed observed during Nuffield farming scholarship travel and/ or interviews. NB this is not an exhaustive list!

Sustainability initiative in feed ingredients	Example from Nuffield travels/ interviews
Third party certification e.g., Marin Trust, ASC, ProTerra, RTRS	Brazil soy (RTRS, ProTerra, Cargill SSS) (Picture 1) USA algal oil (ASC/MSC) UK/ Norway marine ingredients (MSC/ Marin Trust) Norway salmon (ASC) (Picture 8) Thailand shrimp feed mills (BAP, Marin Trust, MSC, RTRS, Cargill SSS) (Picture 3) ASC feed standard
Regenerative farming principles	UK fava beans (Picture 6) Brazil soy (Picture 1)
Carbon footprint analysis	UK/ Singapore insects USA algal oil Brazil soy UK/ Norway marine ingredients
Local feed sourcing	Brazil tilapia (Picture 4) Thailand small scale aquaculture (excl soy/ FMFO) (Picture 2)
Utilisation of 'waste' products	UK/ Singapore insects Brazil tilapia Brazil yeast USA algal oil Norway marine ingredients
Research and development	UK/ Singapore/ Norway: Alternative ingredient feed trials (Picture 5) Singapore/ USA/ Norway/ UK: Recirculating aquaculture systems (RAS) USA: Alternative aquaculture species research
Collaborative stakeholder initiatives	Thailand marine ingredients- Marin Trust Improver Programme (Picture 7) Norway salmon- feed holistic risk assessment Norway salmon- Brazil soy advocacy UK soy manifesto IFFO Marine ingredients roundtable North Atlantic Pelagic Advocacy group

Picture 2: A small-scale organic farm, Koh Phangan, Thailand. Clockwise from top: Grouper and other fish species are grown on the farm fed with some ingredients grown on farm; Grouper curry with farm produced ingredients; The team at Raitiaviset Organic farm.

Picture 3: A large feed mill near Bangkok, Thailand. Shrimp feed is produced here largely for domestic shrimp farms. Feed ingredients are imported from all over the world to make into compound feed pellets. Clockwise from top: compound feed bags ready to be shipped, a tour of the feed mill, feed pellets from the production line.

Picture 4: The Copacol cooperative in Paraná state, Brazil incorporates the entire value chain from feed ingredient producers and tilapia farmers to retail outlets. Feed ingredients fed to tilapia are produced locally from within the same state. Clockwise from left: Farmed tilapia products on sale in a supermarket, tilapia ponds at a farm, tilapia industry professionals on a farm tour.

Picture 5: Testing 'alternative' feed ingredient performance is a critical part of moving to more sustainable aquaculture feed. Research centres such as Pontus Group, St John's Island Singapore carry out trials of new feed formulations.

4.2 Part 2: Responsible sourcing of feed and supply chain action

4.2.1 Aquafeed data and certification use in aquafeed supply chains.

Almost half of aquafeed stakeholders (46%) were not asked any questions about aquaculture feed ingredients by their customers. The most common queries were around the environmental impacts of marine ingredients and soy.

Environmental third-party certification scheme data were collated by 60% of supply chain stakeholders (excluding feed ingredient producers) for at least one of fishmeal/ fish oil (Marine Stewardship Council, Marin Trust), soy (ProTerra, RTRS) and palm oil (RSPO). 40% of interviewees collated data about ingredients beyond marine, soy and palm oil however, data were limited to the country of production. Two interviewees stated they collate data on third party aquaculture certification schemes e.g., ASC, in order to assess feed ingredient sustainability rather than collating ingredient specific data.

None of the stakeholders interviewed had already established systems of collating data about workers involved in the production of feed ingredients. However, several stakeholders (30%) interviewed identified that they are currently exploring how to do this.

4.2.1 Who is responsible for ensuring sustainable aquafeed?

When asked to nominate who in the aquafeed and aquaculture industry is currently working on feed sustainability, 83% of stakeholders identified feed companies (Figure 5) which were always cited first. Retailers and fish farmers were also highlighted multiple times (33% and 25% respectively) as stakeholders currently working to improve the sustainability of aquaculture feed (Figure 5).

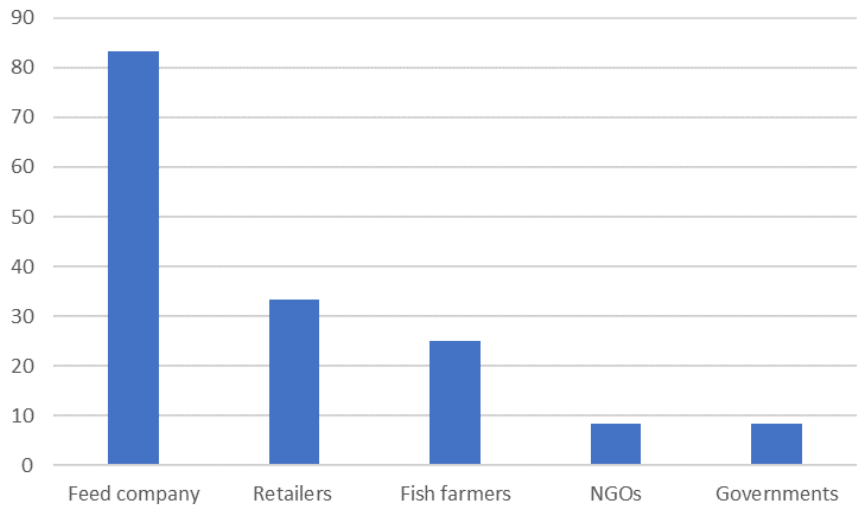


Figure 5: Stakeholders responses to the question: 'Who in the supply chain and aquaculture industry currently takes responsibility for ensuring sustainable aquaculture feed?'

'Feed manufactures are leading the progress of sustainability development in aquaculture feed. This is mainly through self-initiatives which are competitive, and marketing led'

- ***Stakeholder 10***

'Some of the big multinational feed companies are not buying soy and corn from farms in the Amazon biome in Brazil. In some cases, supermarket chains are taking responsibility for feed sustainability, but this may be driven by broader sustainability marketing campaigns.

- **Stakeholder 6**

Feed companies were also highlighted as those who *should* be working to improve feed sustainability; twelve of fourteen respondents gave feed companies the highest score (Figure 6). Stakeholders in the supply chain deemed to have the least responsibility for feed sustainability were seafood consumers. A third of stakeholders interviewed highlighted that the whole supply chain should be taking at least some responsibility for the sustainability of aquaculture feed (Figure 6).

'Anyone who is involved in aquaculture feed in a professional context should have responsibility for the sustainability of feed'.

- ***Stakeholder 1***

'Retailers and brands could engage further down the supply chains to understand challenges in sustainable aquafeed to then implement for informed policies.

- ***Stakeholder 9***

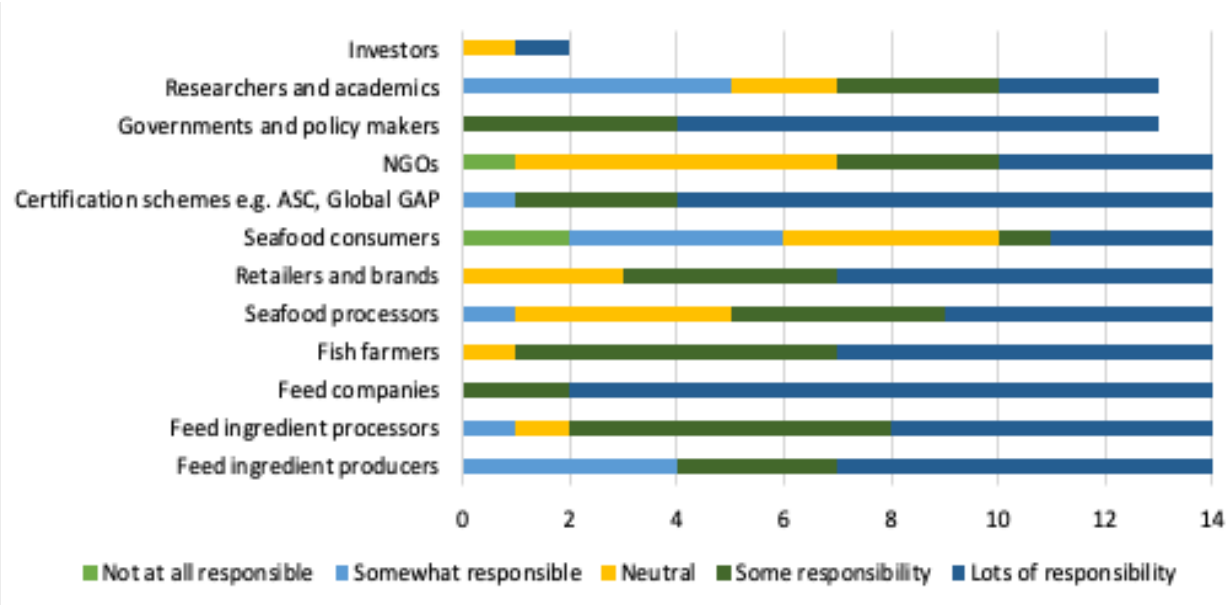


Figure 6: Interviewees responses to the question: Who in the supply chain should take responsibility for ensuring sustainable aquafeed'? Interviewees were asked to score each aquafeed stakeholder from 1= not at all responsible to 5= lots of responsibility. Two interviewees chose to score an additional aquafeed stakeholder: Investors.

4.2.2 *What limits the aquafeed supply chain from working on feed sustainability?*

The most common reasons cited that limit aquafeed stakeholders' ability to improve feed sustainability were lack of data on feed ingredient production and its sustainability credentials followed by lack of investment by the supply chain into feed ingredient sustainability (cited by 43% and 36% of respondents respectively; Figure 7). Limited influence over other supply chain actors and lack of traceability in feed ingredient supply chains were each suggested by three (of fourteen) respondents.

'Risk beyond marine ingredients is worrying. I'm not an expert in other ingredients. It's hard to upskill myself and find information about feed ingredients production and I need to know what questions to ask'

- ***Stakeholder 12***

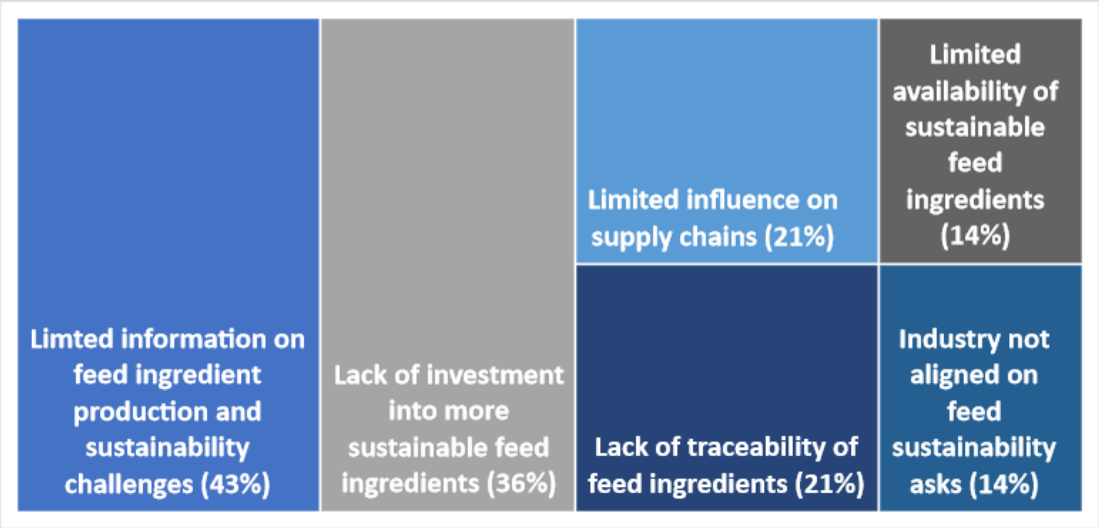


Figure 7: Interviewees responses to the question: What limits your ability to improve the sustainability of feed?

4.2.3 *Future priorities for aquafeed sustainability*

When stakeholders were asked what the priorities were for ensuring more sustainable aquafeed in the next five years, over half of the stakeholders interviewed (57%) cited finding alternative sustainable feed ingredients as being a top priority to ensure more sustainable aquafeed.

Beyond this there was limited consensus amongst aquafeed stakeholders as to the priorities for the industry to move towards more sustainable feed (Figure 8).

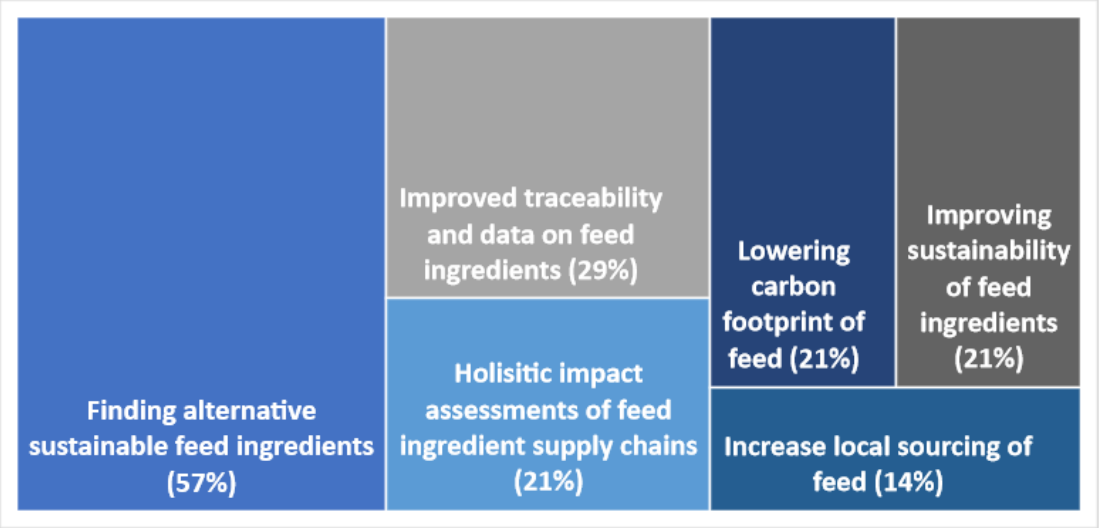


Figure 8: Interviewees responses to the question: 'What do you think are the biggest priorities for the feed and/ or aquaculture industries in ensuring more sustainable aquaculture feed in the next five years?'

Chapter 5 - Discussion

5.1 Part 1: Factors affecting the sustainability of aquafeed ingredients.

5.1.1 A balancing act

Environmental sustainability challenges and opportunities exist across all aquafeed ingredients; traditional, alternative, and novel (Table 6 and 7). As well as balancing cost, health and welfare and nutritional factors when formulating feed, the impact of feed ingredient production should be prioritised (Naylor *et al*., 2009).

The skewed focus on marine, soy and palm ingredients by supply chain policies, certification schemes, seafood ratings tools, the media and NGOs may result in risks being overlooked in other ingredient supply chains. Feed sustainability should be assessed at an individual supply chain level, as LCA analyses show that environmental impacts are highly context specific (Silva *et al*., 2018; Pelletier *et al*., 2018; Figure 3). Some NGO approaches which dismiss all marine ingredients may not be helpful in improving sustainability as LCA analysis shows some marine ingredients may be less environmentally damaging than some terrestrial ingredients (Malcorps *et a*l., 2019). There were examples of sustainability initiatives observed during Nuffield travels in marine ingredient (e.g., using waste products from human seafood supply chains in Norway and collaborative stakeholder initiatives in Thailand) and soy (e.g., regenerative farming principles in Brazil).

Over half of the stakeholders interviewed cited finding alternative feed ingredients as the top priority for future aquafeed sustainability. Sustainable 'novel' ingredients have fantastic potential to increase the volume of feed available to the aquaculture industry and take pressure off high-risk ingredients (Mitra 2020). Although some alternative ingredients may have encouraging sustainability credentials (e.g., utilisation of waste in UK insects, using third party certification in algae oil), these data should be in the public domain. Additionally, many alternative ingredients are currently not at large enough scale to be commercially competitive and replace traditional ingredients (Naylor *et al*., 2021). Therefore, the supply chain should focus working to improve the sustainability of all traditional and alternative feed ingredients.

5.1.2 What is 'sustainable' aquaculture feed?

There is widespread use of the term 'sustainable' in relation to feed, despite there being no agreed industry definition. It would be highly valuable for the industry to agree on a set of measures of carbon, environmental and social footprint to allow comparison between feed ingredients. Ideally these should be conducted by a third party, independent and transparent.

5.2 Part 2: Responsible sourcing of feed and supply chain action

Many UK retailers and seafood companies have set ambitious targets to reduce their scope 3 carbon emissions and reduce environmental impacts of their food supply chains (e.g., Table 3). Given the high contribution of feed to the environmental and carbon impacts of farmed fish production (Little *et al*., 2018), companies have a vested interest in supporting sustainability improvements in aquafeed supply chains. In addition, retailers and brands could be used by the supply chains to help influence key players in the feed industry.

UK retailers have established a responsible sourcing approach for seafood supply chains which advocates companies to '*source from the best, avoid the worst and work with the rest*'. Retailers and supply chains can influence feed ingredient production through responsible sourcing policies, supply chain initiatives and collaborative projects (Naylor *et al*., 2021).

The biggest opportunity for the supply chain to support more sustainable feed production is to address risk across the entire feed basket rather than advocating for removal of perceived high risk feed ingredients (e.g., some campaigns to remove marine ingredients).

Retailers and suppliers can support more sustainable aquaculture feed through:

- Managing risks e.g., using data and certification and responsible sourcing policies
- Supporting improvement efforts e.g., supply chain engagement, advocacy and investment

5.2.1 Managing risk in feed ingredient supply chains.

A limiting factor to assessing risk in feed supply chains and improving feed sustainability was identified as the lack of publicly available information and data on the production of feed ingredients. Although there are existing data and certification tools available, supply chains should advocate for improved traceability and transparency of ingredient supply chains to allow more effective use of these tools.

Data and certification

Traceability challenges in feed ingredient supply chains

Many feed ingredients (particularly plant ingredients) are traded on the global commodity market and have long, complex supply chains which makes traceability and transparency of production impacts challenging (Malcorps *et al*., 2019). Data is often limited to production country for these ingredients and several stakeholders raised concerns with traceability systems of global commodity traders. Digital traceability tools such as blockchain could help address the current traceability challenges in feed supply chains (Tolentino- Zondervan *et al*., 2023) and give better visibility of feed production data to the supply chain.

Picture 6: Fava bean storage post processing in the UK. Beans are processed close to farms where they are grown for use in Scottish salmon and UK livestock feed.

Life cycle assessment databases

Although public life cycle assessment (LCA) databases e.g., The Global Feed LCA Institute (GFLI), cover a range of feed ingredients, specific feed supply chain information is needed in order to identify correct data and assess feed impacts accurately e.g., carbon footprint. Such databases are difficult for many non- feed specialist stakeholders to understand, comparison between LCAs is difficult (due to different methodologies) and there are ongoing efforts into refining and updating LCA data.

Third--party certification for known 'high risk' ingredients.

Stakeholders interviewed were reliant on third party environmental certification schemes for known 'high risk ingredients' i.e., marine ingredients soy and palm oil, for traceability and assurance for feed manufacturing standards (Malcorps *et al*., 2019). Aquafeed stakeholders should have dialogue with feed certification schemes e.g., through public consultations, to ensure they continuously evolve to meet the needs of the entire supply chain.

Fish farms visited in Norway, Brazil and Thailand with seafood products destined for export markets use feed certified to a third-party aquaculture standard e.g., ASC, Global GAP, which do not always assess feed ingredient risk holistically (Table 2). However, the latest iteration of the ASC feed standard requires risk assessment of all feed ingredients with more than 1% inclusion in the diet (ASC, 2023) as well as measuring greenhouse gas emissions, energy and water use. This could provide a useful framework for the industry to use to drive feed sustainability.

Social challenges in feed ingredient production

The lack of focus on social data for feed ingredient production is a huge oversight by the aquaculture industry. Mariojoules *et al*., 2019 found that aquaculture certification schemes heavily focused on assessing environmental data and there was little focus on social data. However, sparks *et al*., (2022) warns against adapting environmental seafood schemes to protect workers in supply chains and instead advocates for supporting worker led initiatives.

Picture 7: A salmon farm in Norway. Norwegian salmon is fed non- GM feed which uses third party certified soy and largely certified marine ingredients.

Responsible sourcing policies

Retailer and seafood company policies

Approaches to responsible sourcing of feed by retailers and the aquafeed value chain are difficult to assess as much information is kept out of the public domain (Mariojouls *et al*., 2019; WWF 2022). However, retailer asks on feed sustainability have historically been inconsistent and limited (Tacon *et al*., 2021) which is echoed by this study.

A limiting factor in stakeholders engaging on feed sustainability was cited as limited leverage with feed supply chains and being unsure what questions to ask. There is anecdotal evidence that sustainability roles at retailers may have high turnover and limited subject matter expertise on feed according to several conversations during this study. Despite lots of research on feed ingredients and data being available, this is not currently in a format which is easy to use by the supply chain.

Consumers do not expect seafood products they buy to have negative impacts on the environment or people in the supply chain. Consumer views on feed ingredients is unclear (Naylor *et al*., 2021) and, anecdotally there is currently little demand from consumers for sustainable feed ingredients specifically. Further research would be beneficial.

Holistic risk assessment tools

An opportunity to support best practice and drive sustainability could be the creation of an independent holistic risk assessment tools focused on feed ingredients and in a format readily accessible to non-feed experts. Such a tool could help retailers understand feed production opportunities and challenges in a uniform way. This would allow companies to take more informed decisions when setting policies and taking action to mitigate risks and/ or support improvements within their feed supply chains.

5.2.2 Supporting improvement efforts in feed supply chains.

Supply chain engagement: the role of feed companies

Feed companies are perceived to be leading current work on feed sustainability. Although some larger feed companies visited in Norway and Thailand have sustainability programmes in place (e.g., LCA analysis, novel ingredient testing), they also face significant challenges with traceability of feed ingredients, particularly plant based, the majority of which can only be traced to country level (Skretting, 2022). Feed companies' sustainability reporting is largely focused on marine ingredients, soy, palm oil as the 'high risk' ingredients (Cargill, 2022; Skretting, 2022). Feed companies need to go further to ensure all feed ingredients are fully traceable and be transparent about feed production. Ideally all ingredients should be fully traceable to boat/ farm/ production site level to allow risks to be properly assessed.

More clear and consistent asks from aquaculture supply chains could encourage feed companies to prioritise feed sustainability when formulating feed rather than defaulting to the 'lowest cost formulation' model.

Supply chain collaboration

A common theme across interviews and visits was the need for collaboration through the whole supply chain to drive sustainability improvements in feed supply chains. There are examples of existing collaborative supply chain projects focused on aquafeed sustainability e.g., IFFO Marine Ingredients roundtable and the UK soy manifesto (Appendix 1, Table 7). The Norwegian salmon sector is showing leadership on addressing aquafeed sustainability e.g., developing a holistic feed risk assessment tool (Appendix 1). The majority of soy in Scottish and Norwegian salmon already goes beyond most UK retailers' soy targets (author observation) however, other feed ingredient and aquaculture species supply chains are less progressive. It would be excellent to see collaborative supply chain projects extending to aquaculture feed ingredients involving the whole supply chain.

Picture 8: A meeting for the Gulf of Thailand Mixed- Trawl (multispecies pilot) Marin Trust Improver Programme in Bangkok, Thailand aiming to improve the sustainability of this fishery, which provides marine ingredients to the aquaculture feed sector. The IP is a collaborative project including multiple stakeholders from different parts of the industry.

Supply chain investment

'Don't ask me why my seafood is expensive, ask why theirs is so cheap' (Overheard at the Seafood Expo North America, March 2023)

Several stakeholders raised lack of investment into feed supply chains as a limiting factor to more sustainable feed and target markets are not currently rewarding sustainability improvements with higher prices or improved market access (Naylor *et al*., 2021). The price of cheap seafood products at one end of the supply chain may be at the expense (economic, environmental, or social) to feed ingredient producers at the other end.

5.2.3 The future for sustainable aquafeed

Aquafeed stakeholders interviewed suggested a priority research and development area to ensure more sustainable aquafeed in future was the development of sustainable alternative feed ingredients. As discussed previously, novel feed ingredients can be a fantastic way to reduce pressure on 'high risk' ingredients provided they can demonstrate sustainability credentials. Local sourcing of feed ingredients was considered a future priority by some stakeholders, which is consistent with other feed sustainability initiatives (Cargill, 2022). Local feed sourcing was the norm on tilapia farms in Parana state, Brazil and within small scale fish farms in Thailand (Appendix 1) in contrast to Scottish salmon feed which largely relies on imported ingredients. Championing the use of more local ingredients would support UK agriculture and could reduce the environmental impacts associated with transport.

There are many global examples of stakeholders within the industry working towards more sustainable aquaculture feed production. UK retailers and seafood companies have ample opportunity to support best practice in aquafeed supply chains if they are willing to invest time, resource and/ or money and this will help them work towards their sustainability goals. Collaboratively addressing responsible sourcing of aquaculture feed ingredients could support the long-term sustainability and availability of feed ingredients for the aquaculture sector. To truly say farmed fish has been responsibly sourced, the supply chain must address environmental and social risks in its most valuable asset- feed!

Chapter 6 - Conclusions

Factors affecting the sustainability of aquafeed ingredients.

- All feed ingredients have environmental impacts and opportunities, these are context specific.
- Some nutritionally important ingredients e.g., fish oil is limited.
- Sustainability can be improved in all feed ingredients- there are multiple examples of good practice globally.

Certification and data

- Of stakeholders interviewed, aquafeed data and certification was focused on 'known risks' i.e., environmental impacts of marine ingredients and soy.
- Sustainability data collection was largely using third party certifications where available.
- Data collection on workers in feed supply chains was limited.

Aquafeed supply chain stakeholders

- Stakeholders agreed that feed companies are currently leading work on feed sustainability.
- There are opportunities for other aquafeed stakeholders i.e., those in aquafeed and aquaculture supply chains to support feed sustainability initiatives.
- Retailers and seafood companies may be limited in working more on feed sustainability due to lack of information and data on feed production and sustainability challenges.
- Future priorities included finding alternative ingredients, improving traceability and holistic risk assessment of feed ingredients.

Chapter 7 - Recommendations

For the feed industry

1. Prioritise digital traceability to farm/boat and standardised data collection of all feed ingredients e.g., through robust ingredient certification schemes.
2. Understand risks and challenges faced by workers in feed supply chains in order to address the challenges and ensure good practice.

For retailers, seafood companies and supply chains

3. Prioritise feed! Engage with aquaculture feed supply chains. Get educated and ask questions.
4. Use sourcing polices and brand influence to raise the importance of feed sustainability and advocate for better traceability and transparency of feed ingredients.

For anyone with an interest in aquaculture feed sustainability

5. Sustainable alternative feed ingredients are a priority of the industry however, environmental credentials should demonstrate lower impacts- encourage feed stakeholders to make production data (e.g., LCAs) comparable and in the public domain.
6. An independent holistic accessible feed risk assessment tool would be a huge benefit to the aquaculture (and agriculture) industry to allow retailers and supply chains to support the most sustainable feed options and gain a better understanding of the topic. The latest ASC feed standard provides a useful framework.

Chapter 8 - After my study tour

I've learnt more than I ever realised I could about the sustainability of aquaculture feed and have even more questions than when I started!

Commencing my Nuffield scholarship during the Covid- 19 pandemic meant there was a significant delay in my international trips. Although this was a challenge, it gave me opportunity to have many virtual meetings and carry out visits in the UK which greatly enhanced my understanding of the subject as well as my network.

Writing my report through the accredited route with Aberystwyth University supported me to explore the published literature behind my topic and identify the gaps before I set off on my travels. This allowed me to be more targeted with my questions during visits and meetings. I may continue my studies to obtain a Post Graduate Certificate (but may have a break first!).

Travelling outside of my work remit was a fantastic opportunity to be able to ask questions more freely and explore areas outside of my sphere. My meetings with feed producers and aquafeed stakeholders were more open than had I been visiting in a supply chain capacity. My Nuffield travel has given me insight into businesses and parts of countries I would otherwise have missed. A highlight of the Nuffield experience for me has been the Nuffield network both in the UK and abroad. It has been fantastic to learn more about the world of food and farming beyond seafood and meet scholars from across the globe. The trip to Brazil was the highlight of the Nuffield experience for me and wouldn't have been possible without the Nuffield Brazil network. I hope to remain part of the Nuffield network in the future.

Towards the end of my Nuffield experience, I moved on from my job in retail to move back into the NGO world, still with a focus on seafood supply chains. I work with retailers and seafood companies globally and I am directly using my Nuffield experience to support my day-to-day conversations on aquaculture feed. I've also been invited to speak on the topic of responsible sourcing of aquaculture feed at several conferences and events.

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Thank you so much to everyone who I visited in person and virtually for your time, hospitality and sharing your expertise on this topic. I've spoken to so many enthusiastic and knowledgeable people and learnt a huge amount from you all. A small fraction of this is reflected in this report. Particular thanks to Sally Thompson (Nuffield Brazil) for giving so much time and enthusiasm towards supporting me plan my Brazil trip and Mauro Nakata (2018 Brazil Nuffield scholar) for helping to make it a reality by taking time out to help plan my Southern Brazil road trip as well as driving, translating and hosting! Obrigada!

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Diolch to my tutor Peter Wootton- Beard at Aberystwyth University for your patience and support, your time and enthusiasm has been incredibly valuable. I certainly wouldn't have got as much from the scholarship experience without opting for this route. Thanks to my Nuffield mentor, Rufus Pilgrim (2016 Nuffield scholar) for your help in navigating the Nuffield world and reassuring me that I was on the right track!

The world of Nuffield scholarships was introduced to me by previous scholar Paul Fox (2003 Nuffield scholar), who suggested I might want to consider Nuffield, thank you so much for suggesting I should apply and starting off the chain of events that followed. Thank you to Dale Hill for introducing me to the world of aquaculture feed and planting the seed for me to want to learn more about this topic!

Finally, thank so much to my family and friends for your patience and support. I'm looking forward to spending more time with you and promise to (mostly) stop talking about aquaculture feed.

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Appendix 1: *Case studies*

1. Sustainability initiatives in feed ingredient supply chains

Examples of sustainability initiatives encountered during the Nuffield scholarship experience are outlined below. This is not an exclusive list but serve as an illustration of some examples of sustainability initiatives taking place in aquaculture feed supply chains.

***Utilisation of 'waste' products*- Pelagia: Marine ingredients. Norway, May 2022**

Pelagia is a leading producer of fishmeal and fish oil products for aquaculture feed in Norway, UK and Ireland. Annually over 1,000,000 tons of pelagic fish e.g., mackerel, blue whiting and herring are processed to produce human food products (e.g., fresh and frozen fillets), aquaculture feed ingredients (protein concentrate, fishmeal and fish oil) and dietary supplements. Pelagia ensures close to 100% of the fish is utilised thereby ensuring valuable marine resources are not wasted and used most effectively rather than creating competition between human food and aquaculture feed.

***Regenerative farming principles*- Grupo Morena: soy. Brazil, October 2022**

Grupo Morena is located in Mato Grosso state, Brazil's largest producer of soy. Mato Grosso state incorporates part of the Amazon as well as parts of the Cerrado savannah and the Pantanal wetland; important habitats for biodiversity and nature. There is widespread media and NGO criticism of soy (and cattle) production in Brazil, largely focused on deforestation of the Amazon and land conversion of the Cerrado biome.

Grupo Morena has a vision to '*Inspire and encourage people to practice sustainable conduct in agribusiness, being a reference in the Brazilian market*' and uses conservation practices in place e.g., crop- livestock- forest integration, precision agriculture and no- tillage. In addition, Grupo Morena keeps 20% of native vegetation set aside in line with national legislation and produces soy to RTRS and Cargill SSS standards.

Soy from Grupo Morena is purchased by one of seven large trading companies (e.g., Cargill, Bungee) dealing with agricultural commodities in Brazil and mixed with soy from many other farms in the region. Traceability of soy for animal and fish feed is a major challenge and is necessary for the supply chain (e.g., retailers and fish farmers) to demonstrate progress towards targets around deforestation and conversion free soy and to allow carbon and environmental data to be calculated accurately.

***Third party certification*- *Veramaris: algal oil.* USA, October 2022**

Veramaris produces EPH& DHA Omega-3 algae oil for use in aquaculture feed as well as pet food. The process uses USA produced sugar cane which is fermented to produce algal oil as well as co-products for use in cattle feed and biogas.

As well as adding to the global supply of nutritionally valuable feed ingredients, the production system is land based and allows the algal oil to be fully traceable. In 2021, Veramaris became the first microalgal oil producer for feed to be certified to the joint ASC- MSC Seaweed standard. In addition, Veramaris shares life cycle assessment (LCA) and production data with its customers. This transparency in environmental assessment and production data is useful for the aquaculture and seafood supply chains to assess the impacts of algal oil as a feed ingredient.

***Local sourcing of feed ingredients*- Brazil Tilapia industry, Brazil, October 2022**

Brazil is one of the largest tilapia producers in the world (FAO 2022). In Paraná state, Copacol is a cooperative which includes tilapia and poultry producers as well as farmers producing feed ingredients e.g., soy and corn. Most feed ingredients for tilapia are produced from within the cooperative and within the same state. In doing so, feed ingredients are more able to be traced back

to producer farm and subsequently could be risk assessed if tilapia producers and the supply chain wish to do so. This contrasts with Scottish and Norwegian salmon sectors where a large proportion of feed ingredients are imported.

In Sao Paulo state, Cristalina tilapia reiterated the approach of sourcing feed using domestically produced feed ingredients. In addition, trimmings from tilapia processing are purchased by Brazil's increasing pet food sector. This is another good example of utilisation of waste products.

Thailand small scale aquaculture, Thailand, July 2022

Thailand is home to large scale shrimp production destined for the export market as well as numerous small scale fish farming operations. Raitiaviset Organic farm, Koh Phangan produces grouper on site as well as growing a range of plant and vegetable ingredients which are added into the diet for the fish. Although the majority of feed ingredients are produced on site, soy and fishmeal were bought in from feed companies. This is consistent with a study by WorldFish (2019) which showed utilisation of a range of local ingredients by small scale aquaculture producers whilst imported soy and marine ingredients were common.

2. Collaborative stakeholder initiatives

Gulf of Thailand Mixed- Trawl (multispecies pilot) Marin Trust Improver Programme- Marine ingredients, Thailand, July 2022

Marin Trust have partnered with non-certified fisheries including in the Gulf of Thailand to develop assessment an assessment methodology for multispecies fisheries which could then be incorporated into the main Marin Trust standard. The project includes a variety of stakeholders from the fishery, fishmeal producers, scientists, government and the Marin Trust standard and is a good example of a collaborative approach to improving responsible sourcing of an aquaculture feed ingredient, in this case fishmeal.

Grieg salmon aquaculture feed risk assessment tool- All feed ingredients, Norway, May 2022

Grieg seafood is one of the world's largest salmon farming companies, with headquarters in Norway. Grieg has partnered with WWF- US to evaluate environmental, social and governance risks in salmon feed ingredients in a holistic manner i.e., assessing risks in all feed ingredients related to carbon footprint, biodiversity, human rights and more. The aim is to increase transparency and traceability of all feed ingredients and identify areas where risk can be reduced. Grieg led a group of salmon supply chain stakeholders (including salmon farmers, processors and retailers) in advocating to Brazilian soy traders to agree to only trade deforestation and conversion free soy (with a 2020 cut-off date and monitoring plan). The work on responsible sourcing of aquaculture feed at Grieg was the most progressive and proactive example from the Nuffield experience and is a fantastic example for other aquafeed stakeholders to learn from.

3. Research and development

Alternative feed ingredients research trials

Pontus Group, Singapore, July 2022; Wales, August 2021

Pontus Group offer aquaculture feed trials and have extensive experience of carrying out trials into alternative feed ingredients at sites in Wales and Singapore. Although specific feed ingredients may be available, it is critical that they enhance the welfare and performance of the fish rather than having negative impacts. Visiting research facilities emphasised the importance of optimising feed formulations not only for sustainability but also for fish health and performance.

Appendix 2: Interview questions

1. Feed Production

a) In 1 minute, please can you tell me how you produce the product to the point where it is sold as a feed ingredient:

b) Over the next five years, what are the priority areas when producing the feed ingredient (3 max)

- Environmental impact of production e.g., pesticides, carbon footprint
- Workers' rights and welfare
- Cost of production
- Efficiency of production
- Quality of output
- Traceability
- Legislation and compliance
- Other……

c) Thinking about sustainability, what are the main advantages to producing the feed ingredient(s)? *E.g., Environmental e.g., low carbon footprint; Social e.g., provides jobs to local economy; Economic e.g., good quality.*

d) Thinking about sustainability, what are the main challenges with producing the feed ingredient(s)? *E.g., Environmental e.g., pollution; Social e.g., labour shortage; Economic e.g., price of finished product*

2. Responsible sourcing: Data and certification use

a) Do you collate information regarding environmental sustainability verification involved in the production of feed ingredient(s)? E.g., third party certification scheme, data.

b) Do you collate information about workers involved in the production of the feed ingredient(s)? E.g., third party certification scheme, data

c) What environmental or social data are you asked for by your customers if any?

d) Are there any data you are not asked for that you think the supply chain should be using?

e) Why do you think that this data isn't being asked for/ used?

3. Responsible sourcing: supply chain action

a) Who in the supply chain and aquaculture industry is responsible for ensuring sustainable aquaculture feed?

b) Who <u>does</u> have responsibility for feed sustainability?

c) Who <u>should</u> have responsibility for feed sustainability? Please score from 1-5:

1= not at all responsible, 2= somewhat responsible, 3= neutral, 4= some responsibility, 5= lots of responsibility

- Feed ingredient- fisherman/ farmers
- Feed ingredient producers

- Feed companies
- Fish farmers
- Seafood processors
- Retailers and brands
- Seafood consumers
- Certification schemes e.g., ASC, Global GAP
- NGOs
- Governments and policy makers
- Researchers and academics
- Other: please specify

d) How could aquaculture feed stakeholders support more sustainable aquafeed?

3. Responsible sourcing: Future thinking on feed

1. What is your vision for how you could achieve the most sustainable feed ingredient? (i.e., what does brilliant look like?)
2. What limits your ability to improve the sustainability of feed?
3. What do you think are the biggest priority(ies) is for the feed and/or aquaculture industries in ensuring more sustainable aquaculture feed in the next five years? (three max)

How can retail and supply

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