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ARTICLES

Perspectives on Salmon Feed: A Deliberative Assessment of Several Alternative Feed Resources

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Abstract The future of salmon aquaculture depends on the adoption of alternative feed resources in order to reduce the need for fish meal and fish oil. This may include resources such as species from lower trophic levels, by-products and by-catch from fisheries and aquaculture, animal by-products, plants, genetically modified (GM) plants, nutritionally enhanced GM plants and products from microorganisms and GM microorganisms. Here, we report on a deliberative assessment of these alternative feed resources, involving 18 participants from different interest groups within Norwegian salmon aquaculture. The participants defined a broad range of appraisal criteria concerning health and welfare issues, economical issues, environmental issues, and knowledge and social issues. A number of uncertainties, in the form of incomplete knowledge, diverging opinions, and context specific factors were identified when the participants evaluated the alternatives. Our findings support the need for more research on the suitability of alternative feed resources for farmed salmon. Additionally, the study underlines the importance of facilitating deliberative assessments in order to map the plurality of perspectives and explore qualitative aspects of uncertainty. Such initiatives improve the information base upon which decisions on future feed resources for farmed salmon are made.

Keywords Salmon aquaculture · Feed resources · Multicriteria mapping · Scientific uncertainty · Decision making

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Introduction

Almost half of the seafood found on grocery store shelves today comes from a farm. Aquaculture has maintained an average annual growth of 8.7% since 1970 and is thereby growing more rapidly than any other food producing sector in the world. Farmed fish is expected to play an important role in global food supply, especially as wild fisheries are declining due to overharvesting (FAO 2009). Economic incentives have contributed to this trend and led to rapid expansion of the production of carnivorous finfish species in marine aquaculture (Deutsch et al. 2007). Global production of farmed salmon has roughly quadrupled in volume since the early 1990s and is currently the world leader in farmed carnivorous finfish production and value, with Norway as the largest producer (Le Curieux-Belfond et al. 2009).

Salmon feed has largely been based on fish meal (about 40–60%) and fish oil (about 20–30%) from wild marine fish such as anchovies, pilchards, mackerel, herring, and blue whiting. This is primarily because these resources satisfy the nutritional requirements of carnivorous fish species. Secondly, they secure high levels of marine fatty acids (omega-3 polyunsaturated fatty acids) in the fish fillets with beneficial impacts on human health (Connor 2000). Aquaculture currently absorbs approximately 56 and 87% of world supplies of fish meal and fish oil respectively (FAO 2009), and the demands are expected to increase as the industry expands. Hence, in a short time the marine resource base will not be able to sustain the demand for fish meal and oil coming from aquaculture and other industries (primarily poultry, pig, and pet feed, as well as functional food and pharmaceutical industries). Increasing demands for finite resources consequently lead to increasing prices. Feed represents the largest expense in intensive aquaculture. Between mid-2005 and mid 2008, the prices of fish meal and fish oil rose 50 and 130%, respectively (Naylor et al. 2009). Thus, limited availability and increasing prices of marine resources are the main forces pushing the search for, and development of, alternative feed ingredients (Naylor and Burke 2005; Tacon and Metian 2008).

Despite major advances in feed formulation, feed manufacturing technology, and feed management at the salmon farm level in recent years, salmon farming continues to consume more marine resources than it produces (Naylor et al. 2000). The ratios of wild fisheries inputs to farmed fish outputs presented in current literature varies. For instance, according to Naylor et al. (2009) the "fish-in to fish-out" ratio for farmed salmon is currently 5.0, while Ellingsen et al. (2009), calculated that 2.3 kg of fish is needed to produce enough oil for 1 kg round consumable salmon. This is close to the numbers presented by the Norwegian Seafood Federation (2009), who claims that it takes about 2 kg of wild fish to produce 1 kg of farmed salmon in Norway. In any case, farming salmon results in a net reduction of marine resources. This, along with concerns regarding discharges from fish pens (e.g., feed surplus, fish excrements, antibiotics, and chemicals), farmed fish escapes, and transmission of parasites and diseases to wild salmon, have led to growing demands for more environmentally friendly production practices from consumers, retailers (Frankic and Hershner 2003), and policymakers (see for instance; Holmenkollen guidelines for sustainable aquaculture 1998; FAO 1995; EU Commission 2002b; Norwegian Ministry of Fisheries and Costal Affairs 2009). Thus, the challenge facing the salmon feed industry is to identify alternative feed resources that are economically viable, sustainable and of high nutritional quality.

A number of alternative feed resources are currently being explored or are already in use (see for instance Gatlin et al. 2007; Tacon et al. 2006; Turchini et al. 2009; Waagbø et al. 2001). As shown in Fig. 1 salmon diets in Norway are for instance currently based on approximately 60% marine ingredients, the remainder being plant oils, plant proteins, and various minerals, vitamins and color (Ellingsen et al. 2009). There is, however, a recognized need for more research on the suitability of different feed resources before large-scale adoption of these alternatives takes place (Norwegian Research Council 2008; Norwegian Scientific Committee for Food Safety 2009; Waagbø et al. 2001).

Here we present results from a deliberative assessment of alternative feed resources for farmed salmon, involving 18 participants from different interest groups within Norwegian salmon aquaculture. The study was conducted in order to: (1) map some of the key issues to be addressed when evaluating alternative feed resources for farmed salmon, (2) gather knowledge and perceptions about alternative feed resources among different actors in Norwegian aquaculture, and (3) address uncertainties associated with the alternatives. We applied a deliberative assessment tool—Multicriteria Mapping (MCM)—which has been developed in order to open up evaluation processes and explore how values, interests, and underlying assumptions influence the assessments (Stirling 2005; Stirling 1997; Stirling and Mayer 2001). We start by presenting the feed resource alternatives that were evaluated by the participants. Then, we briefly introduce the MCM method and describe how it was applied in our study. When presenting the results from the exercise, we focus on: (1) the range of criteria defined by the participants and the significance given to them, (2) how the performance of the alternatives differed between the interest groups, and (3) areas identified as associated with uncertainty. Finally, the implications and relevance of facilitating this type of comprehensive and deliberative assessments are discussed.

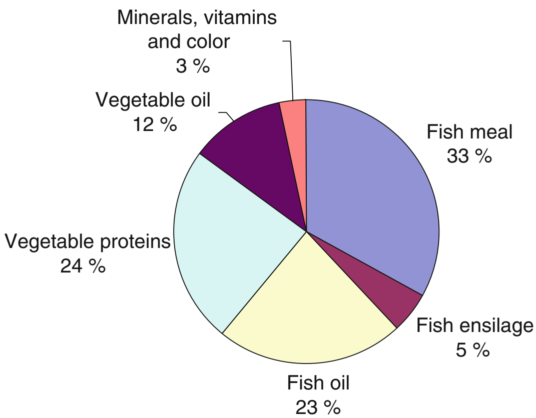

Fig. 1 Typical composition of ingredients in feed for farmed Atlantic salmon (based on data from Ellingsen et al. 2009)

Alternative Feed Resources

Species from Lower Trophic Levels

Various species of zooplankton, mesopelagic fish, and some species of squid are considered suitable for salmon feed production (Waagbø et al. 2001). Antarctic and North Atlantic krill are, due to high abundance, viewed as the most promising feed resource (Nicol and Endo 1999; Nicol and Foster 2003). Antarctic krill is currently harvested commercially and used as additives in fish feed (Nicol and Foster 2003) and pharmaceutical and nutraceutical products (Naylor et al. 2009). Krill represents an excellent source of omega-3 polyunsaturated fatty acids as well as vitamins, minerals, essential amino acids and natural carotenoids (astaxanthin), nucleotides, and organic acids (Suontama et al. 2007a). It has been reported that full substitution of fish meal with Antarctic krill does not change the health condition or product quality of Atlantic salmon (Olsen et al. 2006; Suontama et al. 2007a, b). Concerns have been raised regarding the high level of fluorine in the krill exoskeleton, but no studies have shown a negative influence on fish health and it is assumed that it contributes only marginally to human exposure (European Food Safety Authorities 2004; Norwegian Scientific Committee for Food Safety 2005). It has been reported that chitin in the krill exoskeleton may lower lipid uptake in fish and induce diarrhoea, but it is also documented that it can function as a prebiotic and immunostimulant (Olsen et al. 2006). The global catch quota for krill is nearly 6 million metric tons (mmt), but total harvest is currently less than 1 mmt (Nayor et al. 2009). Still, major concerns are raised regarding potentially serious ecosystem impacts of harvesting krill. Krill is at the base of aquatic food webs and harvesting could reduce food resources for predators such as penguins, seals, and whales. Moreover, krill is particularly sensitive to environmental variables, including climate change. Thus, it has been warned that the understanding of the population dynamics of krill is currently not sufficient to define sustainable catch quotas (Naylor et al. 2009; Suontama et al. 2007b).

By-products and by-catch from fisheries and aquaculture

33% of the raw material supplied to the fishmeal and oil sector in Europe came from fish by-products in 2002 (Huntington 2004). As over 30% of processed seafood is inedible for human consumption (Miller et al. 2008), better utilization of these by-products may become an important source of marine raw materials in salmon feed production (Tacon et al. 2006). However, high ash content in fish meal produced from by-products (as most of the fish muscle is removed when making fillets) may cause mineral deficiencies in farmed fish. The ash content can be reduced when processing the feed, but this will require investment and thereby increase processing costs. The use of by-products is at present highly regulated in order to prevent the spread of diseases and bioaccumulation of contaminants such as PCBs and dioxins (see for instance The European Union Animal by-products regulation, European Commission 2002a). Turchini et al. (2009) report that there is no documentation of fish disease outbreaks associated with the transmission of fish pathogens via fish meal and fish feed. Oidtmann et al. (2003) have, however, shown that fish have DNA that codes for the production of prion proteins and thereby theoretically can produce prion diseases such as transmissible spongiform encephalopathies (TSE). Hence, intra-species recycling of feed resources is currently prohibited in Europe (European Commission 2003b).

By-catch is non-target fish and other aquatic animals caught while fishing. The global weighted discard rate is estimated to be 8% of total recorded landings (Kelleher 2005), and includes by-catch but also target species that are not considered suitable to bring ashore. Better utilization of by-catch is encouraged, but also contested, as relaxed by-catch regulations may pose a threat to the already over exploited wild fish stocks. Thus, management strategies that limit landings of by-catch are in place (Scottish Executive Central Research Unit 2002).

Animal By-products

Animal by-products, such as bone, meat skin, and feathers from various land animals, may represent a possible protein and lipid source for salmon feed. Studies have shown that animal fats can be a valuable ingredient in fish feed (Turchini et al. 2009). Animal by-products are generally rich in protein, but do often have a high ash content as bone and other non-muscle materials constitute a large part of the by-products. This problem can be dealt with by improving the processing practices in order to increase the digestibility and quality of these ingredients (Bureau et al. 1999). The use of animal by-products is currently limited, partly because of low digestibility and variable quality, but most importantly due to fear of disease transmission. The European Union Animal by-products regulation (European Commission 2002a) only allows for the use of processed blood meal from non-ruminant animals. European salmon manufacturers do, however, not currently use feeds with animal by-products as they fear consumers' reactions.

Plants

Both the use of plant proteins and oils as ingredients in fish feed have been intensively investigated (Gatlin et al. 2007), and indeed the fish feed industry has already used a large degree of plant resources in their feed formulations for many years. Soy protein products are among the most studied and perhaps the best accepted protein source due to high protein content, steady supply, and reasonable prices. Other plant resources utilized in aquaculture are primarily rapeseed, corn gluten, wheat gluten, barley, pea and lupin meals and oil from palm, soybean, maize, rapeseed, coconut, sunflower, linseed, and olive (Tacon et al. 2006). Turchini et al. (2009) report that vegetable oil can replace substantial amounts of fish oil in the diets of many fish species without affecting growth or feed efficiency, as long as omega-3 polyunsaturated fatty acids are supplied in the diet. The main challenges in using plant protein sources in diets for carnivorous fish are related to their low levels of protein and high levels of starch, unfavorable amino acid and mineral profiles, high levels of fiber and the presence of anti-nutritional factors and/or antigens. A report published by the Norwegian Scientific Committee for Food Safety (2009) concludes that there is a lack of studies about the interactive effects when exchanging both fish meal and fish oil with plant ingredients in diets for Atlantic salmon.

Genetically Modified Soy and Maize

About 70% of soy and 25% of maize cultivated globally is genetically modified (GMO compass 2009). Thus, genetically modified (GM) soy and maize represents the major GM crops currently cultivated. The most commonly expressed traits are herbicide tolerance and insect resistance or a combination of these. The cultivation and use of GM plants in food and feed have revealed a broad range of views among scientists regarding their documented and potential health and environmental impacts (see Andow and Zwahlen 2006; Weaver and Morris 2005 and references therein). For instance, Flachowsky et al. (2005) report that genetic modification of plants can lead to alterations in the amount and profile of antinutrient factors between the GM variety and its near-isogenic parental line, with potential implications for its suitability as a feed resource. Furthermore, DNA from herbicide tolerant soya has been identified in the epithelial cells in salmon intestine after feeding (Sanden et al. 2006), but the biological significance of GM DNA persistence in the intestines remains unresolved. The Norwegian Scientific Committee for Food Safety (2009) are not able to draw any clear conclusions regarding the effect on fish health from the use of GM plants in salmon diets, although they do claim that growth, digestibility, feed utilization, and other health parameters seem to be more influenced by the plant material as such, rather than whether the plant is GM. EU requires labeling of food and feed products containing more than 0.9% of an approved GM ingredient (European Commission 2003a), whereas animals fed with GM feed are not labeled as GM. The use of GM in food and feed production is generally not well accepted among European consumers. This is not only due to concerns for potential risks to health and the environment, but also because GM may have unwanted economical, social, and ethical implications (Melo-Martin and Meghani 2008; Wynne 2001).

Nutritionally Enhanced GM Plants

Gatlin et al. (2007) describe how plant genetic research can facilitate altered levels of many important antinutrients (e.g., phytic acid) and nutrients (e.g., lysin, β-glucan and micro nutrients such as vitamin E) and change the starch structure and oil content of plants—all characteristics that will improve the plants' qualities as a feed resource. Qi et al. (2004) were the first to report successful accumulation of omega-3 polyunsaturated fatty acids in GM plants, but the accumulated levels of these fatty acids are still low. Robert (2006) does, however, emphasize that plant oils from GM plants producing omega-3 polyunsaturated fatty acids do not need to match the fatty acid composition of fish oil, as research has shown that fish maintains its health benefits with reduced amounts of fish oil in the diet. Accordingly, it is advocated that this strategy provides a more sustainable source of omega-3 polyunsaturated fatty acids compared to the use of marine sources (Napier et al. 2006; Robert 2006). Others express concerns regarding the potential unintended health and environmental consequences, similar to those already referred to for GM soy and maize. There is also a lack of understanding of whether unintended metabolites with potentially unintended impacts on health and the environment can be produced in the plants along with the nutritional molecules (Schubert 2008).

Products from Microorganisms

Bacteria, yeasts and unicellular and filamentous algae can, through a fermentation process using natural gas as an energy source, produce proteins and fatty acids for fish feed production (Naylor et al. 2009; Miller et al. 2008; Tacon et al. 2006). It has been documented that an inclusion of 20% bacterial proteins in diets for farmed Atlantic salmon resulted in a slightly reduced growth rate. No significant effects on the sensory characteristics such as taste, smell, or texture were detected (Berge et al. 2005). Tacon et al. (2006) consider this a promising resource, as it has both high protein content and nutritive value and no anti-nutrients, but emphasize that there is a need for further research on health effects. The main concern regarding products from microorganisms, such as bacterial proteins, is the physiological impacts from the nucleic acid fractions in the products (Waagbø et al. 2001). The availability of this resource is still limited, due to technical production constraints, and the price is consequently high (Naylor et al. 2009).

Products from GM Microorganisms

Microorganisms can be genetically modified to produce components that are beneficial for fish. This includes components such as essential amino acids, omega-3 polyunsaturated fatty acids, vitamins, pigments, or enzymes for the break down of antinutrient factors (Waagbø et al. 2001). Products from GM microorganisms are currently not commercially available and very little research has been carried out, both regarding how to produce them and their impact on fish and human health.

Multicriteria Mapping

Multicriteria assessment exercises cover a variety of non-monetary evaluation techniques sharing a basic framework under which a number of alternatives can be scored against a series of defined criteria and to which users attach weights reflecting the relative importance of the criteria (Gough and Shackley 2006). These techniques intend to broaden the scope of assessments and promote deliberative and participatory approaches, thereby facilitating more inclusive and comprehensive decision making processes. Stirling is particularly interested in how the outcomes of assessments are conditioned by values, interests, and underlying assumptions, and developed MCM as an attempt to "open up" assessment processes in order to "*explore the way in which different pictures of strategic choices may change, depending on the view that is taken—not prescribe a particular 'best choice'*"

(Stirling 2005: 5). MCM was initially used to assess perspectives on risks related to food production (Stirling and Mayer 2001), but has now been tested for appraisal of options and management strategies in a number of fields ranging from energy policy (McDowall and Eames 2007), development of criteria for the evaluation of public consultation and engagement processes (Burgess and Clark 2006), strategies to prevent obesity (Stirling et al. 2007), carbon storage options (Gough and Shackley 2006), and public health responses to the shortage of kidney donors (Burgess et al. 2007).

The MCM exercise is based on individual interviews (lasting 2–3 hours) where participants, supported by the researcher, work interactively with a piece of dedicated computer software (MC-Mapper) in order to complete four basic steps: (1) discuss the proposed alternatives and possibly identify additional ones, (2) define a range of criteria for the assessment of the proposed alternatives, (3) assess scores to each alternative under each criterion. The participants are asked to assign two scores to each alternative—one reflecting performance under the most favorable assumptions, the other under the most pessimistic assumptions. In this way the participants are able to express uncertainties and to take context specific factors, that could influence the performance of the alternative, into account. A criterion can also be defined as a principle. In this case each alternative is evaluated as either "acceptable" or "unacceptable" under the given principle. Finally, the participant is asked to (4) assign weights to each criterion in terms of their relative importance, reflecting the participant's individual judgments and values. This information is used to produce real time simple charts that visualize the overall performance of each alternative. These charts are produced by the software using a weighted sum of normalized criteria scores. As participants are asked to assign both "best" and "worst" performance scores, the rankings are not expressed as single numbers, but as intervals. (A more detailed presentation on the mathematical operations performed by the software can be found in Stirling 2005). Throughout the interview the participants are free to return to and make changes to the different steps in the MCM process. Thus, the method is very flexible—the participants are asked to develop their own appraisal criteria, define their own additional alternatives, and perform their own assessments. The interviews are audio recorded and the participants are encouraged to explain the rationale behind their choices and assessments in as much detail as possible. In this way the exercise provides both quantitative and qualitative data.

For this specific study, it is important to mention that each of the feed resource alternatives defined for the study consisted of a variety of species/types of products. Additionally, there were considerable differences between the alternatives with regard to current use or developmental stage, primarily due to technological, economical, and legal restrictions. Moreover, the participants were asked to evaluate the feed resource alternatives within a 20 year perspective, which meant that they had to make predictions about the future. Finally, salmon feed is typically based on a combination of different feed resources and the composition of feed ingredients might vary during the production cycle in order to optimize feed and fish quality. When evaluating each of the alternative feed resources the participants were, however, asked to consider each alternative as the only resource used in the feed, irrespective of this resource's share in current or potentially future feed formulations for farmed salmon.

Selection of Participants

We recruited participants from a broad group of people who held different roles, interests, and areas of expertise regarding salmon farming in Norway (Table 1). In order to do this we used a "snowball sampling" technique, where we started by asking scientists with whom we were communicating during the development of the study, to suggest relevant groups and people to participate in the study. When they were invited, we sought their suggestions for other potential participants, and so forth. In the end we had contacted 35 people and among them 18 agreed to participate in the study.

The participants were asked to participate in the study as individuals, presenting their personal point of view. The study does not aim for statistical representation and the results should not be interpreted as representative for all actors involved in Norwegian salmon aquaculture. Still we believe that the group of participants was sufficiently representative to explore and open up for a diversity of issues and perspectives related to alternative feed resources for farmed salmon.

Results

Criteria Defined by the Participants

In total, 87 criteria (of which two were defined as principles) were defined by the participants. These were categorized in four main categories, divided into 11 subcategories (Table 2). The categorization of the criteria was based on the participants' explanations when defining their criteria, as well as their comments

Table 1 Categorization of participants into perspectives and number of participants in each of the categories

Perspective	Number of participants
Feed industry	4[a]
Fish farmer	3[b]
Scientist	
Researcher in fish nutrition	2
Researcher in fisheries economics	1
Researcher in animal welfare	1
Researcher in marine ecology and fish nutrition	1
Market analyst for Norwegian Salmon	2
Environmental NGO	2
Policy advisor	2

[a] One of them works for an organization that represents both fish farmer and feed industry

[b] One of them is an organic fish farmer

Table 2 Main categories (bold font) and subcategories (normal font) of defined criteria, and number of criteria defined under each main/subcategory

Criterion	Total number of criteria defined under each main/subcategory
Health and welfare issues	**31**
Fish health	18
Animal welfare	3
Consumer health	10
Economical issues	**30**
Price	7
Resource availability	7
Consumer acceptance	9
Product quality feed	4
Product quality fish	3
Environmental issues	**20**[a]
Knowledge and social issues	**6**
Knowledge	4
Social considerations	2

[a] Two of these criteria were defined as principles

when assessing the alternatives. One participant defined seven criteria when assessing the alternative feed resources, whereas most participants defined between four and six criteria and two participants defined three criteria for their assessment. As seen from Table 2, most criteria concerned either health and welfare issues or economical issues. About one-fourth of the criteria concerned environmental issues, and six criteria concerned knowledge and social issues.

Health and Welfare Issues

The criteria selected by the participants concerning health and welfare issues included criteria about fish and human health and welfare, centered on four key questions:

- To what extent does the feed resource meet the nutritional requirements of farmed salmon?
- How does the feed resource influence the ability of the fish to master its environment?
- Does the feed resource contain components that are poisonous or unhealthy to consumers?
- Does the feed resource maintain human health benefits from consuming farmed salmon?

These questions were primarily assessed by evaluating the nutritional quality of the feed resource (e.g., type and composition of amino acids, fatty acids, energy sources, vitamins, and minerals). Some participants also evaluated the content of components such as immunostimulants, disease vectors, environmental pollutants (including medicine and pesticide residuals), and antinutrients. Criteria on animal welfare issues concerned whether the feed resource could cause disease, deficiency symptoms, pain, and deformations, as well as its impact on the health, growth, and well being of the fish. Human health benefits were generally evaluated by the content of omega-3 polyunsaturated fatty acids in the feed resource.

Economical Issues

When evaluating economical issues, the participants addressed the following key questions:

- What is the price of the feed resource?
- Is the feed resource available in sufficient amounts and with stable availability over time?
- What is the quality of the feed resource?
- Does the feed resource secure fish of good quality?
- Will consumers accept the use of this feed resource?

Price was always evaluated relative to the quality of the feed resource and depending on availability. The quality of the feed resource was determined by the nutritional characteristic of the feed resource, occurrence of unknown or toxic components, impact on the feed conversion ratio and physical characteristics of the feed pellet (e.g., texture). Parameters for assessing fish quality included sensory qualities such as color, texture, and taste, as well as nutritional quality and maintenance of human health benefits. Consumer health benefits, food safety, and environmental impacts were most frequently mentioned as important aspects influencing consumers' acceptance of the feed resource. In addition, other consumer concerns mentioned were whether the feed resource is part of the natural diet of the fish, its impact on fish welfare, its appearance (e.g., physical defects or waste product), and whether it was genetically modified.

Environmental Issues

The criteria defined by the participants concerned two main questions:

- What are the environmental impacts from harvesting or cultivating the feed resource?
- Is the harvest, production, and use of the feed resource sustainable?

Sustainability was generally described as a practice that secures future use of the resource without irreversible damage to the environment or changes in the ecosystem from where the feed resource originate. When assessing the sustainability and environmental impacts of the feed resource alternatives, the participants focused on: (1) impacts from discharges of feed surplus on the environment surrounding the fish farm, (2) resource and energy requirements during cultivation, harvesting or processing of the resource, (3) CO_2 emissions during transport of the feed resource, as well as (4) potential alternative uses of the resource.

Knowledge and Social Issues

When defining criteria concerning knowledge and social issues, the participants raised the following questions:

- What is the level of scientific knowledge regarding environmental and health impacts from harvesting, cultivating, and using this feed resource?
- What are the impacts on local communities where the feed resource originated?

Regarding the level of knowledge, the participants were concerned with knowledge gaps that can result in unintended adverse consequences. Another important issue was related to power (e.g., who controls the knowledge and knowledge production and whether the information is well documented and available for consumers). Impacts on the local communities included an evaluation of harvesting and cultivation methods and to what extent this activity was controlled by the local communities or would generate employment for local people. Adverse effects on local communities from harvesting or cultivating the resource were also addressed.

The Participants' Definitions and Weighting of Criteria

The participants would generally define a range of criteria belonging to different subcategories (Fig. 2). Seven participants did, however, select two or three criteria belonging to the same subcategory, which reflected their specific interest or area of expertise. For instance, one of the researchers in fish nutrition only defined criteria

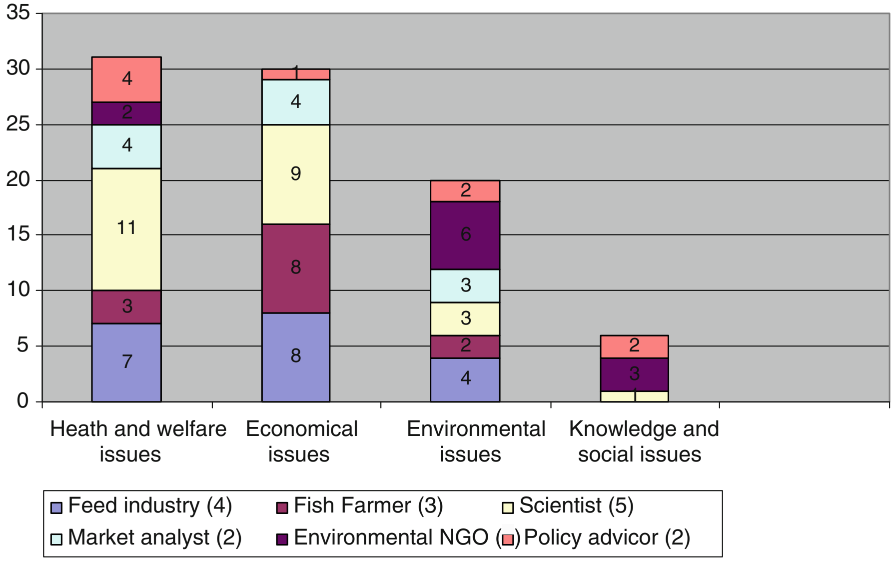

Fig. 2 Number of criteria defined by participants belonging to the same interest groups for each main criteria category

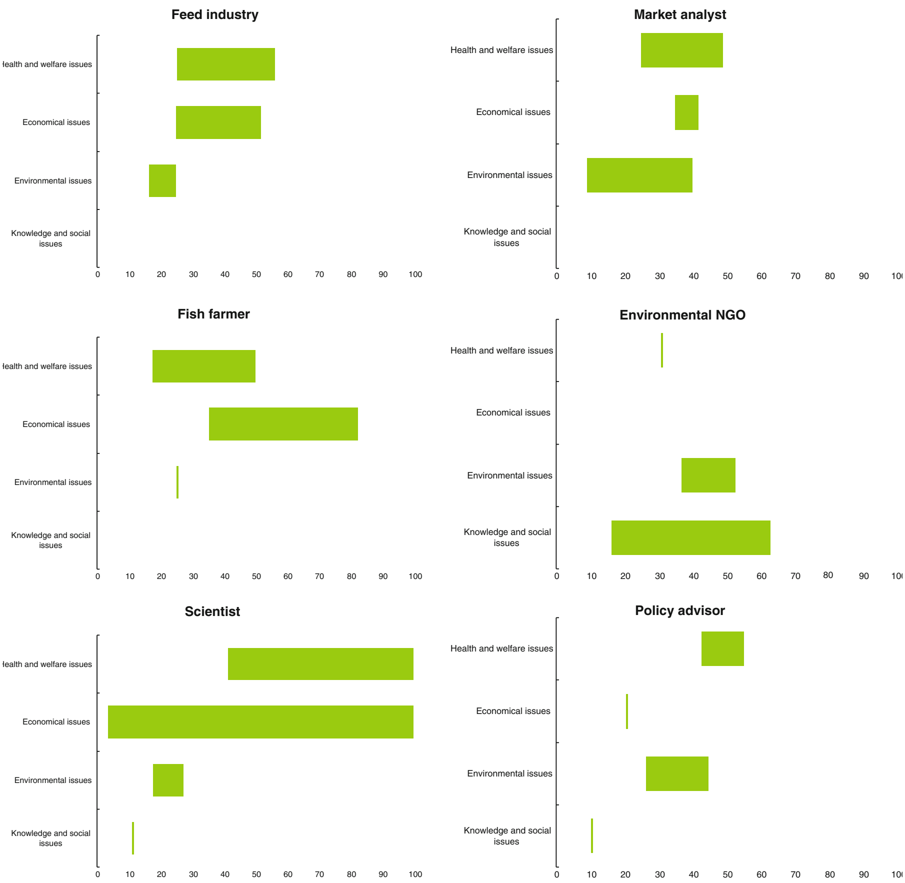

Fig. 3 The six charts show the overall value of weight assigned to criteria from the same category by participants belonging to the same interest groups

concerning fish health, and the other two researchers in this field each defined three criteria concerning fish health. All the criteria selected by the researcher in fisheries economics concerned economical issues and nearly 1/3 of all the criteria concerning environmental issues were defined by people working for environmental NGOs. The criteria concerning knowledge and social issues were selected by four of the participants (the researcher in fish welfare, two participants working for environmental NGOs, and one of the policy advisors).

The participants were asked to indicate relative criteria importance by distributing 100 weighting "points" among the criteria they had defined. Criteria concerning fish health and consumer health and environmental issues were generally given high weighting among participants who had defined these criteria, whereas criteria concerning resource availability were generally given low weighting. Figure 3 shows that there are certain trends in the assigning of weight that correspond with the participants' interests or area of expertise. For instance, all

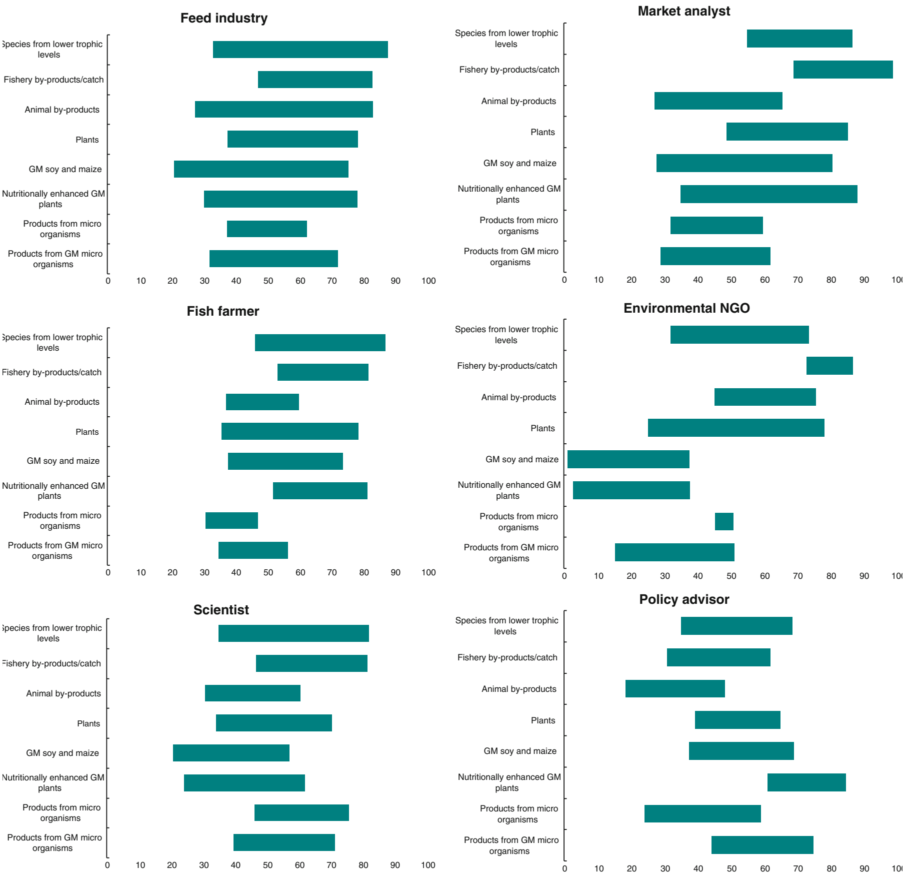

Fig. 4 Aggregated performance scores among participants belonging to the same interest group. The *x*-axis is a relative 1–100 scale showing performance, with better performing alternatives further to the right. Bar length is a result of the degree of difference between pessimistic and optimistic scores, and is thus a function of the degree of uncertainty

researchers in fish nutrition gave highest weighting to criteria concerning fish nutrition, while the market analysts gave highest weighting to criteria concerning consumer health and consumer acceptance. Both participants working for an environmental NGO gave highest weighting to criteria concerning knowledge. All the participants working in the feed industry gave criteria concerning consumer health the highest weighting and criteria concerning consumer acceptance and resource availability the lowest weighing. Two of the fish farmers gave highest weighting to criteria concerning fish health whereas the third fish farmer gave the lowest weighting to this criterion. The two participants who were policy advisors gave the highest weighting to criteria concerning environmental issues. Two of the participants (one fish farmer and one working for an environmental NGO) chose to define sustainability as a principle as they considered this a non-negotiable issue.

Overall Assessment of the Feed Resource Alternatives

All the participants agreed with the proposed feed resource alternatives and none included additional alternatives in their assessment. As shown in Fig. 4, the overall assessment of the alternatives differed considerably between the interest groups, both with regard to alternative performance (expressed by how far to the right the bar extends) and uncertainties (expressed by bar length). No particular pattern describing trends in the performance of the alternatives emerges, except that by-products from fisheries and aquaculture were given high scores by all interest groups. Furthermore, one of the participants who worked for an environmental NGO defined sustainability as a principle and ruled out species from lower trophic levels and the three alternatives that involved GMOs, as he did not consider these alternatives to be in accordance with the principle of sustainability. As each chart shows the aggregated performance score among all participants for each interest group, the length of the bars is also an expression of the diversity of assessments among participants belonging to the same interest group. This is exemplified in Fig. 5, which shows how each of the policy advisors evaluated the alternatives and the uncertainties associated with these alternatives. These two charts express considerable differences both with regard to alternative performance and degree of uncertainty. When comparing the aggregated performance score among all participants for each alternative (Fig. 6), we see that all alternatives were centered

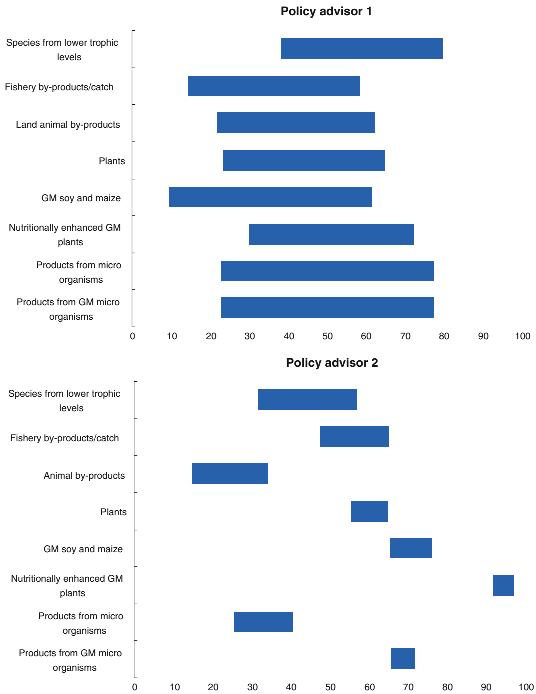

Fig. 5 Performance scores for each of the policy advisors. See Fig. 4 for explanation of the bars

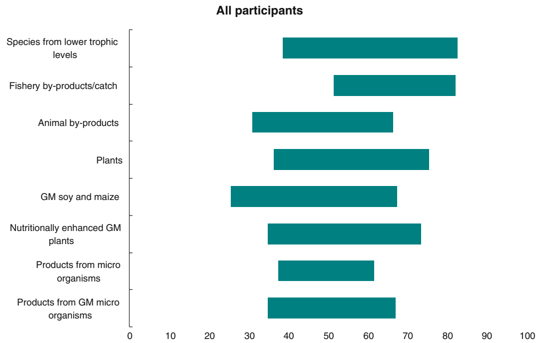

Fig. 6 Aggregated performance scores for all participants. See Fig. 4 for explanation of the bars

on a mid score (50) and there was only minor variance between the performance and uncertainties associated with the various alternatives.

Uncertainties Associated with the Feed Resource Alternatives

The participants were asked to give special attention to the exploration of uncertainties when evaluating the alternatives, which was technically done by assigning two scores for each option, reflecting the performance of the alternative under favorable and pessimistic assumptions. In this way, the participants were able to express uncertainties in the form of incomplete knowledge and to take context specific factors that could influence the performance of the alternative, into account. Additionally, diverging opinions regarding benefits and concerns among the participants, which contribute to further uncertainty, were identified.

Areas Characterized by Incomplete Knowledge

Many participants emphasized that the current understanding of the nutritional requirements of farmed salmon is generally limited, especially the relationship between the fish's diet and its vulnerability to diseases. More specifically, the participants identified the following areas as characterized by incomplete knowledge when evaluating health and welfare issues: (1) transmission of diseases from animals to humans if by-products from animals are used as a feed resource, (2) transmission of fish diseases to salmon fed on by-products and by-catch from fisheries and aquaculture, (3) impacts, especially on the fish's regulatory system, of replacing both fish meal and fish oil with plant resources, and (4) occurrence of toxic compounds and high levels of nucleic acids in products from microorganisms.

With regard to economical issues, a need for more research was recognized by the participants in order to: (1) improve the harvesting technology for species from lower trophic levels, (2) improve the production technology for microorganisms, and (3) develop nutritionally enhanced GM plants and GM microorganisms.

When evaluating environmental issues the participants identified the following areas as characterized by incomplete knowledge: (1) the population dynamics of species from lower trophic levels, (2) long term environmental impacts from cultivating GM soy and maize and nutritionally enhanced GM plants, and (3) impacts from GM feed surplus on the environment surrounding the fish farm. The three participants who defined criteria concerning the level of knowledge emphasized that the knowledge about disease transmission from animal by-products and environmental and health consequences from GM soy and maize is limited.

Diverging Opinions Among the Participants

The participants expressed highly diverging opinions about benefits, concerns, and uncertainties when evaluating GM soy and maize, nutritionally enhanced GM plants, and species from lower trophic levels. For instance, when evaluating GM soy and maize under criteria concerning health and welfare issues, six participants (four from the feed industry, one researcher in fisheries economics, and one policy advisor) considered GM soy and maize as identical to non GM plants. The other ten participants assessing similar criteria expressed concerns regarding potential unintended health impacts from GM soy and maize both for the salmon and consumers—referring, for instance, to the fact that transgenes from the feed have been detected in the fish a long time after feeding, as well as to the observed increase in intolerance and allergies to foodstuffs among consumers. The same concerns were raised when evaluating nutritionally enhanced GM plants.

When assessing environmental issues, the participants expressed opposing views with regard to whether current knowledge about species from lower trophic levels is sufficient to define sustainable levels of harvest. Moreover, the sustainability of plant production in industrial agriculture, and particularly the cultivation of GM plants, were contested issues. One of the policymakers argued that "GM is the only way to promote an optimal and fully sustainable feed production for aquaculture" and that "Nutritionally enhanced GM plants is the most sustainable feed resource alternative as it uses the photosynthesis for feed production." Other participants expressed concerns about the possibility for long term environmental impacts, both from the cultivation of GM plants and from discharges of GM feed surplus into the environment surrounding the fish farm.

Context Specific Factors

The most frequently mentioned context specific factor was timescale, as the participants were asked to assess the alternatives based on the current situation and expectations about the future (20 years from now). Most participants found it difficult to make predictions about future situations, particularly regarding future availability, price, and consumer reactions. Some participants expected, for instance, that consumers will support the use of species from lower trophic levels as a feed resource because it is beneficial to human health and an abundant resource that can be harvested sustainably. Other participants, however, expected low consumer acceptance, arguing that consumers would see this as "stealing food from the whales." Similarly, whereas some participants believed that consumers are positive to the use of plants in feed production due to environmental concerns, other participants believed that consumers might be skeptical, as “salmon is not naturally a vegetarian.”

Variability within the feed resource alternatives was the second most frequently mentioned context specific factor. This can also be attributed to the way the study was designed, as each alternative consisted of a variety of species/types of products. For instance, the use of by-products and by-catch from fisheries and aquaculture were included in the same alternative, but most participants emphasized that the environmental impacts from using these resources differs considerably. Whereas the use of by-products from fisheries and aquaculture is considered environmentally friendly, since this resource would otherwise become waste, many participants feared that the use of by-catch might lead to increased by-catch and thereby further increase the pressure on wild fish stocks.

Additionally, the participants commented that the price of the feed resource depends on availability, and is relative to nutritional quality and consumers’ willingness to pay for the final product. Availability may depend on regulation (e.g., current regulation limits the use of animal by-products and GM products). Species and type of by-product, as well as origin or place of cultivation and harvesting time were mentioned as context specific factors influencing the nutritional quality of a resource. Finally, factors such as management regimes and regulations, intensity and level of harvest, and alternative use of the resource (especially whether it was suitable for direct human consumption) influence the performance of the alternatives when assessed under environmental criteria.

Discussion

Mapping Perspectives on Feed Resources for Farmed Salmon

The study shows that different actors within Norwegian salmon aquaculture represent an important source of knowledge about alternative feed resources for farmed salmon. Thereby, the study provides valuable inputs to the aquaculture industry and policy-makers when deciding on future feed strategies for farmed salmon. As we see it, one of the most insightful outcomes of the study lies in the broad range of criteria identified by the participants, including (1) health and welfare issues, (2) economical issues, (3) environmental issues and (4) knowledge and social issues. Within these categories the most frequently defined criteria concerned fish health, consumer health, consumer acceptance, price, resource availability and environmental impacts. The criteria point to issues that are important to take into consideration when assessing and making decisions on future feed resources for farmed salmon. Interestingly, some criteria such as impacts on local communities from where the feed resource originate and the various environmental criteria, exceed what is typically seen as driving feed resource substitution, such as price, availability, and consumer acceptance (Naylor and Burke 2005; Tacon and Metian 2008). Thus, the wide range of criteria identified underlines the need for comprehensive evaluations that are broad in scope.

The participants found all the feed resource alternatives relevant and no additional alternatives were suggested during the exercise. No clear conclusions regarding what constitutes the most desirable feed resources can, however, be drawn from the study. Rather, it shows how the suitability of an alternative depends on which criteria the alternative is evaluated against and how these criteria are understood and prioritized. The evaluation of species from lower trophic levels exemplifies that criteria could be conflicting. All participants assigned high scores when this alternative was evaluated under criteria concerning health and welfare issues, whereas low performance scores or uncertainties were generally expressed under criteria concerning environmental issues. Furthermore, conflicting views on the same topic were frequently expressed among the participants, especially with regard to what constitutes sustainable practices. The different views were partly depending on timeframe, significance attached to uncertainties, and whether the sustainability of an alternative was evaluated relative to other practices.

Most participants experienced MCM as a useful exercise that stimulated reflection and provided a good overview about the suitability of alternative feed resources, and how this varied depending on appraisal criteria. Some did, however, express that they did not think that the final chart sufficiently described all the nuances and complexities involved in decision making on future feed strategies. This was primarily because the assessments of the alternatives involved highly context dependent judgments, reflected in the numerous "this would depend on…" comments made by the participants when evaluating the alternatives. As already described the most frequently mentioned context specific factors were time scale and variability within the feed resource alternatives. These factors can primarily be attributed to the study design, as many of the alternatives the participants were asked to assess consisted of different species/types of products and as they were asked to make predictions about the future. As the intention of the study was to gather perspectives on a range of alternative feed resources, including alternatives not yet in use, we purposely chose broad definitions and long-time frames for the assesment. We do, however, recognize that this posed additional challenges for the participants.

Qualitative Aspects of Uncertainty

Several areas characterized by incomplete knowledge were identified by the participants. These may guide future research priorities and support the need for more knowledge regarding the suitability of the different feed resource alternatives (Norwegian Research Council 2008; Norwegian Scientific Committee For Food Safety 2009; Waagbø et al. 2001). In discourses on science for decision making, increasing awareness is, however, given to uncertainties that are not necessarily reduced through more research, and several typologies characterizing different types of qualitative dimensions of uncertainty have recently emerged (e.g., Felt and Wynne 2007; Funtowicz and Ravetz 1990; Stirling 2007; Stirling 1999; Stirling and Gee 2002; Walker et al. 2003; Wynne 1992). These may be synthesized as (1) indeterminacy—describing knowledge as conditional and fallible due to the impossibility of including all relevant factors and interactions into research on complex, open and interacting systems, (2) ambiguity—describing uncertainties resulting from different framing conditions, as knowledge generated about a system depends on how researchers frame the systems and impacts they are interested in, and the way they approach, interpret, and understand the knowledge and calculations generated about them, and (3) ignorance—describing situations where we don't know what we don't know, and thus completely unexpected events may occur (Wickson et al. 2009). MCM is developed in order to address these qualitative dimensions of uncertainty, particularly how different values, interests, and underlying assumptions held by the participants influence their assessments—above referred to as ambiguity. Ambiguities identified in this study are illustrated in Fig. 4, which shows the differences in the aggregate performance scores between different interest groups, and in Fig. 5, which shows the differences in performance scores given by each of the policy advisors. As previously described, the participants' view on occurrence and significance of uncertainties was particularly diverging when they assessed GM soy and maize, nutritionally enhanced GM plants, and species from lower trophic levels. The participants who characterized these alternatives as very uncertain emphasized that it is difficult to predict long term impacts on health and environment. This underlines that agricultural and aquatic ecosystems are highly complex, open, and interactive systems, which are typical features of systems characterized by indeterminacy and ignorance. Thus, the study illustrates how ambiguities particularly prevail under such conditions.

There are no simple answers as to what constitutes the best solution in situations characterized by ambiguity, indeterminacy, and ignorance, as multiple and equally plausible descriptions of a problem—and how to solve it—exist. It is under these conditions that MCM may provide important insights to policy-makers, by simply mapping the plurality of scientific and socio-political perspectives on a problem. As we see it, the richness of this study is the broad range of criteria identified, and that it shows how the performance of the alternatives is influenced by the values and interests of the participants, reflected in the definition and weighting of criteria and in the evaluation of the performance (scoring) of each feed resource alternative under these criteria. In this way, the study helps to "open up" the evaluation process and thereby strengthens the information base upon which future choices can be made.

Conclusion

In this MCM exercise we wanted to map different perspectives on alternative feed resources for farmed salmon. One of the most insightful findings from the study was the broad range of criteria identified, including (1) health and welfare issues, (2) economical issues, (3) environmental issues, and (4) knowledge and social issues. This underlines the need to facilitate comprehensive assessments that go beyond the concerns that are typically seen as driving fish meal and fish oil replacement, such as price, availability, and consumer acceptance. No clear conclusions regarding the suitability of the feed resource alternatives can be drawn from the study. It describes different forms of uncertainties associated with the feed resource alternatives, which originate in incomplete knowledge, diverging opinions among the participants, and context specific factors. Furthermore, the study shows that individual values and interests held by the participants influence the assessments. This underlines the importance and usefulness of carrying out deliberative processes in the early stages of development in order to explore the plurality of scientific, social, and political perspectives on the issue. We believe that comprehensive assessments where a broad range of issues are taken into account, can contribute to improving the information base for decision making on feed strategies for farmed salmon.

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