Sustainable Aquafeeds to Maximise the Health Benefits of Farmed Fish for Consumers

In 2008, global seafood consumption was estimated at 143 million tons, growing by 43% in just 8 years. With fisheries supplies stable at around 90 million tons, it is aquaculture that has provided 53 million tons of seafood, representing an overall growth rate (APR) of 8.4%. Farmed products now represent 47% of the seafood consumed by humans and, with an increasing global population, future demand is certain to require further growth in aquaculture production. Nonetheless, this has to be achieved in a sustainable manner and, to achieve the position where the growing aquaculture industry can produce safe and healthy seafood products, the sector has to cope with several important challenges.

The three major issues identified in the beginning of the project are:

1. **A shortage of marine resources**.

There is a growing concern as to whether there will be sufficient fish meal and fish oil to meet the increasing demands of aquaculture and, therefore, whether the growth forecast will be limited by their availability. The expansion of fish farming requires the development of sustainable feed resources and their successful inclusion in fish diets.

2. **Nutrients and contaminants in fish.**

It is already well known that eating seafood is good for one's health. At the same time, fish – farmed as well as wild – can become contaminated with undesirable substances, like PCBs and dioxins, which may affect human health and must be reduced to minimal levels.

3. **Environmental impacts of the food chain.**

More information and data is needed on the factors affecting the environmental impacts and contributions of the complete food production chain.

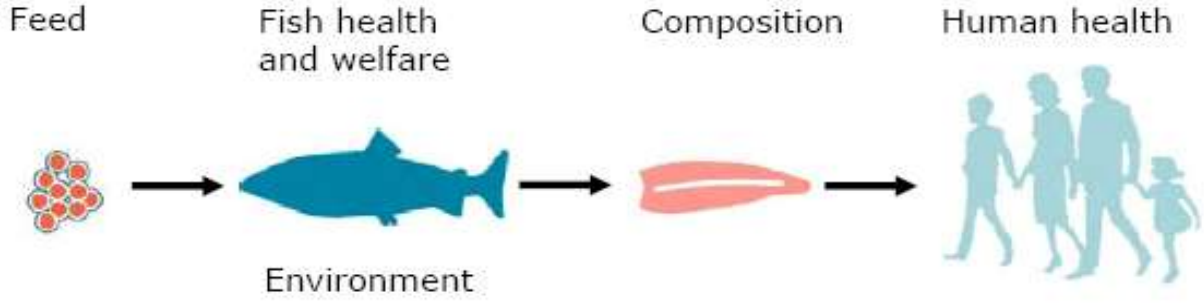

Fig 1: The production of safe and healthy seafood from aquaculture starts with the feed. Source: NIFES

Aim of the 'Aquamax' project

The 'Aquamax' project has been set up in line with the need to cope with these challenges. The basic aim was to develop feeds, based on sustainable alternatives to fishmeal and fish oil, to produce healthy and minimally contaminated fish that are highly nutritious, health-beneficial and acceptable to consumers.

The basic aim of the project is translated into 4 objectives covered by 4 research programmes:

 **Objective 1** To develop new feeds based on sustainable alternatives to fish meal and fish oil to produce healthy and minimally contaminated fish that are highly nutritious and acceptable to consumers. **Progr.1 - Coordinator: Prof. Sachi Kaushik** kaushik@st-pee.inra.fr	 **Objective 2** To assess health benefits of fish produced on the new feeds with a focus on pregnant women and allergic diseases. **Progr.2 - Coordinator: Prof. Philip Calder** P.C.Calder@soton.ac.uk
 **Objective 3** To assess the safety of fish farmed on the new feeds analysing the direct toxic effects of contaminants and the modulating effects of beneficial nutrients in fish. **Progr. 3 - Coordinator: Prof. Anne-Katrine Lundebye Haldorsen** anne-katrine.haldorsen@nifes.no	 **Objective 4** To assess the consumer perception of farmed fish and fish fed new diets and devise a framework to communicate the risks and benefits of consuming farmed fish. **Progr. 4 - Coordinators: Dr. Anne Katrin Schlag -** anne.schlag@kcl.ac.uk **Prof. Ragnar Lofstedt -** ragnar.lofstedt@kcl.ac.uk

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32 partners from fourteen countries have participated in the 'Aquamax' project.

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The website provides up-to-date information on the project and its achievements as well as a free subscription-based electronic newsletter.

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SIXTH FRAMEWORK PROGRAMME

OBJECTIVE 1

To develop feeds based on sustainable alternatives to fish meal and fish oil to produce healthy and minimally contaminated fish that are highly nutritious and acceptable to consumers.

'Aquamax' has surveyed and analysed a wide range of alternative ingredients, considering fully their nutritional suitability for fish, their economic viability, their sustainability and their safety. A comprehensive database of potential alternatives has been put in place and validated by Life Cycle Analysis.

At the beginning of the project, a range of analytical methods was already available for a range of undesirable contaminants within farmed fish and their feeds. However, increasing consumer concerns necessitated continuing development of analytical methodology to achieve even lower limits of detection than were available at that time. **'Aquamax' has advanced analytical methodology in order to detect very low levels of contaminants and has applied these upgraded techniques to alternative feeds and farmed fish to ensure they are as low in contaminants as possible.**

Persistent organic pollutants analysed in feed ingredients and fillets have been detected only at trace levels while market-size fish, fed 'Aquamax' diets, show only trace levels of pollutants - well below EU maximum permitted levels.

'Aquamax' was designed to identify and achieve major levels of replacement of both fish meal and fish oil with sustainable alternatives in fish feeds for Atlantic salmon, rainbow trout, sea bream and carp; it was important not to compromise the growth performance or the health and welfare of the fish species, nor the health benefits or the consumer acceptability.

Novel diets with a low content of fish meal and fish oil have been developed for: Atlantic salmon, rainbow trout, gilthead sea bream, common carp and Indian major carp.

The new 'Aquamax' diets have been tested in short and long-term feeding and field trials.

The radical dietary changes developed in 'Aquamax' have required particularly extensive and thorough monitoring and evaluation of the different fish species fed on these new diets. 'Aquamax' has achieved most of this by developing and applying molecular genetic technology using powerful performance-monitoring tools based on transcriptomics and also by the application of proteomic techniques. These approaches also contributed to our understanding of the underlying molecular and physiological mechanisms that determine the fish's ability to convert the new diets into high quality nutritional products, and their capacity to cope with these diets so as to ensure their health and welfare.

Results confirm that both fish meal and fish oil in feeds can be substantially replaced, without affecting the growth performance of the fish and their feed/nutrient utilisation, thus reducing the "Fish-In Fish-Out (FIFO)" ratios.

Assessing the environmental burdens associated with aquafeeds is a critical component for evaluating and improving the environmental performance of aquaculture. Going beyond the environmental impacts at the farm level, associated with feeds and their utilisation, studies undertaken under 'Aquamax' aimed to apply the Life Cycle Assessment (LCA) methodology to all stages of feed and fish production under diverse farming systems. LCA is a technique for assessing the environmental aspects and potential impacts throughout the life of a product or service. **Results showed that the development of new feeds led to improvements in terms of net primary production, whilst the increased use of vegetable sources can induce an increase in land competition as well as other impacts such as eutrophication and terrestrial ecotoxicity. This has to be taken in consideration in the feed formulation in order to minimise these environmental effects.**

'Aquamax' has assessed the fish produced on the new diets by expert taste panels, by electronic olfactory analyses, and by direct surveys of consumers purchasing fish through retailers.

Results from the flesh samples of 'Aquamax' fish that were subjected to electronic nose analysis and to evaluation of organoleptic properties by expert panels have established that the differences in sensory attributes are slight and that only small changes in odour, flavour and oiliness are detectable.

Consumer evaluation studies, made in Greece and France, on 'Aquamax' sea bream and trout have resulted both in high acceptance and appreciation of the fish farmed on the new diets. In both studies consumers' satisfaction was at least equal or even better for the fish farmed on 'Aquamax' feeds, showing that the substitution of FM and FO with vegetable alternatives is a fully feasible option for widespread implementation in the near future.

OBJECTIVE 2

To assess the health benefits of fish farmed on the new diets created in the 'Aquamax' project with a focus on pregnant women and allergic diseases

A large body of evidence attests to the health benefits of eating fish, in particular oily fish, that contain high levels of long chain omega 3 (Ω-3) fatty acids (eicosapentaenoic acid [EPA] and docosahexaenoic acid [DHA]) that play an important role in reducing the risks of cardiovascular diseases. DHA is also an important structural component of the eye and the nervous system including the brain. This is used to make nerve and brain cells and also the parts of the eye which communicate sight (retina). The human body can not produce these essential fatty acids so it is very important to take these in through the diet. Therefore, an early supply through maternal diet and breast milk is vital for optimal visual and neural development and function in the developing baby both in the mother's womb and during infancy.

'Aquamax' has substantially progressed knowledge in this area by validating the health benefits of fish produced on the new diets in pregnant women and young children.
For these two groups, information on the health benefits of fish is far from complete, due mainly to difficulties in conducting nutritional trials during pregnancy because of the potential presence of environmental contaminants in fish. Such concerns have been linked mostly to wild marine fish but also encompass farmed fish because of the use of marine fish meal (FM) and fish oil (FO) in aquaculture feeds.

Within the 'Aquamax' project, the development of tailor-made salmon, with minimal contaminant levels and a high content of Ω-3 fatty acids, has enabled the project to conduct the first nutritional intervention study on oily fish consumption in pregnancy.
Evidence has pointed to a low dietary intake of long chain Ω-3 fatty acids during pregnancy being a significant factor in infants developing atopic disorders (asthma, hay fever, dermatitis and allergies). Children who are affected by allergies have lower amounts of Ω-3 fatty acids in their blood and blood cells. This observation suggested that increasing the supply of Ω-3 fatty acids to babies, even before they are born, may help to "normalise" their levels of Ω-3 fatty acids and lessen their chances of developing allergies.

123 pregnant women from families with a history of atopy participated in the study. Of these, 61 continued their habitual diet (characterised by low fish consumption) and 62 consumed two salmon meals per week from week 20 of pregnancy until delivery.
The goal was thus to investigate whether the consumption of farmed 'Aquamax' salmon would improve the nutritional status of these women and that of their babies. Furthermore, follow up on the development of atopic disorders has been made on the babies.

Results show that when pregnant women (who do not regularly eat oily fish), eat two portions of salmon per week, the intake of long chain Ω-3 fatty acids (EPA and DHA) is significantly increased, as well as the levels of selenium and vitamin D which are also found in oily fish. Moreover, they have a higher amount of long chain Ω-3 fatty acids in their bloodstream and so, therefore, will their baby. Since these key functional fatty acids decline in the mother's blood during pregnancy, due to the demands of the growing baby, this is important. This dietary change can thus enable the mother to supply more optimally these nutrients to the developing baby before it is born. Consumption of salmon in pregnancy also resulted in a higher content of EPA and DHA in breast milk meaning allowing better supply of these fatty acids to the baby after birth.

The follow up on atopic disorders performed on the babies at birth and at 6 months of age did not point out any differences between the two study groups, the next check will be at 3 years of age and this will allow a more intensive comparison of allergic symptoms.
Further studies of increased long-chain Ω-3 PUFA provision during pregnancy, lactation, and infancy are needed to more clearly identify the immunologic and clinical effects in infants and children to identify protective and therapeutic effects and their persistence.

The intervention study has been supported by data from a parallel cross-sectional study in China assessing nutrient intakes among pregnant women from 3 different regions that represent different eating habits with respect to fish and seafood (coastal, inland, river and lake). This observational study aimed to investigate the impact of different dietary intakes of long chain Ω-3 PUFA on the nutrient status of pregnant women and their babies and markers of allergy and sensitisation in infants. The women selected were encouraged to remain on their habitual diets during the course of the study. Dietary surveys were conducted on the women recruited and fatty acid analyses of their diets and their blood determined. These measurements will be associated with atopic disease outcomes in the babies.

OBJECTIVE 3

To assess the safety of fish farmed on the new feeds by analysing the direct toxic effects of contaminants and the modulating effects of beneficial nutrients in fish

Controversy remains as to the safety of consuming certain types of seafood, particularly during pregnancy. While seafood is rich in vital nutrients it also may be a source of environmental contaminants, such as persistent organic pollutants (POPs) or methylmercury (MeHg).
In traditional aquaculture feeds, fish meal and fish oil from marine fish are respectively the primary sources of MeHg and POPs. By developing new diets, 'Aquamax' has achieved major advances in knowledge in how to drastically reduce the levels of contaminants in both feed and farmed fish. To assess the safety of fish farmed traditionally and on the new feeds, 'Aquamax' has deployed conventional and new molecular genetic technology (transcriptomic and proteomic analyses). The research was conducted on mouse cell cultures and on mice fed fish produced by 'Aquamax', considering both direct toxic effects of known and putative contaminants and possible modulating effects of beneficial nutrients in farmed fish.

'Aquamax' has developed innovative food safety toxicity tests by identifying and characterising signature effects of key toxicants in fish:
Built on the hypothesis that the effects of chemicals on an organism start with the interaction between a chemical and one or several biomolecules, the assumption was made that each interaction changes the production of proteins and that toxic chemicals with a similar mechanism of action have similar gene (mRNA) and protein expression profiles.
To test this assumption, mice were fed salmon-based diets spiked with model toxicants. Different toxicants fed at high doses generated unique mRNA and protein expression profiles. However, in mice fed daily salmon containing environmentally-realistic concentrations of single toxicants, few effects on gene expression occurred.

'Aquamax' has elucidated actions of key toxicants and their amelioration by fish nutrients in developing mice and cultured mouse cells:
The expression of thousands of genes (mRNA) and proteins in mouse brains and cultured mouse brain cells were measured alongside pathological indices in tissues, changes in hormone levels, and neurodevelopment. 'Aquamax' studies focused primarily on the effects of MeHg and the emerging group of brominated flame retardants.
High concentrations of MeHg caused oxidative damage in specific brain cells but more diverse effects included the disturbance of immune proteins and evidence of competition for zinc in proteins.
Brominated flame retardants showed related effects on the brain, notably in disturbances of calcium and thyroid hormone signalling, protein unfolding and the activation of neuro-degenerative pathways. In mice, environmentally-realistic concentrations of brominated flame retardants caused subtle changes in tissues and hormone levels when the animals were fed contaminated fish every day for four weeks. The brominated flame retardant, BDE47 accumulated in the brains of maternally-exposed offspring, reflecting maternal intake. Accumulation of BDE47 was significantly lower in offspring from dams fed a fish-based feed compared to a casein-based feed. A few early reflexes were significantly impaired by exposure to BDE47 and better nutrition did not improve behavioural tests. Few effects were observed on neurodevelopment in mouse pups of dams fed diets containing MeHg.

Many nutrients in seafood may counteract effects of environmental pollutants. In the experiments on mice and cultured cells, both selenium and Ω-3 fatty acids protected against MeHg toxicity. Ω-3 fatty acids also protected against toxic effects of the brominated flame-retardant, HBCD, commonly found in oily fish. Therefore, the protective effects of nutrients in fish must be balanced with the risk of consuming toxicants in fish.

'Aquamax' has conducted food safety tests in animals fed fish farmed on traditional and new feeds.
Several genetic, physiological and morphometric biomarkers have been identified, which are symptomatic of exposure to groups of environmental contaminants commonly found in fish. In all previous studies, exposures involved addition of single toxicants to a salmon-based diet. In the final study of 'Aquamax', mice fed for four weeks on feeds made from heavily contaminated Baltic salmon, 'traditional' farmed salmon and salmon produced with 'Aquamax' technology, are being analysed for detectable effects.

OBJECTIVE 4

To assess the consumer's perception of both farmed fish and fish fed with new diets and devise a framework to communicate the risks and benefits of consuming farmed fish

The public is often presented with conflicting scientific advice about the potential risks and benefits of consuming (farmed) fish. The media tend to report health risks associated with fish consumption with much greater frequency than the related benefits, neglecting to provide a balanced approach.

An in-depth understanding of lay perceptions of food risk is a prerequisite for developing effective communication strategies with the public and to provide implications for policy and decision makers in Europe. Without this understanding, risk communication strategies may be ineffective.

Using the knowledge gained within 'Aquamax', a framework for communicating to the public and other stakeholders on the risks and benefits of consuming farmed fish has been devised and tailored risk communication strategies are being developed.

To understand the current perception that the public has towards the consumption of farmed fish, scientific risk and benefit assessments of aquaculture were summarised and compared to risks perceived by the lay public, as outlined in social science literature.
There is a broad range of lay concerns about aquaculture which often differ from the scientific risk assessments. This makes the development of a risk communication strategy on aquaculture, which satisfies both expert and lay concerns, highly challenging and complex.
Overall, consumers demand more credible and balanced scientific information and a more inclusive public dialogue. Lay people want to be informed; however, science needs to be presented in a clear and accessible way, to make the information understandable and believable.

'Aquamax' analysed media coverage of both farmed fish and fish farming so as to assess agenda setting and interpretations of risk and benefits by the media. Over 1,000 articles in print media in Estonia, Germany, Norway and the UK were analysed over a five-year timeframe, showing historical developments in reporting on farmed fish.
Overall, when reporting on environmental topics, the media focused primarily on risks. A vast variety of environmental risks associated with aquaculture were reported, often using terminology that could heighten public anxieties. In contrast to the environmental issues, economic issues were largely reported in a positive manner and framed in terms of benefits.
In all countries, human health issues associated with farmed fish consumption and with fish farming received far less media coverage than either environmental or economic topics. Coverage tended to be negative, focusing on the health risks rather than the benefits.
Media coverage also highlighted a variety of organisational and regulatory risks, such as concerns about the mismanagement of the industry, and the lack of regulations and labelling standards.

From this analysis it is evident that aquaculture is an activity that may elicit public concerns because of the dominance of reporting on the industry's risks, often at the expense of its benefits. The potential issues to be addressed are multiple and wide-ranging, highlighting the challenges for the development of risk communication strategies.

Assessment of the awareness and the perception of the risks and benefits associated with aquaculture and the consumption of farmed fish using focus groups in 7 European capitals.
A large scale focus group study of lay perceptions of farmed fish and fish farming in Europe was conducted by 'Aquamax'. Consumer perceptions of farmed fish and aquaculture were explored to show how risks and benefits are assessed. 28 focus groups were conducted in the capitals of seven European countries: France, Italy, Germany, Greece, Norway, Spain, and the UK.
Results show that consumers are aware of and knowledgeable about the benefits of fish consumption (farmed or otherwise) for human health. However, there is significant concern about the environmental impacts of both aquaculture and capture fisheries. Furthermore, consumers express a lack of trust in the regulation and control of the aquaculture industry. Most participants have only limited awareness and knowledge of farmed fish and fish farming and request further information. In particular, information about regulation of the sector and labelling of farmed fish is required to reassure and inform consumers.