Draft Strategic Research Agenda

Introduction/Scope

Cultured species in Europe depend on compound feeds, traditionally based on fish meal and fish oil, which are products of capture fisheries. Fish meal and fish oil production has stabilized to about 6-7mt and 1mt respectively since 1985. World Aquaculture is today absorbing 50% of fish meal production the rest of it being used for terrestrial species. Utilization of fish oil is even higher amounting to 90%, half of it being used for salmonid feeds. It is therefore of outmost importance that high quality alternatives to fish meal and fish oil, produced in a sustainable way and provided at a competitive price, are selected and used for the replacement of these commodities. Feed utilization by fish should also be optimized to guarantee the future sustainability and development of the Industry as well as minimal environmental impact.

Much research has been devoted in recent years in the direction of replacement of both fish meal and fish oil. The results are encouraging since a high level of substitution was possible in a number of fish studied. However it was also clear that introduction of new materials at high concentrations is affecting fish metabolism and could create problems in fish health and welfare. It was also indicated that responses are species specific.

From the side of Aquafeed Industry difficulties are being encountered in setting standards of quality to raw materials that would have a well defined meaning for the final feed quality. Finding raw materials of competitive price is also a problem since values and availabilities of even plant materials seems to fluctuate a lot in recent years due to their use as biofuel substrates. Including new materials in the diets also requires adjustments in production procedures since physical characteristics of pellets change

On the basis of the experience gained so far the main issues requiring further study in order to achieve the production of sustainable and high quality feed for the future are the following:

- Increase the diversity of raw materials, which can be included in the diets based on solid knowledge of their physicochemical characteristics, nutritional quality, effects on fish health and welfare as well as their safety for the consumer.
- Understand better the fish nutritional needs concerning both nutrients and needs for micro-ingredients, with the aim of achieving higher growth and feed efficiency as well as assimilation of protein and retention of n-3 HUFA. This should cover all stages of growth with larval nutrition being a specific issue since this task is tightly connected to the development of satisfactory microdiets.
- Take advantage of developments made in other sectors to select raw materials of high quality, and utilize appropriate technological and biotechnological processes to improve raw material and feed quality, selecting also procedures and products of low environmental impact.
- Looking in the future and the great advances already made and expected to be achieved in the sector of molecular biology and genetics it is quite imperative to use all modern tools provided, to gain more knowledge on aspects of basic metabolism and fish health and welfare, changes occurring due changing feed composition and to find indices characterizing the status of the fish.
- Finally looking at the side of fish and not feed, selection of strains better equipped to handle new diets or programming these at early developmental stages to do so is another promising option

According to a recent EU-level Delphi study, research on development of future feeds is a major issue, with strong expectations for new achievements up to year 2020.

Competitive advantage

European Aquaculture Industry is a leader in Technology Development and Innovation. Many Industries of fish feed production are located in Europe and provide fish feeds in Europe as well as in other parts of the world. However Europe is still dependent upon the important of many key raw materials including fishmeal, fish oil, soybean meal, cereals. Including a larger variety of raw materials locally produced will strengthen other agriculture areas and increase employment.

Europe is unique in that its partnerships between industry (the farmer, the ingredient supplier, the feed manufacturer or equipment supplier) and the research community (University, Government Laboratories) is very close and focused on a limited number of high value marine and brackish water fish species, including cold water marine finfish species and salmonids as well as warm water finfish species. This partnership is an excellent basis for further accomplishment of innovating research

Goal 1: Strengthen sustainability of aquaculture by developing Future Fish Feeds based on sound scientific basis

Much progress was made in recent years, through EU projects torwards FM and FO substitution. This showed that for protein and essential amino acid supply, no single alternative ingredient can replace FM. However, mixtures of plant protein sources supplemented for limiting amino acids (if required), can easily replace up to 75% - 90% of FM in most teleosts' feeds. Regarding FO, studies confirmed that single vegetable oils or better a mixture of vegetable oils can replace a major portion of FO in most fish feeds. The changed FA profile can be tailored back, to a certain extent, by appropriate finishing feeds rich in FO.

Despite progress many questions concerning dietary formulations and use of alternative materials remain. Data on nutrient and energy requirements are limited to a few major species and do not cover all life stages (from larvae to broodstock) as well as the impact of husbandry conditions. Some knowledge has been gained on effects of antinutrients (ANFs) on fish performance, which has to be further enriched taking into account differences among species and life stages. Micro-ingredient contribution to supporting growth and nutrient assimilation is insufficiently explored. New ingredients are developing from intensification of other activities, rise to new promising alternatives. FO substitution should not alter the beneficial nutritional profile of the product and to this respect more efficient means for conserving the HUFA profile of fish fillet are required. Furthermore the concern about climatic changes requires sustainable aquaculture practices by using raw materials selected on basis of their sustainability (e.g., CO_2-footprint, waste production).

Major research challenges:

a) Nutritional requirements of fish

There is a strong need to consolidate our knowledge base on the nutrient requirements to fill in current gaps in basic knowledge for all species of interest to European aquaculture using novel methods. Additional information on specific physiological demands of various life stages and of environmental factors including novel farming systems is also required. Within the issues requiring study increasing protein efficiency still further is definitely a major issue, especially in marine fish.

Outcomes

- Nutrient requirements and Energy allocation over the full life cycle: "from larvae to broodstock"
- Feed (ingredient), fish, farming system interactions.

b) Nutritional value and sustainability of alternative raw materials/ feeds

There is a potential of including of a number of raw materials in aquaculture feeds, which have not adequately tested up to now like, co-products of the emerging bio-fuel economy, microalgae, krill, trash fish, tailored plant proteins (GMOs) or single cell proteins derived from other industries (fuel or feed). Avoided ingredients, like terrestrial animal by-products can also be considered based on solid science, including social sciences. Concerning lipid nutrition a number of oils not used so far but being promising sources in terms of sustainability, cost and easier restoration of fish FA profile should be tested in the future. Feed intake regulation requires further assessment driven by the changing feed composition.

For all evaluations of outmost importance is to develop reference diets and to implement standardised experimental procedures, as well as to perform more systematic and concrete studies on the wide variety of potential ANFs and possible toxicants (for example mycotoxins) present in ingredients. Furthermore future feeds with novel ingredients will have to be systematically subjected to scrutiny in terms of sustainability of raw materials and environmental impact of aquaculture (waste production).

Outcomes

- Types and range of levels of ANFs and possible toxicants in different ingredients in relation to origin and treatment. Biological value of ingredients to fish.
- Development of feeds using novel feed ingredients for different species
- Feed intake and regulation at group and individual fish level
- An integrative sustainability index for ingredients and control of the environmental impact of aquaculture through optimal feeding

c) Micro-ingredients

In micro-ingredients are considered vitamins, minerals and other trace elements in feeds necessary for growth as well as different bioactive compounds that could optimize performance. The role of the first for fish is well known although their study is far from complete. The knowledge of the exact requirements is important in view of the changing matrix of feed ingredients. A great range of bioactive compounds exist, which could support the fish organism capacity to respond to the new feeds and optimize performance but their use requires efficient screening as well as studying the efficacy of the delivery method to target tissue and organs.

Outcomes

- Sound estimations of trace element requirements in major farmed species at different life stages and practical farming conditions.
- Identification of novel feed additives of nutritional (pigments, enzymes, "health promotors", novel phytochemicals) or of technological interest (enzymes, additives, nanoparticles…)
- Clear understanding of the mechanisms associating micro ingredients with a bioactive role with nutrient utilization in fish under different farming systems

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Goal 2: Improved technologies for larval and fish feed production

Introduction / Scope

Feed manufacturing technologies have over the last years evolved into an energy intensive direction using costly processing equipment. The demand for high pellet quality and stricter regulations regarding hygienic quality has driven feed development towards the use of advanced and energy demanding processing technologies. Increasing energy prices and the fact that there may be unintended negative effects of heat treatment on nutrient utilization, calls for more gentle and less energy demanding processes that can provide high quality feed ingredients and safe feeds.

Use of new feed ingredients have increased the complexity of the feed manufacturing process and may cause variation in the physical properties of feeds. This may result in increased requirements in feed processing, and problems associated with the operation of automatic feeding devices, reduced nutrient availability and/or problems associated with nutrient leakage. Although not well studied, feed intake and nutrient digestibility in fish can be affected by the physical properties of the feed. For example, processing technology and physical quality of feeds for marine fish larvae are particularly complicated, and this is generally considered to be one of the greatest bottlenecks to large scale production of marine carnivorous fish species.

To secure a sustainable development of the European aquaculture industry new alternative feed resources are needed, including new technologies for upgrading of the nutritional value and removal of unwanted compounds. In addition there is a need for development of new cost-effective feed production technologies.

Major Research Challenges

a) New environmentally friendly production technologies for producing high quality feeds

Production of modern high quality marine aquafeeds requires high inputs of energy and heat. Raw materials are also usually preprocessed in protein and oil ingredients, which is also an energy requiring process. Heat is beneficial for some nutrients but generally creates losses to added micronutrients or makes impossible the addition of certain others due to high losses. Taking advantage of new energy efficient production technologies with improved heat integration to reduce energy cost, as well as use of raw materials without preprocessing necessitate evaluation of pellet quality,.

Local processing of by-products from fisheries and aquaculture with use of small scale processing equipment may also be a more energy efficient way to produce future fish feed. The greatest research challenge for small scale feed production can be summarized to logistics, intermediate storage, raw material freshness and homogeneity and limiting leaching of water soluble dietary components.

Outcomes:

1. New technology for direct use of low processed ingredients and local small scale low cost processing of feed.
2. Improved drying technology and heat integration to reduce energy costs during production of ingredients and feed.
3. Development of new techniques to improve the carry through of heat sensitive ingredients in the feed manufacturing process.

b) Larval feeds

Disease susceptibility, high mortality, inconsistent fry quality, poor feed conversion and suboptimal growth are all frequent problems in the production of fry that can be related to the lack of appropriated larval feeds and lack of knowledge about larval nutrition. Today marine larvae are start fed with cultured live feed such as rotifers and *Artemia*, which are not a natural prey for fish larvae. In spite of the development of enrichment processes and diets, which are effective for delivery of essential fatty acids, the live feed content of indispensable amino acids, vitamins and minerals is difficult to control.

New technology for production of formulated small particle's feeds and earlier weaning will therefore reduce the need for live feed organisms and will result in faster growth rate, improved survival, and fewer deformities. The main challenges in production of compound feed for larvae can be summarized to production of even particle size with a high physical and nutritional quality that are water stable and stimulate feed intake.

Improved nutritional quality of live feed and effective early weaning diets will allow a more precise determination of nutrient requirements along larval development. Improved quality of compound diets will in the future reduce the dependency on live food for production of marine fish in hatcheries.

Outcomes:

1. Improved quality of live feed and microdiets that results in higher feed intake, higher growth rate, improved disease resistence, lower mortality and lower incidence of larval deformities.
2. New technologies for the early weaning of marine fish.
3. Determination of larval nutritional requirements.

c) Optimizing physical quality without compromising nutritional quality of fish feed

The physical quality of feed is strongly associated with feed ingredients and processing conditions. Variation in feed intake when fish are fed diets with new ingredient composition are commonly reported as poor palatability, but is often most likely associated with variation in physical pellet quality. More research is needed to understand how various ingredients and processing conditions affect the pellet microstructure and physical properties, and how these characteristics are correlated to the nutritional properties of the feed.

Outcomes:

1. Improved flexibility in use of various ingredients without compromising physical quality of the feed.
2. New analytical methodology to characterize feed ingredient physicochemical properties and improved understanding of how these properties influence physical pellet quality.
3. Improved understanding of how feed intake and nutrient utilization in fish is affected by physical quality of the pellet.

Goal 3: Understand and minimize negative effects of alternative diets on fish health and welfare

Losses due to disease represent a major cost in the aquaculture industry internationally, and feeding and diet composition are among several factors that may influence fish health and welfare. The gastrointestinal tract (GIT) is the first line of defence to pathogens. However, it is constantly exposed to a conglomeration of nutrients, anti-nutrients and non-nutrients, also comprising food antigens and microorganisms, which might alter its integrity. Nutrition and diet composition may thus directly or indirectly influence susceptibility to infectious and non-infectious disease by affecting various organs, metabolic pathways and the immune system. Optimal health is irretrievably connected to welfare. But other welfare issues more indirectly linked to health, such as stress, pain and behaviour, may also be influenced by feeding, diet composition and nutrition.

Most feed ingredient evaluations conducted on various fish species have focussed on testing single substitutions of fishmeal. Traditionally, the emphasis has been on effects on growth parameters, feed utilization, flesh quality and other parameters of economic relevance. The studies have also been in the relatively short term rather than whole production cycles. Although health and welfare aspects of feedstuff evaluation are now enjoying more attention, little is still known, especially long- term repercussions. Very recent results suggest that combinations of feedstuffs and their components may lead to very different results, with negative effects on fish health, than when the feedstuffs were tested alone. Certain feed additives have been used to improve fish health status but interactions and outcomes when used with maximum substitution diets is mostly unexplored.

A major challenge is therefore to ensure that changes in diet composition brought on by the need for more sustainable feeds do not compromise fish health and welfare.

Major research challenges

a) Diet and the alimentary system’s function and integrity

Knowledge gaps exist regarding the digestive tract’s and associated organs’ (e.g. liver and pancreas) structure and function. Research is required to evaluate the effects of diet ingredients, including feed additives, and physical characteristics of the feed on digestive functions and structure, as well as provide suitable indicators of malfunction for understanding these interactions.

Outcomes:

- Improved basic knowledge on the physiology and morphology of the gastrointestinal tract and associated organs in cultured fish species
- Development of methods and markers for assessing effects of feeds, feed ingredients and their components (individually as well as in combinations), feed additives, and nutrition on gastrointestinal function and structure
- Identification of the impact of commensal microbiota on gastrointestinal structure and functions, and the interactions with diet

b) Diet, the immune system and disease susceptibility

The gastrointestinal tract is considered a prominent component of the immune defence of the body and the development of a rigorous surveillance system is essential to protect the body from pathogens. The roles of nutrition, diet composition and feed additives on the gastrointestinal and systemic immune system and subsequently on disease susceptibility in fish are, however, largely unknown.

Outcomes:

- Increased understanding regarding the influence of dietary components, individually as well as in combinations, on the gastro-intestinal and systemic immune system, including interactions with the commensal microbiota, with the aid of newer technologies such as gene and protein expression profiles
- Identification of other potential stresses that feeds and dietary components may cause and their influence on disease susceptibility

c) Diet involvement in the aetiology of production diseases

Production diseases are a health and welfare problem in aquaculture as they are in other forms of animal production. They are usually characterized by complex non-infectious, multifactorial aetiologies in which diet and nutrition can play central roles. Examples include skeletal deformities, cardiovascular diseases, indigestion, cataracts, and even tumours. Coupled with the changes in diet composition, the occurrence of production diseases may vary within and between species.

Outcomes

- Epidemiological studies in which interactions between the incidence of production diseases in different fish species, changes in diet composition and other aetiological factors are mapped
- Development of methods and markers for assessing involvement of feeds, feed ingredients and their components (individually as well as in combinations), nutrition and metabolism in various production diseases
- Increased knowledge regarding the contribution of physical characteristics of formulated feeds on the occurrence of production diseases

d) Diet involvement in other aspects of fish welfare

Endocrinological responses can be affected by diet and thus also stress responsiveness. During feeding, intense fish-fish interaction occur that can affect feed intake (inter-individual variation) as well as induce aggression. Studies on the direct influence of feeding strategies, diet composition, feed additives and nutrition on welfare aspects such as stress and behavioural responses are rare. This is largely due to the difficulty in designing such studies and gauging the results due to the dearth of knowledge on normal ranges of various markers for physiological characteristics for different fish species under varying environmental conditions. However, recent breakthroughs in stress and behaviour research and newer technologies such as RNA and protein expression profiling may be of assistance for future studies in this area in fish.

Outcomes

- Development of methods and markers for assessing implications of feeding strategies, feeds, feed ingredients and their components (individually as well as in combinations), nutrition and metabolism on fish welfare issues such as stress and behaviour responses.
- Improved basic knowledge on the impact of interaction between feeding methods, dietary component and nutrition regarding stress responsiveness and behaviour.
- Identification of feeding methods and dietary components that may act toward stress remediation and prevent negative behavioural responses such as aggression

Goal 4: Adapt and utilize advanced methods to understand and model nutritional responses.

Understanding fish metabolism and its response to changing nutritional components requires sophisticated tools that would either give information of the effects on cellular level or provide an integrated view of the effects on fish metabolism and health status. Cell culture models are a valuable tool for understanding the response of the cells, while nutrigenomic provide a more holistic approach to changes occurring at an organism level. Nutrigenomics involve a whole range of –omics methods like transcriptomics, proteomics and metabolomics since no simple technique is adequate to analyse all different types of molecules that are involved or produced in response to a nutritional effect. Information collected by these methods can fit into models to predict the organism response to a nutrient as well as growth and diet utilization a tool that would be a great help in designing feeds in the future.

In recent years advances in examination of the transcriptome and proteome have been directly related to the increased sequence coverage of genes in major aquaculture fish species. Salmonids have greatest sequence coverage at present but many other farmed species will soon have equivalent or greater sequence coverage. The accelerating speed of sequence data accumulation, generated from new technologies will yield complete genomes of aquacultured species within the next few years. To exploit maximum benefit from this a number of approaches are required to integrate this information into the aquaculture nutrition. The genomics data needs to be correlated with other physiological data to help understand responses to diets involving new computational models.

Major research challenges

a) In vivo and in vitro models to examine physiological responses to nutrients

(i) Cell culture models used for reporter cell lines/ promoter analysis/ expression pathways

To predict which effects to expect when changing feed raw materials in future fish feed we need to know the effects of single nutrients and the interaction between nutrients in fish. *In vivo* studies cannot discriminate the roles of hormonal *versus* metabolic factors to explain the nutritional control of gene expression. Cell culture models are an essential *in vitro* methodology for elucidating the effects of single nutrients and nutrient interactions in a controlled environment . Studies successfully utilising fish primary cells relevant for nutrition studies (hepatocytes, adipocytes, muscle- and bone cells) are currently increasing, as well as studies with fish stem cells including embryonic and mesenchymal stem cells.

(ii) Model fish species such zebra fish allow for targeted fundamental nutritional studies.

Post-genomics analysis to test the function of unexpected or unknown genes including transgenesis, gene knock out and development.

Outcomes

- Cell lines developed to examine the control of gene promoter regulation (using reporter genes) signalling mechanisms triggering gene expression and protein function.
- Elucidate cross-talk between cell types (tissues) and development of fish cell co-cultures.
- Develop fish stem cells to explain effects of nutrients on early development and differentiation and proliferation of cells.
- Gene knock out mutants in model fish to examine the function of nutrient gene interaction, tissue specific gene transcription using reporter genes in transgenic fish.

b) Integrative tools genomic tools:

Nutritional changes in diets cause physiological perturbations in many systems within a fish, obtaining a holistic view of this is a major challenge to nutrogenomics, the integrative tools include transcriptomics, proteomics and metabolomics. (i) Transcriptomics describes the examination of the expressed complement of genes in a tissue and the expression level of these genes. .Microarrays can determine expression 10's of 1000's of genes in parallel. This will enable not only expression but alternatively spliced transcripts and allelic variants all of which will be altered by different nutritional regimes to be related to performance. New high throughput sequences approaches (454, Illumina) will complement or replace arrays within 5 years. (ii) Proteomics: the final products of gene expression are the mature proteins examines the abundance and modification of proteins followed by identification by computational analysis.

In the future more non gel based systems for protein separation and use of isotope tagging (eg ICAT) will be used and techniques to study protein modification, particularly phosphorylation, a major regulatory mechanism for protein activation. All aspects of bioinformatics relating to transcriptomics and proteomics are improving and leading to improved gene and protein identification.
(iii) Metabolomics: This encompasses the study of non-sequence specific metabolic compounds using high throughput methodology resulting from enzymatic outputs controlled by transcriptome and proteome. This is an important, but relatively unexplored area in fish nutrition. For performing metabolomics in fish nutrition studies, the implementation of high throughput systems including bioinformatics tools for interpretation is the main challenge. iv) SNP (single nucleotide polymorphism) chips with tens of thousands of markers covering whole genome allow fine mapping of genes and genomic (marker-assisted) selection to aid selective breeding programs.

Outcomes

- Improved annotation of genes and proteins including gene ontology and protein –protein interactions
- Identification of key marker genes & proteins to assess nutritional quality, use these in eQTL studies.
- Determine protein modifications by phosphorylation and glycosylation relating nutritional changes
- Improved analytical techniques for separating metabolites & analysis of the abundance and identification.
- SNP Chips developed for selection of nutritional related traits

c) Mathematical modeling of nutritional responses in fish.

The available data from experimental nutritional research is already fast and will incline by future research. At the same time the type of data will also strongly diversify by new areas of research, e.g., application of – omics techniques, new in vitro methods and issues in nutritional research (e.g., environmental impact of nutrition). Development of mathematical simulation models will contribute to maximizing/improving the valorization and dissemination of experimental nutritional data both for scientific and practical purposes. For practice, models should aim at integrating existing knowledge into primary production (e.g., development of feeding strategies, feed formulation, waste management, etc.). Nutritional research will benefit from modeling by integrating existing knowledge into new and improved concepts of the nutritional role in biological/physiological systems. This will lead to identifying gaps in knowledge and key research areas for development of sustainable feed production. Modeling can aid at various segregation levels: from cell, organ, organism to farm/ecosystem level. Moreover, modeling can be applied for various biological/physiological process, such as feed intake regulation, digestion, metabolism as well as waste management.

Outcomes

- Integration of existing and future experimental nutritional data.
- Identification of knowledge gaps and key/crucial research areas in nutritional research.
- Valorization and dissemination of experimental nutritional data for practical aquaculture (fish farmers, feed manufactures, ingredient producers, etc.).

Goal 5: Resolve strategic research problems in fish nutrition

The switch from the sole use of animal-protein based feeds to feeds consisting also of non-animal protein ingredients (e.g. plant proteins) creates a challenge for fish nutrition. This calls for in depth studies on metabolic and feed intake regulation, which are of most importance in promoting growth and/or sustaining homeostasis. Sustainable production of protein for human consumption is one main aim of aquaculture. However, assimilation of feed protein by fish is not efficient. Amino acid balance and form and level of energy supply are the most studied parameters in order to optimize assimilation but major challenges remain to be solve to increase production efficiency in practical aquaculture activities. The central role of hormones in regulating growth, feed intake and nutrient utilization by fish is unambiguous. Furthermore, fish endocrine system is sensitive to alternations in nutrient intake. While hormonal balance is not fully understood in fish, the changing nutritional composition is imposing another factor affecting the whole fish homeostasis (incl. feed intake). While most studies concentrate on feed optimisation, an additional way for improvement is to select or condition fish to accept and perform better on alternative feeds. All these developments should be evaluated against their costs and returns, to assess the potential for commercialisation.

Major research challenges

a) Intra-specific differences in amino acid metabolism and improving protein growth under varied production systems

For optimal protein growth, fish need a balanced amino acid profile. When marine protein is reduced and alternative protein sources are added in fish feeds, both amino acids and nitrogen metabolites present in animal feed ingredients change. In terrestrial farm animals, it is well known that both balanced amino acids and the non-protein nitrogen compounds affect accretion and composition of growth (lipid, protein) in different body parts. Thus, the importance of how dietary amino acids signals to metabolism (via endocrinology and key enzymes) for maximal protein accretion and minimizing of lipid deposition need to be explored simultaneously to secure efficient and high quality production with minimal nitrogen waste.

Nutritional environment directly effects fish endocrinology and thus may impact not only nutrient utilisation and feed intake but also on immunology, disease resistance and stress tolerance. Nutrient regulation of the endocrine system is important for insulinotropic, somatotropic and hypothalamic pituitary adrenal axes. Alternative dietary sources modify these endocrine regulatory networks. There is also evidence for an interaction between the somatotropic and the neuroimmune systems, and the new genomic tools (gene expression and mapping) will help to reveal the effects of nutritional background on innate immune response and susceptibility of fish against pathogens and common stressors (e.g. hypoxia, confinement exposure, oxidative stress).

These topics are mainly unexplored in aquaculture and they have potential to be able to produce more healthy and biologically efficient fish with higher quality.

Outcomes

- Identify specific needs for precursor amino acids or non-protein nitrogen compounds during critical stages of life (larval, smoltification, spawning), to maximize protein growth.
- Understanding signalling from indispensable amino acid to protein accretion via endocrinology and key enzymes to maximise deposition of protein and minimize nitrogen waste. Sensing the fuel status within organs or cells is important to secure that lipid and carbohydrate will be used mainly as energy source and nitrogen compounds will thus be deposited as growth.
- Integrated approaches for gene expression profiling and computational promoter analyses to identify downstream genes and physiological functions nutritionally targeted by the endocrine and immunological system, and linking their effects on whole-animal biology and commercial-level phenomena. This is the key for dietary intervention approaches mimicking positive effects associated to hormonal and pharmacological treatments.

b) Genetic determinism in nutrient/ingredient utilisation

Genetic improvement of biological efficiency (feed efficiency, nutrient retention as protein and fatty acids, yield) by selective breeding means that more output (commercial product and return) is obtained with the same level of input (feed and investment). Increased efficiency and feed intake also contribute to reduced nutrient load from aquaculture to environment. Farmed fish retain only 30-40% of nitrogen and phosphorus provided in the feed. Large inter-individual variation exists in feed intake, but its recording remains a challenge. Thus, none of the current aquaculture breeding programmes selects directly for feed intake, feed efficiency or nutrient utilisation.

Outcomes

- Direct or indirect selection methods, including novel genomic tools, for improving life-long biological efficiency (feed intake, feed efficiency, nutrient retention as protein and fatty acids, yields) by selective breeding.
- Selection methods for avoiding the negative impact of novel non-animal feed on efficiency, quality and potential genotype-by-diet interactions.
- Estimates of economical and ecological benefits of the methods developed.

c) Nutritional programming at early developmental stages (broodstock, larvae)

During some specific early critical periods in life, organism have the ability to respond to environmental situations that deviate from normal by alterations at the cellular, molecular and biochemical levels. Thus, differences in nutritional experience at critical periods in early life, both pre- and post-natally, can programme an individual's future development, metabolism, resistance, feed intake, growth performance, and ultimately survival. This process is called 'nutritional programming' and it is well known to occur in humans and mammals. For aquaculture, the potential and diverse possibilities for nutritional programming need to be evaluated.

Outcomes

- Formulation of targeted feed compounds, feeding and fish management practices that lead to nutritional programming at an experimental scale, and if proven useful, at a commercial scale.
- Increased control of animal growth, feed intake, body composition, efficiency of utilizing plant-based diets through a nutritional conditioning at the broodstock and/or larval level. Increased disease resistance, stress tolerance, maturity age, and adaptation to a new environmental after a transfer.

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