Annual Report 2008

Aquaculture Protein Centre (APC)

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1. Executive Summary

In 2008 the Aquaculture Protein Centre (APC) expanded globally and internally, securing a broader base of financial support, strengthening industrial and academic partnerships, and structuring efficient management to administer effective research.

APC's financial stability increased during 2008. External financing grew from approximately 20 million to 24 million NOK. Part of the increase came from APC's first grant from the European Commission, which provides support for the Centre's remaining tenure. The 7th Framework grant is a collaborative effort with the Medical University of Vienna to study the effects of dietary inclusion of GM-crops on growth and reproduction in Atlantic salmon. In addition, APC increased the share of NRC financed projects. In 2008 APC had 9 NRC financed projects in addition to the SFF project.

Additional external support came from industry. Krill Seaproducts AS enabled APC to continue its pioneer research in processing krill for fish feed ingredients. Feed-trials showed that de-shelled krill can replace high-quality fishmeal in high quantities without adverse effects. At moderate inclusion levels, stimulation of growth was seen. APC also worked with Bioprotein AS, guiding the scientific principles behind gas-based technology for producing high-value feed. Several other industrial collaborations were initiated in 2008, e.g. BioMar AS , AddCon Nordic and Vitality Innovation.

Collaborative research with academia also expanded globally. In addition to Europe (e.g. the Medical University of Vienna), APC strengthened its academic network to the Americas and Asia. Chile's Catholic University of Temuco joined APC researchers in exploring the potential of lupines as an alternative aquafeed. And looking to the Far East, the Chinese Academy of Sciences, Institute of Hydrobiology, linked with APC to develop solid state fermentation for processing tilapia feed. Closer to home, the Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, worked with APC assessing the storage stability of krill products to extend its shelf life.

Never before had APC been so involved in such a complex range of research programs as in 2008. New personnel were added; old procedures were evaluated. Under the direction of a Scientific Advisory Board, APC took a fresh look at how to adapt to its rapid growth and broad development. The three international top-level experts in aquaculture and animal nutrition, with experience in strategic research, were invited to review APC research and its relevance to the global aquaculture industry. The Board's recommendations outlined a structured focus for APC, which resulted in the 2009 Annual Research Plan. The Plan not only details initiatives for 2009, it provides continuity for the Centre's future, recommending a strategy for APC to continue after 2012.

APC anticipates maintaining its visibility, both to professionals and the public. In 2008, researchers published 18 papers in peer-reviewed scientific journals (or roughly 1.5 papers per scientist). Research activities were also featured in several articles from the popular press. And complementing the printed word, 11 oral presentations were delivered by APC at the XIII International Symposium on Fish Nutrition and Feeding, Brazil.

The scope and scale of APC achievements are magnified when one considers the size of the organization: 9.5 scientists (1 visiting), 5 post docs, and 8.5 Ph.D. students, supported by 6 technicians. Two students completed their doctoral degrees in 2008, and two more are scheduled to finish in 2009.

Looking towards the future, the Centre will continue to expand its network of industrial and academic partnership, broaden its base of financial support, and target timely issues of global significance.

2. Vision

The vision of the Aquaculture Protein Centre is to secure sustainable growth in aquaculture by providing basic and integrated nutritional, physiological, pathological, and technological knowledge required for optimal use of protein in feeds for farmed fish.

Sustainable development is used in the manner of the World Commission on Environment and Development (1989, Brundtland Commission), that is, to utilize resources so as to meet human needs while preserving the environment so that these needs can be met not only in the present, but in the indefinite future.

The development in fish farming internationally and in the market for marine feed ingredients, traditionally the main sources of nutrients for farmed salmon, illustrates the actuality of our vision.

An annual growth rate of more than 6% makes fish farming the fastest growing animal production worldwide. Demand for compound feed for fish will exceed 20 mill tons in 2010, and is expected to continue growing. The potential average annual production of fish meal is 6-7 mill tons and of fish oil, 1 mill tons (IFFO, 2007). Currently, more than half of the fish meal production is used for fish feed, and fish meal has become a limiting resource. This is reflected by an increase in price from approximately 400 US $/ton in 2001 to more than 1,000 US $/ton since early 2008 (Fig. 1). Prices are expected to stabilize at a level above 1,000 US $/ton (Globefish, 2008). Simultaneously, the price of soybean meal (SBM), which is an indicator of protein price in the commodity market, has fluctuated around 200 US $/ton. Growth in fish farming depends both on efficient and targeted use of the limited marine protein resources and increased use of proteins from other, sustainable sources, of which plant proteins are most abundant.

Major strategies

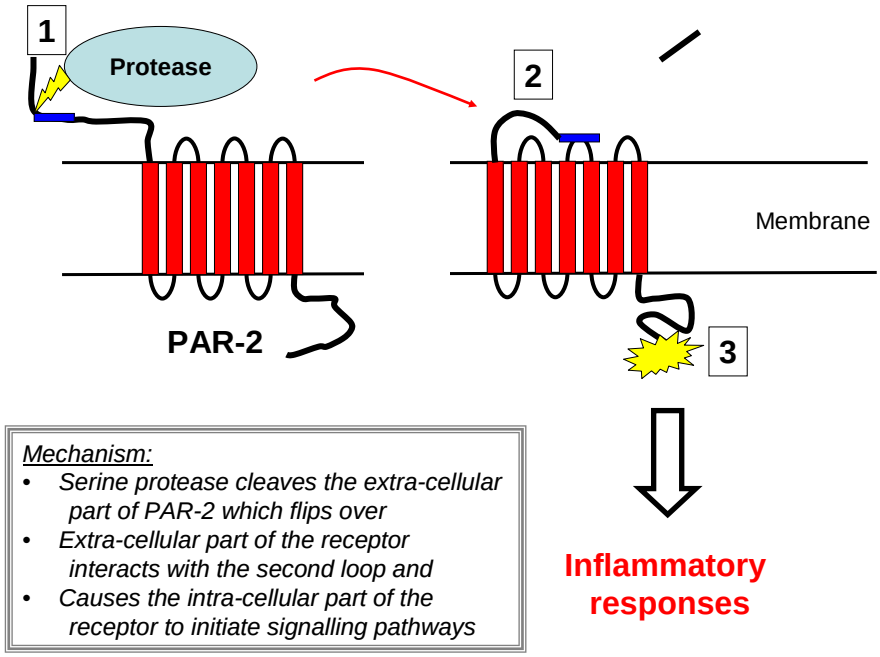
- To develop and improve methods for determination and knowledge of amino acid requirements and protein metabolism in fish.
- To develop and improve methods for identification and elimination of antinutritive compounds in protein sources, and to gain basic knowledge about gut function and responses to dietary antinutritional factors in fish.
- To evaluate new protein sources, and develop and modify processing procedures for protein-rich feed ingredients to permit optimal use in diets for fish.
- To publish new information for use by science, industry, government and the general public.

3. Research highlights

Plant-based diet and gut health

Focus on the animal health in order to maintain a high production value is important in aquaculture. The change from mainly marine based to more plant based feed ingredients represent an increase in exposure to a range of components with potentially biological effects, raise questions of potentially harmful effect, e.g. in the gastrointestinal tract. Tissue injuries of the gut reduce the welfare of the affected animal as well as increasing the risk of infectious diseases. The most abundant and cheapest plant protein source in the world, soybean meal, has been found to induce tissue injury in the gut of the Atlantic salmon. Fish fed diets containing standard qualities of soybean meal develop inflammation in the distal part of the intestine even at inclusion levels below 10%. The intestine changes in shape and form, and immune cells invade this part of the intestine supposedly in a protective process. So far it is not known how soybeans in the feed affect the normal gut in Atlantic salmon. However, also other feedstuffs seem to induce similar effects, and experiments with carp indicate that also other species than salmonid may be sensitive.

Increased knowledge of how food induces tissue injuries and how tissue injuries are handled by the fish is needed in order to utilize soy as a productive protein source in the production of salmonids and to secure animal health and welfare. Strengthening of knowledge of the inflammation process in Atlantic salmon is expected also to be of importance for the understanding of the gut as a barrier towards infections and how the gut inflammatory responses work in others fish as well as other vertebrates such as humans. One of the goals of our research over the last years has addressed the function of cell surface proteins that have been shown to be important in activation of inflammatory responses in other animals. These proteins are termed proteinase-activated receptors (PAR's). Figure 1 illustrates how activation of these receptors in mammals can cause a quick inflammatory response.



With the use of modern molecular techniques we were the first to clone, identify and study the PAR-2 gene in fish. Interestingly, two different PAR-2 genes were identified in Atlantic salmon, while other animals only appear to have one PAR-2 gene. The differences between the two Atlantic salmon PAR-2 genes indicated that they might have different functions in the inflammation process. The results of the work showed involvement of these receptors in both early and late stages of inflammation in the gut of Atlantic salmon fed food containing soybeans. Even if the soybean induced inflammation of the intestine in Atlantic salmon takes 1-3 weeks to develop, the researchers have shown that the cells experiencing tissue damage responds immediately. One of the two PAR-2 genes appears to be turned on already 24 hours after the fish is fed food containing soybeans. Our hypothesis is that the gene is turned on because the tissue is under stress, and that the stress starts as soon as the fish eat food containing soybeans. In our further investigation we seek to develop tools to identify the cells that contain the PAR-2 proteins, and investigate how the proteins are activated.

The results from these studies give specific insight regarding mechanisms behind the soya induced tissue damage. The new knowledge and tools developed will strengthen the understanding of the gut as an immunological organ and as barrier towards foreign compounds in general.

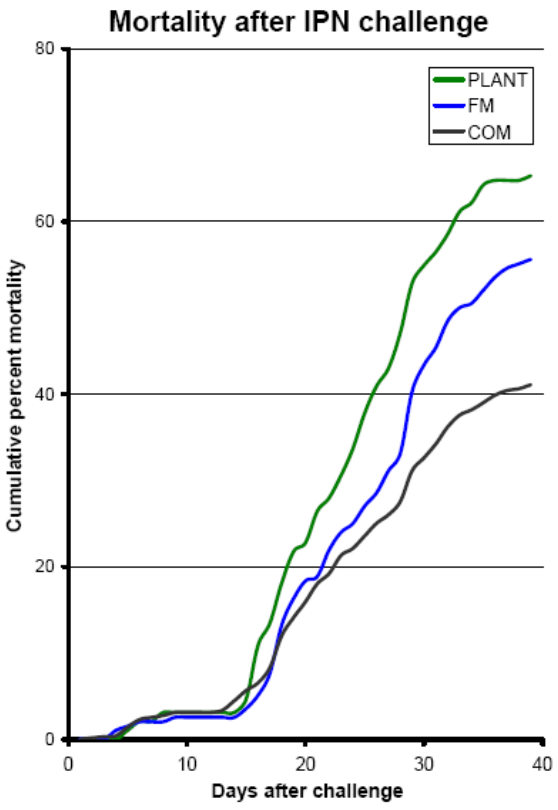
Plant-based diet may change susceptibility of Atlantic salmon to infectious diseases

Since 1996, cultured Norwegian salmon have been selectively bred for improved growth and resistance to disease. During the last several years, however, aquafeeds have changed dramatically with increasing content of plant ingredients. Questions have therefore arisen whether 1) today's fish are capable of utilizing plant-based as well as marine-based diets and 2) the changes in diet change the fish's susceptibility to infectious diseases.

A pilot study was initiated in collaboration with SalmoBreed AS and Akvaforsk Genetics Center AS. Fish groups composed of unvaccinated Atlantic salmon alevins from the same cross-section of families were fed one of three diets: 1) a commercial diet (COM); 2) a fishmeal-based diet (FM) and 3) a plant-based diet (PLANT). In the PLANT diet 67-68% of the protein was derived from wheat gluten, soy protein concentrate, suprex pea, corn gluten meal, sunflower meal and extracted soybean meal (5%). The fish were fed these diets from first feeding. Growth, various indicators of fish health both in the blood and intestine, as well as disease susceptibility following cohabitant challenge with infectious salmon anemia (ISA virus), furunculosis (*Aeromonas salmonicida* bacteria) and infectious pancreatic necrosis (IPN virus) were assessed.

During the period before the challenge trials were initiated, growth was recorded to be significantly higher in the fish fed the COM diet than the two experimental diets. Health parameters, such as red and white blood cell counts, plasma total protein and plasma protein fractions albumin and globulin, in the fish fed the COM diet could also be assessed to be enhanced compared to the fish fed the FM and PLANT diets. These differences in responses are most likely due to the inclusion of appetite-enhancing attractants as well as prebiotic and/or immune stimulatory substances in commercial diets. None of the diets caused changes in intestinal histomorphology. Since no statistically significant differences in growth or health parameters were observed between the FM and the PLANT-fed groups, today's selectively bred Atlantic salmon appear to grow and utilize plant-based diets as well as traditional FM-based diets during early development and up to smolt.

The results from the challenge trials generally reflect the results described above: Mortality was lowest in the groups fed the COM diet for all three infectious agents. Again the reason may be the common practice of including prebiotic and/or immune stimulatory substances in commercial diets. In the ISA and furunculosis trials there were no differences in mortality between the FM and PLANT-fed groups. In the IPN trial, however, mortality was significantly highest in the groups fed the PLANT diet. This may be due to greater stress of plant ingredients on the pancreas and that the fish may then be more vulnerable to infection by the IPN virus. More research regarding this is needed.



The results indicate that selective breeding for disease resistance against ISA and furunculosis is independent of which feed the fish are given. More research is needed to reveal the consequences of selective breeding on susceptibility to IPN. The good news is that today's commercial diets seem to strengthen disease resistance!

Some Research Leaves a Bitter Taste

Lupin, often spelled *lupine* in North America, is the common name for members of the genus Lupinus in the legume family (Fabaceae). The genus comprises between 200-600 species, with a major center of diversity in South America. This might explain why our research collaborators in Chile, Centro de Genómica Nutricional Agro-acuícola and Universidad Católica de Temuco, are interested in this promising feed source. Chile's aquaculture industry ranks number one in South America.

One of our PhD students, Edison Serrano, have along with his supervisors in APC (Liv Torunn Mydland and Trond Storebakken) and colleagues in Chile, investigated the potential of lupins in aquafeed. Although the results are preliminary, the impact is far-reaching.

Although lupins are rich in protein (up to 40% of seed content), their promise is tainted by quinolizidine alkaloids, primarily **lupinine** and **sparteine**. Generally speaking, these bitter tasting alkaloids are not palatable for fish. Moreover, high concentrations in feed may be toxic – or even fatal. Alkaloids are heterocyclic amino acid derivatives produced by the plants as a chemical defense mechanism, and although low-alkaloid sweet lupin varieties have been produced by breeding programs, these are agronomically more costly and difficult to cultivate due to a higher requirement for insecticides.

The balance between tolerance and toxicity of the alkaloids remains uncertain in fish. Thus what Serrano et al. aimed to do was to examine the influence of lupinine and sparteine on feed intake, growth and health in rainbow trout, and from that determine the acute toxicity concentration. To achieve this end, they conducted two 60-day dose-response trials.

The first trial, based in Norway, focused on lupinine. Duplicate groups of rainbow trout (300 g initial body weight) were fed fishmeal-based diets containing eight different concentrations of lupinine (0, 50, 75, 100, 250, 500, 1000 and 5000 mg lupinine/kg).

The second trial targeted sparteine, and was conducted in Chile. Triplicate groups of rainbow trout (65 g initial body weight) were fed the same extruded fishmeal diets as above, but contained 0, 50, 100, 250, 500, 1000, 2500, 5000 mg sparteine/kg.

Both trials mirrored identical procedures. Diets were formulated to contain 45% crude protein and 20% lipids on DM basis. All fish were weighed at the start of the experiment, at day 20, 40 and 60. At the end of the experiments, samples were collected for whole body composition and histology analyses of the kidney, spleen, heart, liver and intestine.

As expected, results showed that increasing doses of bitter-tasting lupinine and sparteine reduced feed intake and consequently the growth. But the tolerance levels were relatively low (100 mg/kg feed) compared with the lupin alkaloid **gramine**. Earlier studies showed no effect of gramine on growth and feed intake in concentrations up to 500 mg/kg.

Somewhat surprising, carcass composition did not vary among treatments, and, there were no morphological changes in the kidney, heart or intestinal tissue. Although glycogen and lipid stores were depleted in the hepatocytes in fish fed the higher levels of lupinine, this was most likely related to lower feed intake. The sparteine experiment is currently being analyzed for histo-pathological changes in head kidney, middle kidney, spleen, hearth, liver, and intestine.

Overall, these results suggest that although lupinine and sparteine alkaloids do not jeopardize the health of rainbow trout, their bitter taste reduce the feed intake at levels above 100 mg/kg feed.

Lupin value, is a matter of balance, according to Serrano et al., as varienties of lupins with lower alkaloids also tend to have lower protein content. And, more pesticides are required to grow them commercially, which makes them more expensive compared with high-alkaloid, high-protein lupines. Currently, aquafeed industries are using 20% of lupin containing 20 mg/kg of alkaloid in their formulations. That level of inclusion seems to be far below the real tolerance threshold (of bitter alkaloids). So, one alternative is to use semi-bitter lupins containing 500mg/ kg of alkaloids in aquafeed at 20% lupin inclusion. This approach will give a lupin meal with a high protein content, but the plant ingredient will be more environmentally friendly at a lower cost.

Edison Serrano has two publications on lupinine and sparteine in progress and will also investigate the effects of the same alkaloids on gut microbiota in his PhD work.

Atlantic salmon have an extreme lysine requirement in the initial period in salt water

We have shown that salmon in the transfer period to salt water have a lysine requirement of 2.79% (protein-bound form). This is 27 to 74 % higher than any lysine requirement values previously reported for Atlantic salmon. This is most likely a reflection of the traumatic experience the salmon undertakes in this transfer period. This metabolic transformation not only prepares the young salmon for the hyperosmotic environment, but also introduces the salmon to a whole new package of production, health and disease related issues.

The final test of the quality of smolts is how smooth the transfer into salt water is. There is no doubt that this transfer can be regarded as one of the most stressful experiences young salmon undertake. Optimizing nutrition in the period prior to the transfer and in the initial period in salt water is a natural part of the production of optimal smolts. Little work on nutrient requirements during this period has been done, however. Improper nutrient supply may make the salmon more vulnerable to other challenges it meets when entering salt water. This includes a new package of parasites and disease organisms, reflected by an average mortality of 4% in this period. So smoltification involves more challenges than just moving into a high salinity environment.

With this background, we conducted a lysine requirement study at the research station at Sunndalsøra. We concentrated on the period from one week before transfer to salt water and the following nine weeks. The 51 tank experiment was a combination between a classical Dose Response trial where the minimum requirement was established and a Requirement by Ration Levels trial where the maintenance requirement and the requirement for growth above maintenance were established.

After one week in salt water, the salmon had regained their appetite. The growth among fish receiving an adequate diet was very good and the fish almost tripled in weight during the trial. Feed utilization was very good, with the best group using 0.58 kg dry feed per kg gain. This is close to the optimum feed utilization we have seen among young fast growing salmon under closely controlled conditions.

We obtained a minimum requirement of 2.79% protein-bound lysine. This value is between 27 and 74% higher then any previously determined lysine requirement for Atlantic salmon. We believe that this extraordinary high requirement is a reflection of the metabolic metamorphism that the salmon undergoes during the transfer to salt water. Interestingly, the lysine maintenance requirement for these fish was similar to that determined for salmon fry and salmon that had resided in salt water for two months. This experiment also showed that salmon fed a lysine deficient diet had an extremely high utilization of digested lysine for growth.

The conclusion from this experiment is that we must play much more attention to the nutrient requirements of the salmon as they enter salt water. Proper nutrition will aid the fish in maintaining its disease resistance, and thus result in the production of a larger, healthier fish. In the Protein and Amino Acid Metabolism section (PAM) of APC we are taking the consequence of this and a main focus of ours is on the amino acid needs of the salmon in this period.

Appendix 1. Publications from APC in 2008

In peer-reviewed journals:

Bakke-McKellep, A.M., Sanden, M., Danieli, A., Acierno, R., Hemre, G. I., Maffia, M., Krogdahl, Å.. Atlantic salmon (Salmo salar L.) parr fed genetically modified soybeans and maize: Histological, digestive, metabolic, and immunological investigations. Research in Veterinary Science. 84: 2008, pp. 395-408.

Barrows, F. T., Bellis, D., Krogdahl, Å., Silverstein, J. T., Herman, E. M., Sealey, W. M., Rust, M., Gatlin, D. M. Report of the Plant Products in Aquafeed Strategic Planning Workshop * : An Integrated, Interdisciplinary Research Roadmap for Increasing Utilization of Plant Feedstuffs in Diets for Carnivorous. Reviews in fisheries science, 16:2008, pp. 449-455.

Mydland, L. T., Frøyland, J. R. K., Skrede, A., Composition of individual nucleobases in diets containing different products from bacterial biomass grown on natural gas, and digestibility in mink (Mustela vison). Journal of animal physiology and animal nutrition, 92:2008, pp. 1-8.

Frøystad, M. K., Lilleeng, E., Bakke-McKellep, A.M., Vekterud, K., Hemre, G. I., Krogdahl, Å.. Gene expression in distal intestine of Atlantic salmon (Salmo salar L.) fed genetically modified soybean meal. Aquaculture Nutrition. 14: 2008, pp. 204-214.

Grisdale-Helland, B., Helland, S., Gatlin, D. M., The effects of dietary supplementation with mannanoligosaccharide, fructooligosaccharide or galactooligosaccharide on the growth and feed utilization of Atlantic salmon (Salmo salar). Aquaculture. 283: 2008, pp. 163-167.

Grisdale-Helland, B., Shearer, K. D., Gatlin, D. M., Helland, S., Effects of dietary protein and lipid levels on growth, protein digestibility, feed utilization and body composition of Atlantic cod (Gadus morhua). Aquaculture. 283: 2008, pp. 156-162.

Haug, A., Rødbotten, R., Mydland, L. T., Christophersen, O. A. Increased broiler muscle carnosine and anserine following histidine supplementation of commercial broiler feed concentrate. Acta agriculturae Scandinavica. Section A, Animal science. 58:2008, pp. 71-77.

Hemmingsen, A.K.T., Stevik, A.M., Claussen, I.C., Lundblad, K.K., Prestløkken, E., Sørensen, M., Eikevik, T.M., 2008. Water Adsorption in Feed Ingredients at Different Temperatures, Particle size and Ingredient Combinations. Drying Technology. 26:2008, pp. 738–748.

Kause, A., Stien, L. H., Rungruangsak-Torriss, K., Ritola, O., Ruohonen, K., Kiessling, A., Image analysis as a tool to facilitate selective breeding of quality traits in rainbow trout. Livestock Science, 114:2008, pp. 315-324.

Kjær, M.A., Vegusdal, A., Berge, G.M., Galloway, T.F., Hillestad, M., Krogdahl, Å., Holm, H.H. and Ruyter, B. Characterisation of lipid transport in Atlantic cod (Gadus morhua) when fasted and fed high or low fat diets. Accepted in Aquaculture.

Ringø, E., Sperstad, S., Kraugerud, O., Krogdahl, Å. Use of 16S rRNA gene sequencing analysis to characterize culturable intestinal bacteria in Atlantic salmon (Salmo salar) fed diets with cellulose or non-starch polysaccharides from soy. Aquaculture Research, 39:2008, pp. 1087-1100.

Romarheim, O. H., Skrede, A., Penn, M., Mydland, L. T., Krogdahl, Å., Storebakken, T., Lipid digestibility, bile drainage and development of morphological intestinal changes in rainbow trout (Oncorhynchus mykiss) fed diets containing defatted soybean meal. Aquaculture, 274:2008, pp. 329-338.

Romarheim, O. H., Zhang, C., Penn, M. H., Liu, Y. J., Tian, L. X., Skrede, A., Krogdahl, Å., Storebakken, T. Growth and intestinal morphology in cobia (Rachycentron canadum) fed extruded diets with two types of soybean meal partly replacing fish meal. Aquaculture Nutrition, 14:2008, pp. 174-180.

Sagstad, A., Sanden, M., Krogdahl, Å., Bakke-McKellep, A.M., Frøystad, M. K., Hemre, G. I., Organs development, gene expression and health of Atlantic salmon (Salmo salar L.) fed genetically modified soybeans compared to the near-isogenic non-modified parental line. Aquaculture Nutrition. 14: 2008, pp. 556-572.

Sørby, R., Espenes, A., Landsverk, T., Westermark, G. Rapid induction of experimental AA amyloidosis in mink by intravenous injection of amyloid enhancing factor. Amyloid: Journal of Protein Folding Disorders, 15:2008, pp. 20-28.

Sørensen, M., Denstadli, V., Alkaline preserved herring by-products in feed for Atlantic salmon (Salmo salar, L). Animal Feed Science and Technology. 144(3-4): 2008, pp. 327-334.

Thorsen, Jim; Lilleeng, Einar; Valen, Elin C; Krogdahl, Åshild. Proteinase-activated receptor-2: two potential inflammatory mediators of the gastrointestinal tract in Atlantic salmon. J Inflamm (Lond). 23;5:18 2008. ISSN 1476-9255

Øverland, M., Kjos, N. P., Borg, M., Skjerve, E., Sørum, H. Organic acids in diets of entire male pigs. Effect on skatole level, microbiota in digesta, and growth performance. Livestock Science, 115:2008, pp. 169-178.
Øvrum Hansen, J., Berge, G. M., Hillestad, M., Krogdahl, Å., Galloway, T., Holm, H., Holm, J., Ruyter, B. Apparent digestion and apparent retention of lipid and fatty acids in Atlantic cod (Gadus morhua) fed increasing dietary lipid levels. Aquaculture, 284:2008. pp. 159-166.

Books and book chapters:

Bakke-McKellep, A.M., Refstie, S. Alternative protein sources and digestive function alterations in teleost fishes. In Feeding and Digestive Functions of Fishes (ed. by J.E.P. Cyrino, D. Bureau, B.G. Kapoor). pp.445-478, Science Publishers Inc., Enfield NH, USA, 2008.
Gatlin, D. M., III, Li, P. Use of Diet Additives to Improve Nutritional Value of Alternative Protein Sources. In: Alternative Protein Sources in Aquaculture Diets (C. Lim, C. D. Webster and C.-S. Lee, eds.), pp. 501-522. Haworth Press, New York, 2008.
Gatlin, D. M., III Non-infectious Diseases: Nutritional Factors. In: Fish Diseases (J. C. Eiras, H. Segner, T. Wahli and B. G. Kapoor eds.), pp. 1201-1224, CABI, Oxon, UK, 2008.
Krogdahl, Å., Fekete, S. Production fish nutrition and feeding. Veterinary Nutrition and Dietetics. "Pro Scinetia Veterinaria Hungarica" Foundation, Budapest, 2008.

Participation and presentation from APC at scientific meetings:

Aslaksen, M., Mydland, L.T., Storebakken, T.. Protein aggregation during feed processing of diets with plant protein sources for atlantic salmon. XIII ISFNF – International Symposium on Fish Nutrition and Feeding 2008, Book of Abstracts, p 266. June 1-5, Florianópolis, Brazil. Poster presentation.
Bakke-McKellep, A.M., Penn, M., Chikwati, E., Hage, E., Chunfang, C., Krogdahl, Å. In vitro effects of various anti-nutritional factors on intestinal glucose absorption and histology in Atlantic salmon. XIII International Symposium on Fish Nutrition and Feeding, June 1-5, Florianópolis, Brasil. 2008. Oral Presentation.
Bakke-McKellep, A.M., Penn, M., Chikwati, E., Hage, E., Chunfang, C., Refstie, S., Krogdahl, Å. Påvirkning av antinæringsstoffer på in vitro opptak av glucose i tarmen hos oppdrettslaks. Programkonferansen HAVBRUK 2008, April 7-9, Tromsø, Norway.
Bakke-McKellep, A.M. Tåler torsketarmen vegetabilsk fôr? / The intestine of Atlantic cod: equipped for a plant-based diet? Torske nettverksmøte 2008 Sats på torsk / Go for Cod, February 13-15, Tromsø, Norway. Invited Oral Presentation.
Gatlin, D. M., III (2008) Expanding the utilization of sustainable plant products in aquafeeds. First International CGNA Workshop: Utilization of novel and sustainable plant products in aqua-feeds: plant genomics, bioinformatics, fish nutrition and bioprocesses. Temuco, Chile. Oral Presentation.
Gatlin, D. M., III (2008) Fish nutrition and immunology. 7th Symposium of World's Chinese Scientists on Nutrition and Feeding of Finfish and Shellfish. Bejing, China. Oral Presentation.
Hansen, Ø. J., Øverland, M., Shearer, K. D., Stjepanovic, N., Storebakken, T. Pellet quality of extruded diets with high inclusion of a mixture of high-fat deshelled krill meal and pea protein concentrate. ISFN IIIVI 2008. June 1-5, 2008, Floranapolis, Brasil. Poster.
Haug, A., Rødbotten, R., Eich-Greatorex, S., Mydland, L. T., Christophersen, O. A., Sogn, T. Broiler feed enriched with selenium, histidine and n-3 fatty acids; implications for human health? The Brain Lipids Conference, September 8-11, Oslo 2008. Poster Presentation.
Helland, S.J., Gatlin III, D.M., Relandeau, C., Grisdale-Helland, B. Does the growth of Atlantic salmon smolts suffer from too low dietary lysine? XIII International Symposium on Fish Nutrition and Feeding, June 1-5, Florianópolis, Brasil. 2008. Oral presentation.
Hillestad, M., Holm, J., Krogdahl, Å., Holm, T.H.A.H., Ruyter, B., Galloway, T.F. and Berge, GM. 2008. Effect of protein and energy on growth, feed utilisation and physiological responses in large rainbow trout (Onchorhyncus mykiss). XII International Symposium on Fish Nutrition and Feeding, Florianopolis, Brazil June 1-5, 2008.

Kjos, N. P., Øverland, M., Sørum, H. Hanngris, fôring og kjøttkvalitet. NORSVIN Fôringsseminar, Mai 27-28, Hamar 2008. Oral Presentation.

Kjos, N. P., Øverland, M. Experiences from Norwegian feeding studies with entire male pigs. Abstract in Proceedings from the EAAP working group on Production and Utilization of Meat from Entire Male Pigs, Monells, Girona, Spain, , March 26-27, 2008.

Koppang, E. O., Sørum, H., Thorsen, J., Huang, Q., Rimstad, E. Temperature- and time-induced expression of Tyr and Tyrp2/DCT in a salmon leukocyte cell line. Abstract in Pigment Cell & Melanoma Research, 21:2008.

Kraugerud, O. F., Aslaksen, M. A., Jørgensen, H. Y., Svihus, B. Screening of physical quality of extruded diets with legumes, oilseeds or cereals. XIII International Symposium on Fish Nutrition and Feeding, June 1-5, Florianópolis, Brasil. 2008. Poster.

Krogdahl, Å. and Bakke-McKellep Einar Lilleeng, Michael Penn, Marianne Frøystad, Thor Landsverk. Feed and health relationships in aquaculture. Presentations by Krogdahl at University of Santiago Chile, Department of Chemistry and Biology, January 24th, 2008.

Krogdahl, Å. and Bakke-McKellep Einar Lilleeng, Michael Penn, Marianne Frøystad, Thor Landsverk. Feed and health relationships in aquaculture. Presentations by Krogdahl at Diagnotec in Puerto Montt, January 28th, 2008.

Krogdahl, Å. Er all fôrproduksjon etisk? Foredrag ved DNVs (FVS) vårkurs 2008- Trygg og etisk mat i helkjedeperspektiv. Trondheim 2/4-08.

Krogdahl, Å. Fiskefôr og fiskevelferd. Endringer skaper utfordringer. Invitert foredrag ved Havbrukskonferansen i Tromsø, 7. – 9. april 2008.

Krogdahl, Å., Holm, T.H.A.H, Berge, G.M., Ruyter, B., Holm, J., Galloway, T.F., Hillestad, M. 2008. Torsk (*Gadus morhua* l.) tilpasser fordøyelses-prosessene til fôrets sammensetning. Foredrag ved Havbrukskonferansen i Tromsø, 7. – 9. april 2008.

Krogdahl, Å., Refstie, S., Penn, M., Chikwati, E., Bakke-McKellep, A.M. 2008. Important Antinutrients in Plant Feedstuffs. Biological Effects and Knowledge Gaps. Invited lecture at XII International Symposium on Fish Nutrition and Feeding, Florianopolis, Brazil June 1-5, 2008.

Mydland, L.T., Kiessling, A., Zimonja, T., Djordjevic, B., Skrede, A., Øverland, M. Dorsal aorta cannulation and plasma free amino acids as a method of feed evaluation in atlantic salmon (*Salmo salar*). XIII ISFNF – International Symposium on Fish Nutrition and Feeding 2008, Book of Abstracts, p 151. June 1-5, Florianópolis, Brazil. Poster presentation.

Penn, M., Campbell, P., Krogdahl, Å., Bendiksen, E.Å. 2008. Vegetable protein concentrates in high energy low fishmeal feeds for Atlantic salmon Salmo salar L. reared at low water temperatures. XII International Symposium on Fish Nutrition and Feeding, Florianopolis, Brazil June 1-5, 2008.

Refstie, S., Åsgård, T., 2008. Feedstuffs used in current fishfeeds. Cargill's R&D workshop on plant protein feedstuffs. May 16, Mechelen, Belgium.

Reitan, K. I., Berge, G. M., Kjørsvik, E., Skrede, A., Gislerød, H. R. The use of microalgae as supplement to feed for marine fish. 11th International Conference on Applied Phycology, June 21-27, Galway, Ireland, 2008. Oral Presentation.

Ringø, E., Olsen, RE, Bakke-McKellep, A.M., Gifstad, T., Aursand, M., Svihus, B., Amlund, H., Hemre, GI. A risk-assessment on the use of plant ingredients in diets for carnivorous fish. WFC 2008 5th World Fisheries Congress, October 20-24, Yokohama, Japan.

Rohloff, J., Krogdahl, Å., Refstie, S., Guttvik, A. and Hillestad, M. 2009. Metabolite profiling and target analysis of antinutritional factors (ANF) in selecetd aquafeeds. XII International Symposium on Fish Nutrition and Feeding, Florianopolis, Brazil June 1-5, 2008.

Romarheim, O. H., Mydland, L. T., Johannessen, A., Rag, A., Skrede, A., Øverland, M. Value added feed products for farmed fish derived from bacterial protein meal produced on natural gas. XIII International Symposium on Fish Nutrition and Feeding, June 1-5, Florianópolis, Brasil. 2008. Poster.

Ruyter, B., Denstadli, V., Berge, G. M., Bakke-McKellep, A.M., Hillestad, M., Holm, H., Krogdahl, Å.. Transport routes of short -and long chain fatty acids from the intestine through internal organs to peripheral tissues in Atlantic salmon. XIII International Symposium on Fish Nutrition and Feeding, June 1-5, Florianópolis, Brasil. 2008. Poster.

Serrano, E., Storebakken, T., Penn, P., Landsverk, T., Øvrum Hansen, J., Mydland, L.T. Responses in rainbow trout (*Oncorhynchus mykiss*) to increasing dietary dose of lupinine alkaloid. 12th International Lupin Conference, September 14-18, Fremantle, Australia, 2008. Oral Presentation.

Storebakken, T. Future Fish Feed - Meeting the feed demand for increasing fish and crustacean farming to 80 million tons in 2025. Workshop on ecotoxicology and aquafeed between NULS and Institute of Hydrobiology, Chinese Academy of Sciences. November 25, Wuhan, Kina, 2008. Oral Presentation.

Storebakken, T. Processing of plant protein ingredients and fish feed to ensure high nutritional and technical quality. 1st International CGNA Workshop, August 4-6, Temuco, Chile, 2008. Poster Presentation.

Sørensen, M., Luyenm, G. O. N., Øverland, M., Skrede, A., Storebakken, T. Quality of extruded fish feed is strongly affected by SME input, carbohydrate source and in barrel steam pressure. ISFN IIIVI 2008. June 1-5, 2008, Floranapolis, Brasil. Oral presentation.

Zimonja, T., Svihus, B., Storebakken T.,Inactivation of protease inhibitors in soy. XIII International Symposium on Fish Nutrition and Feeding, June 1-5, Florianopolis, Brazil. 2008. Poster.

Øverland, M., Sørensen, M., Storebakken, T., Penn, M. H., Skrede, A. Pea protein concentrate in diets for Atlantic salmon (Salmo salar) – effect on growth performance, nutrient digestibility, and gut health. ISFN IIIVI 2008. June 1-5, 2008, Floranapolis, Brasil. Oral presentation.

Øverland, M., Sørensen, M., Storebakken, T., Penn, M. H., Skrede, A. Erteproteinkonsentrat i fôr til laks (Salmo salar) - effekt på vekst, fordøyelighet, tarm, helse og teknisk kvalitet av fôr. Programmkonferanse, HAVBRUK 2008, Tromsø, 7—9. april, 2008. Oral presentation.

Appendix 2. Account statement for APC in 2008

	1000 NOK
Funding	
Unallocated funds	1 998
From Research Council of Norway	10 000
From UMB	6 338
From NVH	2 716
From AKVAFORSK	1 148
International funding	654
Other public funds	6 241
Other private funds	7 005
Total funding	36 100
Expenses	
Payroll and indirect expenses	20 728
Research equipment	
Outsourcing of R&D services	
Other operating expenses	15 567
Total expenses	36 295
Transfer of unallocated funds to 2009	-195

Appendix 3. Personnel assigned to APC in 2008

All personnel in APC are formally employed by the three mother institutions Nofima, UMB and NVH, and subject to the same regulations as employees in these three institutions. Personnel are allocated to APC in three different ways: Part- or full-time positions as own contribution from Nofima, UMB and NVH; Part-time positions, compensated to Nofima or NVH by the grant given by the Research Council of Norway; Hired for the specific APC position, employed by Nofima, UMB or NVH, that is compensated by the grant given by the Research Council or other external funding.

Research personnel:

Section	Name	Position	Funding	Assignment, %
Common resources	Trond Storebakken	Centre director	APC	100
PAM	Ståle J. Helland	Section leader	APC	80
	Barbara Grisdale Helland	Senior scientist	APC	80
GH	Åshild Krogdahl	Section leader	NVH	50
	Thor Landsverk	Senior scientist	NVH	50
	Anne Marie Bakke	Scientist	APC	50
	Ståle Refstie	Senior Scientist	APC	50
	Einar Ringø	Senior scientist	UiTø	20
FIP	Margareth Øverland	Section leader	APC	100
	Anders Skrede	Senior Scientist (prof.em)	APC	50
	Mette Sørensen	Scientist	APC	50
	Birger Svihus	Senior Scientist	UMB	10
	Anders Kiessling	Senior Scientist	UMB	20
	Karl D. Shearer	Senior Scientist	Priv.	100

Research personnel from our collaborating institutions:

Name	Position	Academic institution	Funds from	Start
Delbert Gatlin III	Senior Scientist	Texas A&M Univ. USA	Texas A&M	2004
Anne Helene Tauson	Senior Scientist	Univ. Copenhagen, Denmark	Univ. Copenhagen	2004
Muriel Mambrini	Senior Scientist	INRA , France	INRA	2007
Fredric Barrows	Senior Scientist	USDA/ ARC, Montana, USA	USDA/ ARC	2007
Randal Buddington	Senior Scientist	Univ. Memphis, Tennesee, USA	Univ. Memphis	2007

Doctoral students and post-doctorate fellows:

Name	Position	Funds from	Academic institution	Start - End
Vegard Denstadli	PhD	UMB	UMB	2003.01-2007.03
Vegard Denstadli	Post.doc.	NRC	UMB	2007.08-2009.07
Olav Fjeld Kraugerud	PhD	UMB	UMB	2004.01-2008.08
Olav Fjeld Kraugerud	Post.doc.	NRC	UMB	2008.08-2012.12
Thea Morken	PhD	UMB	UMB	2008.08-2011.08
Morten A. Aslaksen	PhD	NRC	UMB	2006.07-2010.07
Odd Helge Romarheim	PhD	UMB	UMB	2003.01-2007.07
Odd Helge Romarheim	Post.doc.	NRC	UMB	2007.10-2011.12
Einar Lilleeng	PhD	NVH	NVH	2003.08-2008.03
Edison Serrano	PhD	Chilean Scholarsh.	UMB	2006.01-2009.12
Jim Thorsen	Post.doc.	NVH	NVH	2006.08-
Camilio Pohlenz	PhD	Texas A&M	Texas A&M	2008.01-2010.12
Liv Torunn Mydland	Post.doc.	NRC	UMB	2006.01-
Michael Penn	Post.doc.	APC	NVH	2005.12-
Elvis Chikwati	PhD	Norw.Scholarsh.	NVH	2007.08-2010.08
Yuexing Zhang	PhD	UMB	UMB	2007.12-2010.12
Youling Gao	PhD	Chinese Scholarsh.	UMB	2007.10-2010.10
Fredrik Venold	PhD	NVH	NVH	2008.10-2011.10
Gerry Burr	PhD	APC/Texas A&M	Texas A&M	2007.08-2008.08

Technician/administrative personnel:

Section	Name	Position	Funding	Assignment, %
Common resources	Kirsti Pettersen	Centre administrator	APC	100
PAM	Edle Zacchariassen	Technician	APC	100
	Rita Storslett	Technician	APC	100
GH	Inger Rudshaug	Prinsipal engineer	APC	15
	Ellen Hage	Prinsipal engineer	NVH	30
	Elin Christine Valen	Prinsipal engeneer	APC	100
FIP	Tone Stigen Martinsen	Research assistant	APC	100
	Tamara Zimonja	Prinsipal engineer	APC	100

Appendix 4. Coordination with other research programs and research projects

The research at APC was coordinated with nine research projects in 2008, financed by the Research Council of Norway and carried out in collaboration with other research institutions.

- NRC research project 167863/I10 Added value products from barley (ADDBAR).
- NRC research project 172580/S40 Potential of using microalgae to partially replace fish oil and fish meal in aquaculture fish feeds (ALGAFEED).
- NRC research project 189583/I30 Facilitating increased use of inexpensive protein-rich byproducts from biofuel in feed for Nile tilapia through fermentation (BILAT).
- NRC research project 182543/S30 Microbial conversion of natural gas: New processes and products derived from *Methylococcus capsulatus* (GASSMAX).
- NRC research project 172546/S20 Optimizing the nutritional value of non-marine protein sources in extruded fish feed (OPTIMIZE).
- NRC research project 187294 Sources of plant protein for fish feed: Understanding and controlling antinutritional factors (SOPP).
- NRC research project 187264 Molecular characterisation of Atlantic salmon gut microbiota with changing diet formulations: gut health, performance and disease resistance.
- NRC research project 172151/S40 Genetically modified plant products (GMPP) in feed for Atlantic salmon - A follow-up study on physiological responses and DNA traceability.
- NRC research project 143196/I10 Protein produsert fra naturgass - en ny fôrressurs for fisk og husdyr.

EU-financed Programs:

GMSAFOOD - a consortium to study the influence of genetically modified (GM) foods on health and well-being. GMSAFOOD will focus on developing biomarkers that could be followed after a GM food (food made from GMOs) is released on the market.

COST action FA0208 Feed for Health

Groups at Nofima, UMB and NVH:

UMB: Departments of Animal and Aquacultural Sciences; Chemistry, Biotechnology and Food Sciences; Plant and Environmental Sciences; Mathematical Sciences and Technology, Centre of Integrative Genetics (Cigene), Centre for Feed Technology (FôrTek).

NVH: Department of Basic Sciences and Aquatic Medicine, Sections for aquatic medicine and nutrition, Biochemistry and physiology, Anatomy and pathology; Department of Food Safety and Infection Biology, Section of Arctic Veterinary Medicine; FUGE platform for zebrafish research

Nofima: All groups

Other important national and international collaborators:

Aker BioMarine – Aker ASA, Oslo, Norway
Akvaforsk Genetic Center AS, Ås Norway
Agriculture and Food Development Authority, Ireland
AgriMarin AS
Ajinomoto Eurolysine S.A.S, Paris, France
Alimetrics Ltd, Espoo, Finland
BioMar AS, Trondheim, Norway
Bioprotein AS, Stavanger, Norway
Biorigin
Borregaard AS, Fredrikstad, Norway
Central Food Research Institute in Budapest, Hungary
Chinese Academy of Sciences, Institute of Hydrobiology
Commonwealth Scientific And Industrial Research Organisation, Australia
Donald Danford Plant Science Center, St. Louis, MO, USA
Evergreen Co., Ltd., Guangdong, China
Ewos Innovation, Dirdal, Norway
Faculdade de Ciências da Universidade do Porto, Portugal
Forberg AS, Larvik, Norway
GenoMar AS, Oslo, Norway
Hellenic Centre for Marine Research, Heraklion, Greece
Kansas State University, Manhattan, KS, USA
Krill Seaproducts AS, Ålesund, Norway
Medical University of Vienna, Austria
National Institute of Nutrition and Seafood Research, Bergen, Norway
National Veterinary Institute, Oslo, Norway
Nofima Marine, Ås, Norway
Nofima Mat, Ås, Norway
Norwegian School of Veterinary Science, Oslo, Norway
Norwegian University of Life Sciences, Ås, Norway
Novozymes AS, Denmark
Rikshospitalet – Radiumhospitalet Hf, CoE Centre for Immune Regulation, Oslo, Norway
SalmoBreed AS, Bergen, Norway
Swedish University of Agricultural Sciences, Uppsala, Sweden
Teagasc, Moorepark Research Centre, Fermoy, Co. Cork, Ireland
Texas A&M University, College Station, TX, USA
The Catholic University of Temuco, Chile
Troyka Ltd, Metu Technopolis/Odtu Teknokent, Ankara, Turkey
Universitätsklinikum Hamburg-Eppendorf, Germany
University of Aarhus, Denmark
University of California, Davis
University of Copenhagen, Denmark
University of Lecce, Italy
University of Memphis, College of Education, USA
University of Oslo, Institute of Nutrition, Norway
University of Saskatchewan, Canada
University of Sozhou, Jiangsu, China

University of Tromsø, Institute of Marine Biotechnology, Norway
USDA, Agricultural Research Service, Hagerman Fish Culture Experimental Station, Idaho/ Montana, USA
VESO Vikan, Namsos, Norway
Vitality Innovation AS, Norway
Zhejiang Wanli University, Ningbo, Zhejiang, China

Appendix 5. The board and management of APC

The board

In 2008, the board of APC consisted of the following members:

Chairman: Knut Hove, *Rector of UMB*
Members: Lars Moe, *Rector of NVH*
Torbjørn Åsgård, *Research leader, Nofima*
Anne Marie Bakke, *Representative of the scientists at APC*

The board held four meetings in 2008. A total of 26 items were on the agenda.

The main tasks in 2008 were:

- Research plan revisions
- The first meeting of Scientific Advisory Board
- New management

Management

Management of APC is organized in a flat leadership structure, based on consensus in a leader team consisting of the centre director (Trond Storebakken), the centre administrator (Øystein Brunborg/Kirsti Pettersen) and the three section leaders: Ståle Helland (Protein and amino acid metabolism, PAM), Åshild Krogdahl (Gut and health, GH) and Margareth Øverland (Feed ingredients and processing, FIP). From January 2009, Margareth Øverland is appointed as new centre director. Øverland will continue as section leader, FIP, and Liv Torunn Mydland is appointed as assistant section leader, FIP. Kirsti Pettersen has been appointed as centre administrator since May 2008.

The main administrative tasks in 2008 were:

- Scientific Advisory Board
- New routines for budgeting and accounting
- Updating the research plan
- Negotiation with industries on collaboration
- Scientific meeting in APC with invited collaborative partners
- Preparation of applications for research grants from EU, NRC and industrial partners

In addition, many administrative functions in APC have been carried out as own contributions from UMB, Nofima, and NVH.

Economy management

Coordination of the economy management, in accordance with the Norwegian university law, is carried out as own contribution of UMB. Budgeting is supervised as own contribution from UMB. Nofima, NVH and UMB administer salaries and pensions as own contributions.

Other administrative functions

Archiving is currently carried out as own contributions from UMB, Nofima, and NVH
Handling of intellectual property is assisted by UMB, and follows the routines of UMB.

Appendix 6. Infrastructure and localities

The administration is located at UMB, Ås. The FIP section is mainly located at UMB, Ås, the GH section at the NVH campus in Oslo, and the PAM section at Nofima, Sunndalsøra.

UMB, NVH and Nofima contribute with infrastructure such as office facilities, accounting assistance and other administrative tasks, in addition to granting access to their laboratories.

The main fish laboratories are at Nofima, Sunndalsøra.

Fish laboratories are constructed to study fish growth and well-being during various research experiments. A wide range of custom-made fish tanks have been designed to study respiration in rapidly growing fish. The Norwegian School of Veterinary Science (NVH) has aquaria suitable for studies of physiological effects under normal as well as disease conditions. In addition there is a small-scale fish laboratory at the University of Life Sciences (UMB) with abilities to do physiological study on cannulised fish and also other laboratories for measuring digestibility on animals comparable to fish. Furthermore APC is a partner in fish laboratories in the Joint Marine Nutrition Laboratory in Zhejiang, China, and also has access to laboratories at the University of Lecce, Italy and Texas A&M University, USA.
This research cooperation provides a possibility to study comparative aspects in both cold-water and warm-water species.

The Centre of Feed Technology (FôrTek) at UMB is a feed manufacturing plant in miniature, designed for production of research feed according to defined and well-documented procedures. A new extruder line designed for flexible and precise production of research feed was installed in 2005.

At NVH, APC has access to a range of microscopes, including electron, confocal, and laser-capture microscopes for studies of structural and functional morphology; equipment for intestinal nutrient transport studies; a range of fish cell lines and facilities for cell cultivation; laboratories for the study of digestive enzymes and other biochemical parameters. For molecular studies, modern equipment is available, such as PCR (Polymerase Chain Reaction) and real-time PCR machines, microarray facilities, bioanalyzer for RNA integrity measurements, and a Typhoon scanner for semi-quantification in blotting, and other gel electrophoresis studies. Facilities for DNA sequencing are also available.

Appendix 7. Coordination with educational programs at UMB and NVH

In addition to the PhD students, 2 MSc students completed their theses in 2008 based on research at APC. These students are enrolled at UMB, APC is responsible for providing experimental facilities and supervision.

Undergraduate students who completed their MSc thesis in APC in 2008:

Thesis #	Candidate(s)	Thesis	Degree	Dept., School	Year	APC supervisor(s)
T-39	Morken, Thea	Effect of starch source and extrusion conditions on physical quality of fish feed.	MSc	UMB	2008	
T-40	He, Gaojie	Feed pellet durability in pneumatic conveying systems for fish farming.	MSc	UMB	2008	

Appendix 8. Coverage in the media

8 articles on APC are registered published in the media in 2008.

Date	Topic	Media	Journalist (interviewee)
Feb.	Gass gir bedre gris og kylling	Aftenposten, Innsikt	Ole Magnus Rapp (M.Øverland)
Dec.	New knowledge on processing effects on fish feed components	Aquaculture Europe Magazine	OFK (O.F. Kraugerud)
Jan.	Nye arbeidsplasser ikke et argument	Aftenposten, Aften	OFK (O. F. Kraugerud)
April	In vitro kjøtt - kjøtt for vegetarianere?	O-fag, Radio Orakel	LTM (L. T. Mydland)
Dec.	2020 - Del 7 av 8. Varifrån kommer maten i framtiden?	SVT - Sverige	Anders Nord (L. T. Mydland)
Oct.	Kjøtt på glass	Under Dusken, studentavis	Ella Getz Wold (L. T. Mydland)
April	In vitro kjøtt	Osenbanden, NRK P3	Are Sende Osen (L. T. Mydland)
April	In vitro kjøtt	Morgenposten, Radio Orakel	LTM (L. T. Mydland)