水研センター研報，第35号，23－30，平成24年
Bull. Fish. Res. Agen. No. 35, 23-30, 2012

Charting the Future of Aquaculture Feeds in the United States

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Abstract：The development and expansion of farming of carnivorous fish species will be constrained by a limited supply of fishmeal and fish oil for feeds. There is no dietary requirement for specific amounts of fishmeal or fish oil for fish, so feeds that lessen the reliance on these limited feedstuffs － such as alternative protein and oil resources － can, and must, be developed. For this reason, the U.S. Department of Commerce (NOAA) and the U.S. Department of Agriculture (USDA) jointly sponsored an aquaculture feeds initiative to address those issues. The initiative used expert and public consultations to identify and discuss the future of fish feeds and the benefits to the U.S. by the development of such alternative feeds. The resulting report from these meetings was released in draft form for comment at the end of 2010 and was finalized in 2011. This paper covers the processes taken to arrive at the recommendations. The report is available at http://aquaculture.noaa.gov

The report calls for feeds to be evaluated not only for nutritional and economic performance as is done today, but also for environmental and human health performance by taking into account the environmental footprint of feed production and use, and the resulting quality of the product for human consumption. This "triple bottom line approach" － economics, environment and human health － is supported by 20 specific recommendations. Implantation of these recommendations has already started in some cases, but will take time to be fully developed.

Keywords：aquaculture feeds initiative, economics, environment, human health

Introduction

To meet the growing consumer demand for seafood in the United States, increasing supplies of finfish and shellfish will be needed. Most experts agree that development of aquaculture will be the only way to meet this increase in demand. The challenge is how to ensure that aquaculture production increases are sustainable.

For example, the development and expansion of farming of carnivorous fish species such as salmon may soon be constrained by a limited supply of fishmeal and fish oil for feeds. Today, salmon is the third-highest consumed fish in the United States and roughly seventy percent of the world's supply of salmon is now farmed.

Fishmeal and fish oil have traditionally been used to make up a large part of the diet of farm-raised salmon. The composition of these feed ingredients is almost perfectly matched to the dietary requirements of carnivorous fishes. There is no dietary requirement for fishmeal or fish oil for salmon or any other fish. The dietary requirements are for the nutrients they contain (amino acids, fatty acids, vitamins and minerals) not the ingredients *per se*, so feeds that lessen the reliance on these limited ingredients － such as alternative protein and oil sources － can be developed.

For this reason, the U.S. Department of Commerce (NOAA) and the U.S. Department of Agriculture

2011年8月22日受理（Received on August 22, 2011）
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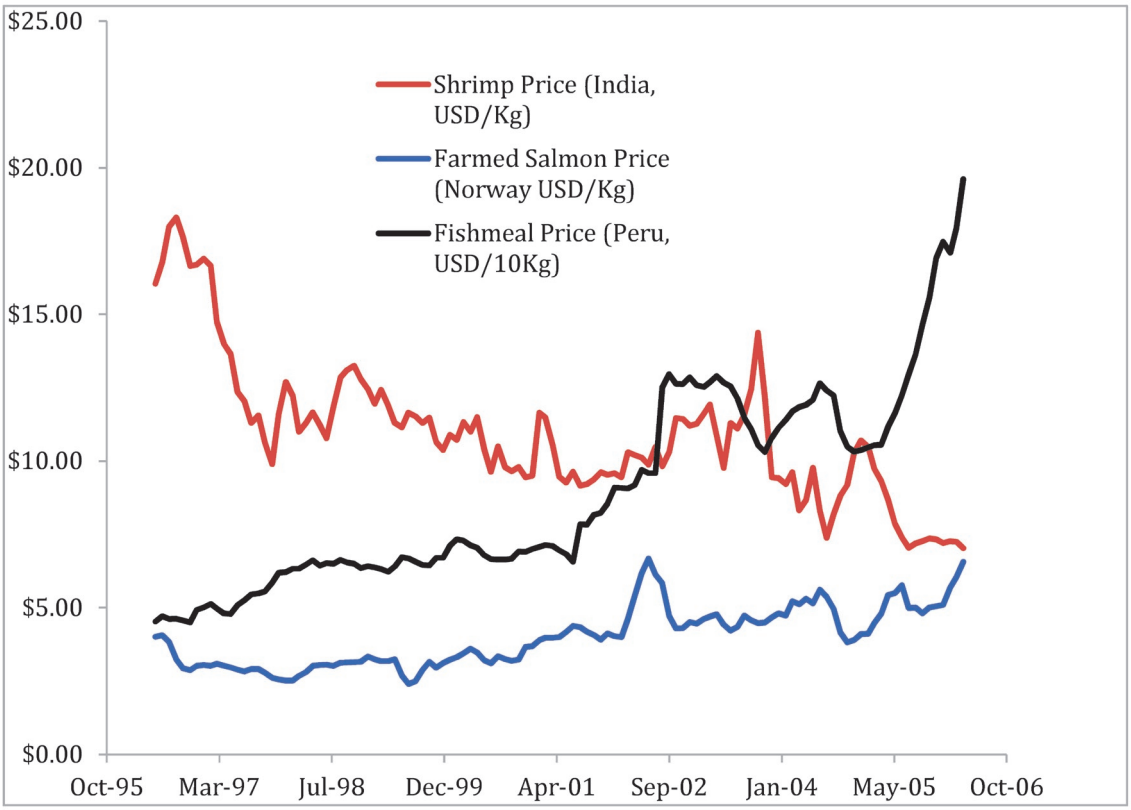

Fig. 1. World price for fishmeal, farmed shrimp and farmed salmon from 2000 to 2010.

(USDA) sponsored expert and public consultations on the future of fish feeds and the benefits to the U.S. economy by the development of such alternative feeds. Those agencies were greatly aided in this effort by help and advice from scientists and others within the Department of the Interior (DOI) and the Food and Drug Administration (FDA).

The Consultation Process

The consultation consisted of eight parts:

1. An invitation to the general public to comment on the issue, and respond to four questions designed to elicit input on a broad array of topics and approaches was published in the Federal Register. The public comment also helped indicate the level of understanding and knowledge that the public has regarding fish feeds.
2. A consultation with experts who are active researchers in the area of fish feeds, feedstuffs, nutrition, and related topics (Research Experts Panel).
3. A consultation with experts who are active stakeholders in the area of fish feeds, feedstuffs, nutrition, and related topics (Stakeholder Experts Panel).
4. Reporting case studies where the shift from reduction fishery fishmeal and fish oil to alternatives is already happening or are areas that might hold promise for the future.
5. Future-casts focused on fish feeds by the attendees at the two experts meetings.
6. Information and recommendations from the above were summarized in a Draft Report addressing the questions raised by the public comment process, summarizing the results of the two experts panels, and reporting on the case studies.
7. A public review of the Draft Report to provide final input from the public and interested groups before it is finalized.

8. Publication of the final Report and outreach to interested parties.

A Steering Committee made up of scientists with expertise in fish nutrition, federal policymakers, and communications experts was assembled to move the process forward.

The purpose of the Steering Committee was to fine-tune the objectives and questions asked, suggest and contact the appropriate scientists, develop dates and locations for panel meetings, choose facilitators for panel meetings, serve as reviewers of the Report, and develop presentations to be given at public meetings. The editorial sub-committee assembled, wrote portions of, and edited portions of the Report. Numerous authors contributed case studies in their areas of expertise and produced future-casts.

In conducting this initiative, the steering committee was guided by several principals when considering an ingredient, process or approach to reduce the use of conventional fishmeal and oil in aquaculture:

- The committee was more interested in what to do, rather than what not to do. Thus all ideas were welcomed equally. Conversely, objections to various feedstuffs were recorded but this was not viewed as justification for their exclusion from consideration or exclusion from the final white paper.
- The committee attempted to adopt a triple bottom line approach when evaluating alternatives. This meant trying to account for:
  - The economic performance of an ingredient, process or approach,
  - The environmental performance of procuring an ingredient, employing a process, or following an approach and,
  - The human health performance of the product resulting from the substitution of an ingredient, process or approach.

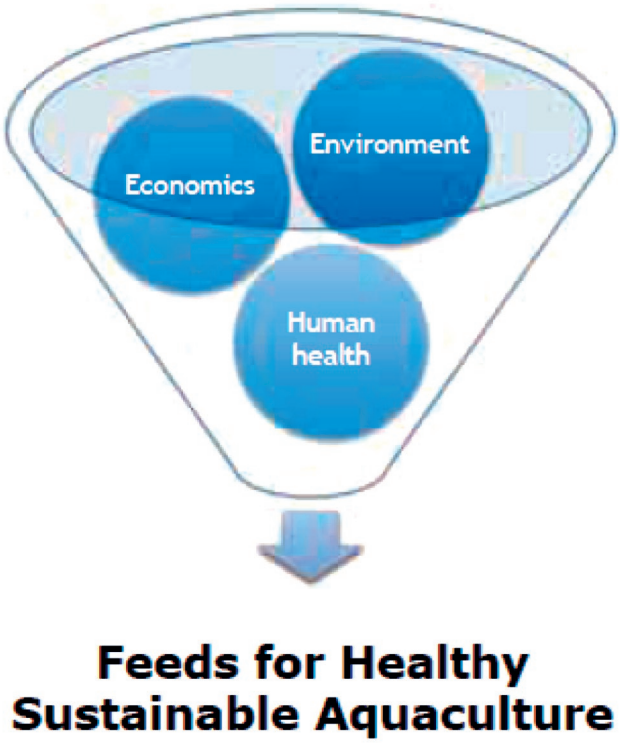

Fig. 2. The "triple bottom line" approach to future aquafeed development.

Public Comment

The Federal Register notice containing questions to solicit input was published November 16, 2007. The public comment period ended February 29th 2008. The questions from the FR notice are:

1) Where should the federal government focus its research efforts in the area of alternative feeds for aquaculture? Are there specific areas that the federal government should not address?
2) What are potential alternative sources of protein and oil for aquaculture feeds? For example, are there specific opportunities for greater use of seafood processing waste and other agricultural by-products in aquaculture feeds? Are there specific obstacles to using these alternatives as alternative dietary ingredients in aquaculture feed?
3) What type of treatments or processes show promise for improvement of existing aquaculture feedstuffs and for developing new feedstuffs? How soon could these technologies be commercialized?
4) Fishmeal and fish oil contribute important human nutritional components to aquaculture feeds, such as omega-3 fatty acids. As the aquaculture feeds industry seeks to replace fishmeal and fish oil with alternatives, how can the nutritional benefits of farmed seafood be maintained or enhanced? For example, what technologies exist for producing omega 3 fatty acids?

The public submitted over 40 separate comments in the following areas: 1) Products for sale, 2) Questions, 3) Statements, 4) Priorities, and 5) Ideas. These comments ranged from very well developed lengthy letters, to one-line statements. The small number of comments makes further analysis difficult.

Experts Panels

Two groups of experts were assembled to develop a path to the development of commercial diets that have no net usage of fishmeal or oil derived from commercial pelagic fisheries. The first panel (Research Panel) was made up of 21 scientists actively working and published in feeds and feedstuffs research, fish and human nutrition, bio-energy, processing, agriculture, and related areas. These scientists provided an unbiased basis for further development. The panel was primarily made up of university and government scientists from around the world. Scientists came from Australia, Canada, Japan, Norway and the United States. This panel met at NOAA's Manchester Lab in Washington State in February 2008.

The second panel (Stakeholders Panel) was made up of individuals who are experts in the practical areas of feeds, human nutrition, and specific feedstuffs. The membership included environmental groups, consumer groups, public hatchery system managers, the commercial aquaculture industry and others with expertise related to the topic. They addressed the same charge as the research panel. This panel met at NOAA headquarters in Silver Spring, MD, in April, 2008.

The expert panel workshops were used to capture expert opinions, develop consensus on key issues where possible, and vet options. Observers included government officials who are responsible for setting research funding priorities, regulators and policy makers at the agencies with interest in feeds for aquatic organisms.

Both panels had the same four assignments:

1) Answer the questions resulting from the Federal Register announcement.
2) Identify the constraints and possible solutions to providing aquafeeds in the future as fishmeal and fish oil resources become scarce.
3) Identify key research and technology transfer needs to overcome barriers for reducing reliance on fishmeal and fish oil resources.
4) Predict (forecast?) the future of aquaculture feeds based on 1), 2), and 3).

Case Studies

The steering committee solicited short write-ups from individuals who are already actively working to replace fishmeal and oil, on case studies of concrete examples of research leading to replacements, actual replacements, or areas that could hold great promise

for replacement in the future.

In total, seven case studies were developed. These case studies covered the use of terrestrial plant diets, soy, seafood processing waste, macroalgae, and the importance of understanding nutrient requirements. Case studies also considered freshwater and marine fish, as well as marine shrimp.

Future-casts

Future-casts are a bit of "science fiction." The convening of both the Researchers Panel and the Stakeholders Panel provided the opportunity to ask each participant to provide a vision of the future of aquaculture feeds as they saw it. At the end of each workshop, attendees were asked to spend some time thinking about and recording what they see as the state of feeds for aquaculture in the future. Specifically, participants were asked to predict the challenges and changes that aquaculture will face, and the developments that will affect both producers and consumers over the next five and 25 years. Participants in each panel varied widely in background and expertise and represented multiple viewpoints providing a variety of visions of the future. Since this was an optional homework assignment, the number of future-casts is smaller than the number of participants in the panel workshops. The future-casts provide an opportunity for those who have an interest in the future of aquafeeds to distill current trends, issues, and science into a plausible vision for the future of aquaculture feeds.

In total, 12 future-casts were submitted. One condition was common to all scenarios and future-casts; human population growth continues and the demand for more fish and seafood increases. The need for aquaculture research to develop sustainable sources of nutrients and develop farmed animal populations that can thrive on a variety of nutrient sources is vital.

Draft Recommendations

The draft Report was released for final public comment late in 2010. Final public comment was due by spring 2011. Barring any major issues discovered during the final public comment period, the report contains the following 20 recommendations.

Fishmeal and fish oil are not nutritionally required for farmed fish to grow: About 40 nutrients – essential amino acids, vitamins, minerals, and fatty acids – are required, but they can be obtained from sources other than fishmeal and fish oil. Fishmeal and fish oil have been the preferred ingredients in fish feeds because they contain the nutrients in nearly perfect balance, are easily digestible by the fish, result in good growth and survival, and provide human health benefits. Combining other ingredients to get the same balance is possible, but will require fully understood fish requirements and alternative performance.

Farming of fish is a very efficient way to produce animal protein and other human nutritional needs: Farmed fish use their feed very efficiently. For example, farmed Atlantic salmon can convert approximately one kilogram of feed (dry) into one kilogram of flesh (wet). In contrast, the feed conversion of poultry is about 3:1, and pork is about 6:1. Fish need fewer calories because they are cold-blooded and do not need to support their weight.

Feed manufacturers making diets for carnivorous fish and shrimp have already reduced their reliance on fishmeal and fish oil: Application of previous research led to cost-effective substitution using alternatives, which helped mitigate feed costs in the face of increasing fishmeal prices (see Figure 1). In the past 15 years the ratio of fish in to fish out has dropped from 3-4:1 to approximately 1.5:1 for major aquaculture species due to increased use of protein and oils in diets from non-marine sources. Fishmeal and fish oil are likely to be increasingly reserved for use in specialty diets (broodstock and larval diets) and finishing diets to maintain the human health benefits from farmed seafood.

Economics is currently the major driver of using alternate feed ingredients in feed mills: Feed producers make substitutions for fishmeal and fish oil according to how their price compares with allowable alternatives (i.e., alternatives for which sufficient nutritional and production knowledge and experience exists to allow their use). Panels identified some crucial factors limiting changes to

feed formulations, including insufficient information on nutrient requirements of farmed species – especially newly domesticated species – and on available nutrient content and nutritional value of alternative ingredients for fish and shrimp. This area requires investments in research to help feed producers understand the costs and benefits of including alternative ingredients in aquaculture feeds.

The net environmental effects of the production and use of alternate feeds should be considered: Consideration should be given to the environmental impacts of making dietary changes to feeds for farmed aquatic organisms.

The human health implications of using alternative feeds needs to be better understood and considered: Long chain omega-3 fatty acids and other nutritional compounds found in fishmeal and fish oil provide important human health benefits. Seafood reared on alternative feeds must continue to provide these health benefits to consumers. Human health considerations should be addressed along with economic and environmental considerations when alternatives are considered. To accomplish this, fish nutritionists should work with human nutritionists and food scientists on promising alternative ingredients to determine impacts of those alternatives on final product quality.

Fishmeal and fish oil are minor contributors to the world protein and edible oil supply: In 2007, fishmeal accounted for approximately 2.3% of total protein meals and fish oil for about 2.0% of total edible oils. The largest supply of protein on Earth is from soybeans. A 4% increase in soy protein meals would nearly equal the total world fishmeal supply. An increase in the amount of soy protein equal to world fishmeal annual production has been achieved about every five years without any additional cropland, based on historical increases in yield per unit area due to intensification, new cultivars, and altered farming practices.

Recovery and utilization of fisheries processing waste should be encouraged and increased: Processing waste has been shown to produce products of similar biological value to fishmeals and fish oils obtained from industrial fisheries. The total worldwide amount of fish processing waste from wild capture and aquaculture may equal the amount of forage fish used for fishmeal and fish oil from industrial fisheries. But fish processing waste is often not economical to obtain because of logistical and technical constraints. Research and financing is needed to help capture the waste products from wild capture fisheries that often are located in remote or inaccessible regions with poor infrastructure. Likewise, research to capture and reuse the waste products from aquaculture should be undertaken. The use of processing waste from aquacultured organisms to produce fishmeal and fish oil eventually could make aquaculture a net producer of fishmeal and oil.

Plants produce the vast majority of protein and edible oils in the world, accounting for 94% of total protein production and 86% of total edible oil production: Plants also make up a substantial proportion of diets for carnivorous fish (e.g., 50-60% of a typical salmon diet). It is likely that plants will deliver the bulk of the amino acids and fats in farmed fish feeds in the future due to abundance, the potential for increased production, and low cost. Research to increase the use of sustainable plant products in feeds for aquatic organisms will help increase the importance of agriculture to aquaculture and vice versa. This area of research would be as important to farmers as to aquaculturists and may represent a significant opportunity for American farmers.

Algae-based biofuel may present opportunities for feed ingredient production because protein is a byproduct of oil recovery from algae, and marine algae produce the long chain omega-3 fatty acids and certain amino acids important to fish and human health: It is too early to understand the ramifications of increased algae biomass production for fish diets, and this area will require communication between algae biofuel scientists and fish nutritionists. Support of research in this area is justified for producing the long chain omega-3 fatty acids alone, as they are a potentially higher value product than biofuel.

There will likely be increased demand for and production of ethanol and bioplastics, and byproducts from those industries could make good ingredients for fish diets: Fish feeds are mostly made up of protein and oils. Ethanol and some bio-plastic

are made from the carbohydrate fraction of plants, leaving behind the protein and oils. Future biofuel production may be quite different from today's focus on ethanol made from corn carbohydrates, which uses a process that degrades the quality of protein waste products. If grain remains a feedstock for ethanol production, new approaches to recover high-quality protein and oil from the ethanol production process will be needed to make it suitable for widespread use in fish feeds. Biodiesel is made from the oil fraction, leaving behind concentrated protein that is already suitable for fish. Fish nutrition researchers should work and coordinate with biofuel scientists to ensure that byproducts are safe and usable for fish. Research that supports processes resulting in high-quality protein and oil byproducts from fuel production should be encouraged.

As replacements, many alternatives are higher in cost per unit fish gain (biological value) than fishmeal and fish oil: However, the recent trend (since 2006) has been for fishmeal and fish oil prices to increase faster than the prices of alternative protein and oil sources. Research that can help lower costs or improve the biological value, without raising costs, will increase the rate of fishmeal and fish oil replacement.

Fish have dietary needs and preferences for specific compounds not found in plants, so there is a need for specialized products that supply those compounds and/or add flavor to the diet: These ingredients will likely be higher in cost than the bulk protein and oil products and will need to contain flavors, nutrients, or other properties not found in bulk proteins and oils but which are needed for fast growth, health, or increased consumption. Examples are algae, invertebrates, animal by-products, and seafood trimming meals and oils. Additional ingredients such as immune system enhancers are also beneficial to enabling the use of higher levels of alternatives. Research is needed to develop materials that will enable greater use of cheaper, more abundant protein meals and oils.

Alternative sources of protein and oil are common commodities used in livestock and companion animal feeds and come from novel byproducts from other industries, underutilized resources, or completely novel products: Existing commodities that have the potential for greater use in feeds include protein concentrates from grains or oilseeds and byproducts from animal proteins. Novel byproducts from other industries include proteins recovered from biofuel production or single-cell proteins produced from inexpensive carbon sources. Other sources include fish processing wastes, trimmings, and/or bycatch from fishing.

New products include meals produced from worms, insects, and marine invertebrates, and meals and oils from algae. What these products have in common is that they are underused and/or underdeveloped protein and oil sources that require variable degrees of investment in research and development to become more widely employed as feed ingredients. Some possess components that are detrimental to fish (e.g., anti-nutrients), or they contain insufficient levels of essential or semi-essential nutrients and need to be processed, blended with complementary products, or supplemented. More information is also needed to evaluate the environmental impacts associated with using various feed ingredients. Information on contaminant content of alternate products is also needed to place risks and benefits to fish wellness and human health into a rational context. Coupled with this is the opportunity to maintain or improve the safety and healthfulness of farmed fish products for the consumer by using alternate ingredients. All these topics will require investments in research and development.

Plants and other alternatives contain some compounds (anti-nutrients) that are detrimental to fish: Although there are processes to remove or inactivate many of these compounds, further research and development is necessary to improve those processes. Fish may also be selectively bred to be more tolerant of the anti-nutrients in present in some alternatives.

Harvest of lower trophic level species, such as krill, for meal and oil production may be possible, but the environmental benefits afforded to the marine ecosystem from those species should be considered along with the economic and nutritional aspects of their use: While this may provide an option in the near term, the harvest of any wild population, including krill, would require careful management

and would be limited to what nature can supply.

The use of bycatch for production of fishmeal and fish oil could provide a substantial amount of those products without increasing the current impact from the wild capture fisheries: Although traditional processes exist to convert bycatch into fishmeal and fish oil, concerns over creating a market for non-target species and the logistical issues associated with dealing with retained bycatch at sea have been expressed.

Demand for long chain omega-3 fatty acids for both direct human consumption and feed ingredients is likely to increase beyond the amounts available from marine resources: Alternative sources such as algae, microorganisms, and/or oilseeds are needed and should be developed. More efficient use of long chain omega-3 fatty acids can be made in aquaculture through improvements in feeding practices and formulation. Research leading to new cost-effective sources of long chain omega-3 fatty acids will benefit human health as well. Research to improve production and the efficiency of use should also be supported.

Farmed fish species are being increasingly domesticated and performance is improving through conventional genetic selection for performance on plant-based and other non-fish based aquafeeds: As aquatic species are domesticated, selection can be directed toward better use of non-fishmeal and non-fish oil ingredients.

Scientific information on the nutritional requirements of farmed fish species, feed ingredients, and the interaction between the fish and the diet will need to expand greatly to make substantial improvements in feed formulation by commercial aquaculture feed producers: Updating the National Research Council (NRC) requirements for fish on a regular basis and support for research that helps define the basic nutritional requirements for farmed aquatic species should be supported.

Annotated Bibliography of Key Works

Mozaffarian D. and Rimm E., 2006: Fish intake, contaminants, and human health: Evaluating the risks and benefits. *JAMA*, **296 (15)**, 1885-1899.

The authors for the first time present a comprehensive human health model based on concentrations of mercury, dioxins, polychlorinated biphenyls, and long chain omega-3 fatty acids for fish and project the impact of increased seafood consumption in the U.S. on the population's health. This model accounts for the increased risks associated with consumption of contaminated seafood along with the benefits from increased consumption of long chain omega-3 fatty acids. Overall the authors predict that increasing the per capita annual consumption of seafood in the U.S. from the current 7.25 to 11.8 kg per person (1-2 servings per week of species high in omega-3 fatty acids) would result in a decrease in coronary death by 36% and an overall decrease in total mortality of 17%. Further the authors provide the amounts to consume of various species and the cost to provide the benefits associated with seafood consumption. Implications for target nutrient and contaminate levels in aquacultured fish can be derived from the information presented in this paper.

Rust M. B., Barrows F. T., Hardy R. W., Lazur A., Naughton K., and Silverstein J., 2010: Draft NOAA/USDA Alternative Feeds Initiative: The future of Aquafeeds. *Agency Technical Report*, available at http://aquaculture.noaa.gov.

This report is the subject of this presentation. More details and recommendations are found on the US approach to future development of diets for aquaculture.

Tacon A. G. J., and Metian M., 2008: Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, **285**, 146-148.

This paper provides a peer-reviewed source of information on aquaculture use of fish meal and fish oil up to the mid 2000's with projections into the future. Environmental implications to the overuse of stocks of industrial fish are discussed.