

1. *Fish meal and fish oil are not nutritionally required for farmed fish to grow.*

About 40 nutrients—such as essential amino acids, vitamins, minerals, and fatty acids—are required but they can be obtained from sources other than fish meal and fish oil. Fish meal and fish oil have been the preferred ingredients in fish feeds because they contain these 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.

2. *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 3-5:1, and pork is 8:1. Fish need fewer calories because they are cold-blooded and they do not need to support their weight.

3. *Feed manufacturers making diets for carnivorous fish and shrimp have already reduced their reliance on fish meal and fish oil.*

Application of previous research led to cost-effective substitution using alternatives, which helped mitigate feed costs in the face of increasing fish meal prices (see Figure 2 on page 2). 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. Fish meal 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 of farmed seafood.

4. *Economics is currently the major driver of using alternate feed ingredients in feed mills.*

Feed producers make substitutions for fish meal 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.

5. *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.

6. *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 fish meal 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 alternatives on final product quality.

7. *Fish meal and fish oil are minor contributors to the world protein and edible oil supply.*

In 2007, fish meal accounted for approximately 2.3 percent of total protein meals and fish oil for about 2.0 percent of total edible oils. The largest supply of protein on Earth is from soybeans. A 4 percent increase in soy protein meals would nearly equal the total world fish meal supply. Fish meal and fish oil are likely to continue to be important ingredients, but as supply is limited, they will increasingly be used in combination with other ingredients or for special diets. Substitution will depend on supply, price, and performance of alternatives.

8. *Recovery and utilization of fisheries processing waste should be encouraged and increased.*

This material has been shown to produce products of similar biological value to fish meals and oils made 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 fish meal and fish oil from industrial fisheries. But fish processing waste is often not economical to capture 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 fish meal and fish oil eventually could make aquaculture a net producer of fish meal and oil.

9. *Plants produce the vast majority of protein and edible oils in the world, accounting for 94 percent of total protein production and 86 percent of total edible oil production.*

Plants also make up a substantial proportion of diets for carnivorous fish (e.g., 50-60 percent of a typical salmon diet), and that proportion is increasing. It is likely that plants will deliver the bulk of amino acids and fats to diets for farmed fish 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 to 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.

10. *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; a potentially higher value product than biofuel.

11. *There will likely be increased demand for and production of ethanol and bioplastics. Byproducts from these 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 wide spread 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 byproducts are safe and usable for fish. Research that supports processes resulting in high-quality protein and oil byproducts of fuels production should be encouraged.

12. *As replacements, many alternatives are higher in cost per unit fish gain (biological value) than fish meal and fish oil.*

However, the recent trend (since 2006) has been for fish meal and fish oil prices to increase faster than 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 fish meal and fish oil replacement.

13. *Fish have dietary needs and preferences for specific compounds not found in plants, so there is a need for specialized products that supply these 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 properties not found in bulk proteins and oils but which are needed for fast growth, health or increase consumption. Examples are algae, invertebrates, animal by-products and seafood trimming meals and oils. Additional ingredients such immune system enhancers are also beneficial to enable 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.

14. *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 including 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 used. Some possess attributes 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.

15. *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 these processes. Fish may also be selectively bred to be relatively more tolerant of the anti-nutrients in some alternatives.

16. *Harvest of lower trophic level species, such as krill, for fish meal and oil production may be possible, but the environmental benefits afforded to the marine ecosystem from these 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.

17. *The use of bycatch for production of fish meal and fish oil could provide a substantial amount of these products without increasing the current impact from the wild capture fisheries.*

Although traditional processes exist to convert bycatch into fish meal 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.

18. *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 are needed and should be developed, such as algae, microorganisms, and/or oilseeds. 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.

Summary of findings

19. Farmed fish species are being increasingly domesticated and performance is improving through conventional genetic selection and selection for performance on plant-based and /or low fish meal based aquafeeds.

As aquatic species are domesticated, selection can be directed toward better use of non-fish meal and non-fish-oil ingredients.

20. Scientific information on the nutritional requirements of farmed fish species, and 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.