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COMMITTEE ON FISHERIES

SUB-COMMITTEE ON AQUACULTURE

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FEEDING THE GROWING AQUACULTURE SECTOR: AN ANALYSIS

Executive Summary

The global population is increasing and in order to maintain at least the current level of per capita consumption, the world will require an additional 23 million tonnes of aquatic food by 2030, which must come from aquaculture. Meeting the future demand for food from aquaculture will largely depend on the availability of quality feeds in required quantities. Although the discussion on the availability and use of aquafeed ingredients often focuses on fishmeal and fish oil resources (including trash fish), considering the past trends and future predictions, sustainability of the aquaculture sector is more likely to be closely linked with the sustained supply of terrestrial animal and plant proteins, oils and carbohydrate sources for aquafeeds. Apart from ensuring the sustained availability of feed ingredients to meet the demand of growing aquaculture, there are several other important areas and issues which require attention. This document provides an analysis of feed ingredient requirements in aquaculture and raises several issues and questions for the attention of the Sub-Committee and seeks guidance, advice and future directives for FAO's work on feeding future aquaculture.

The Sub-Committee is invited to:

1) review the document, consider national situations and importance of addressing the issue of feeding future aquaculture at all levels, and
2) guide and advise the Secretariat on how to improve FAO's contribution in the field of feeding tomorrow's fish towards improving the overall aquaculture sector sustainability, globally.

Introduction

1. In 2008, global aquaculture production reached 68.8 million tonnes; 52.9 million tonnes of aquatic animals and 15.9 million tonnes of aquatic plants. The volume of aquatic animals produced represented 46.7 percent of the global food fish supply during the same year. Considering the increasing global population and recognising that there will be no additional aquatic food coming from marine capture fisheries, it has been estimated that, at least to maintain the current level of per capita consumption, by the year 2030, the world will require an additional supply of 23 million tonnes of aquatic animal food, which will have to be originated from aquaculture.

2. Although aquatic plants and molluscs are produced without any supplementary feeding, production of other aquatic animals requires some form of food. Filter-feeding finfish (e.g. silver carp, bighead carp) receive their food (primarily in the form of phytoplankton and zooplankton) produced in the pond/water body through natural productivity and/or through fertilization. These species do not require any other forms of feeding thus aquafeeds are not used for their production worldwide.

3. Aquafeeds are usually used for feeding omnivorous fish (e.g. tilapias, catfishes, common carp, milkfish, etc.), carnivorous fish (e.g. salmons, trouts, seabass, seabream, tuna, etc.) and crustacean species (marine and brackishwater shrimp, freshwater prawns, crabs, lobsters, etc.).

4. Fish which are fed with aquafeeds during culture practice are referred to as “fed fish” and fish which do not receive any feeding are generally referred to as “non-fed fish”. Aquaculture practices which produce fed fish are called “fed aquaculture” [1] the opposite being “non-fed aquaculture”. The same species of fish may be cultured both as fed fish or non-fed fish in different production systems, thus having precise production data and information on the use of feed for several aquaculture species, especially some omnivorous species such as common carp, Indian major carps, and herbivore species such as grass carp is difficult. For example, in many aquaculture production systems, grass carp are fed exclusively on plant materials/grasses, while in other system this species is produced through externally supplied farm-made or commercial aquafeed. This shortfall prevents us in making accurate estimates of feed use for many such species.

5. According to FAO estimates, in 2008, about 31.7 million tonnes (46.1 percent of total global aquatic animal production) was feed dependent, either as farm-made aquafeeds[2] or as industrially manufactured compound aquafeeds[3]. In 2008, fed aquaculture contributed to 81.2 percent of global fish and crustacean production of 38.8 million tonnes and 60.0 percent of global aquatic animal production.

6. Although more than 200 species of fish and crustaceans are currently believed to be fed on externally supplied feeds, nine species account for 62.2 percent of the total global-fed species production, including grass carp, common carp, Nile tilapia, Indian major carps, whiteleg shrimp, crucian carp, Atlantic salmon, and pangasiid catfishes. Over 67.7 percent of farmed fed fish productions are contributed by freshwater fish including carps and other cyprinids, tilapias, catfishes and miscellaneous freshwater fishes.

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[1] Aquaculture production that utilizes or has the potential to utilize aquafeeds of any type in contrast with the farming of filter-feeding invertebrates and aquatic plants that relies exclusively on natural productivity.

[2] Typically a feed that is produced by farmers or small-scale feed manufacturers using some form of processing on farm or in a small processing plant, resulting in a moist dough or a simple moist or dry pellet.

[3] An aquafeed comprised of a number of ingredients that are mixed in various proportions to complement one another to form a nutritionally complete compound diet.

Aquafeed production and use

7. Meeting the future demand for food from aquaculture will largely depend on the availability of quality feeds in required quantities.

8. Fed aquaculture farming systems range from the use of low-cost earthen pond-based semi-intensive production systems for the mass production of freshwater omnivorous fishes (e.g., carps, tilapias, milkfish) destined for local domestic consumption, to the use of more intensive pond, cage or tank-based production systems for the production of freshwater/diadromous/marine carnivorous fishes (marine fishes, salmons, trouts, eels, snakeheads) and crustaceans (marine shrimps, freshwater prawns, crabs, etc) for export or high-end domestic markets.

9. The choice of the feeding method is based upon a variety of factors (which may vary from country to country and farmer to farmer) and a variety of objectives (local/home consumption or cash crop/export) Important factors include the market value of the cultured species, the financial resources of the farmer and the local availability of appropriate fertilizers and feeds. Globally the feeding methods employed by farmers can be divided into three basic categories, namely:

- **no feeding**: fish/crustacean growth dependent upon the natural productivity of the waterbody (e.g., traditional extensive pond farming systems);
- **endogenous feeding**: fish/crustacean growth dependent upon the endogenous production of natural food organisms within the culture system through the use of fertilizers and manures as a source of nutrients (e.g., modified extensive pond farming systems);
- **exogenous feeding**: fish/shrimp growth dependent upon the external supply of feeds, either (i) in the form of supplementary feeds (e.g., single feed ingredients or mixtures of more one than feed ingredients) in combination with endogenous feeding regimes, (ii) in the form of a single food item of high nutrient value (such as low-value fish/trash fish) and/or (iii) in the form of a nutritionally complete formulated compound diet (farm-made/semi-commercial feed or commercially produced industrial pellet).

10. This document mainly deals with fish and crustaceans fed through exogenous feed, particularly aquafeed that is industrially produced as the comprehensive information on other feed types are generally lacking.

11. Compound aquafeeds are used both for the production of lower-value (in marketing terms) food-fish species such as non-filter feeding carps, tilapias, catfishes and milkfish, as well as higher-value species such as marine finfishes, salmonids, marine shrimps, and freshwater eels, snakeheads and crustaceans.

12. Globally, 708 million tonnes of industrial compound animal feeds have been produced in 2008, out of which 29.2 million tonnes were aquafeeds (4.1 percent of the total animal feeds). As animal production has been increasing readily, the global industrial compound animal feed production has also been increasing.

13. Total industrial compound aquafeed production has concurrently increased almost four-fold over the past decade. It has increased from 7.6 million tonnes in 1995 to 29.2 million tonnes in 2008, at an average rate of 11.0 percent per year. The production is expected to continue growing at a similar rate to 51.0 million tonnes by 2015 and to 71.0 million tonnes by 2020.

14. By volume, industrial compound aquafeeds used by major species/species groups are estimated to be as follows: fed carps (9.1 million tonnes, 31.3 percent of total), marine shrimps (17.3 percent), tilapias (13.5 percent), catfishes (10.0 percent), marine fishes (28.3 percent), salmons (7.0 percent), freshwater crustaceans (4.5 percent), trouts (3.0 percent), milkfish (2.0 percent), eels (1.4 percent), and miscellaneous freshwater fishes (1.6 percent).

15. As mentioned earlier, in contrast to compound aquafeeds, there is no comprehensive information available on the global production of farm-made aquafeeds. The rough estimate is between 18.7 and 30.7 million tonnes in 2006.

16. Farm-made aquafeeds however play an important role in the production of low-value freshwater fish species. Over 97 percent of carp feeds used by Indian farmers are farm-made aquafeeds (7.5 million tonnes in 2006/07).It is the mainstay of feed inputs for low-value freshwater fishes in many other Asian and sub-Saharan countries.

17. There is no accurate information either on the use of low-value fish/trash fish (i.e. as raw ingredients not reduced into fishmeal) as direct feed in aquaculture production. It has been however estimated that the total use of low-value fish/trash fish in aquaculture was between 5.6 and 8.8 million tonnes in 2006 and that in 2008 Chinese aquaculture alone used 6 to 8 million tonnes of low-value fish/trash fish, including marine trash fish, freshwater fish, and live food fish.

Feed ingredients and their availability

18. Feed ingredients used for the production of aquafeeds are broadly categorized into three types depending upon their origin: animal nutrient sources; plant nutrient sources; and microbial nutrient sources. Animal nutrient sources include both aquatic and terrestrial animals.

Aquatic animal protein meals and lipids

19. The major aquatic animal protein meals and lipids used in aquafeeds include fish/shellfish meals and oils; fish/shellfish by-product meals and oils; and zooplankton meals and oils.

20. ***Fish/shellfish meals and oils***: Fishmeal and oil derived from wild harvested whole fish/shell fish including bycatch currently constitute the major aquatic protein and lipid sources available within the animal feed. World reduction fisheries (marine capture fishery products converted to fishmeal) have ranged between 18 and 30 million tonnes during the last 33 years (from 1976 to 2009). In 1976, the world reduction fisheries was 18.2 million tonnes and it progressively increased to 30.2 million tonnes in 1994 and it has been decreasing steadily since then to 17.9 million tonnes in 2009. As a result similar trends were also noted for fishmeal and fish oil production. Global fishmeal production progressively increased from 5.00 million tonnes in 1976 to 7.48 million tonnes in 1994. It has decreased steadily since then to 5.74 in 2009. Similarly global fish oil production steadily rose from 1.02 million tonnes in 1976 to 1.50 million tonnes in 1994 (with the exception of high production of 1.67 and 1.64 million tonnes recorded in 1986 and 1989) and since 1994 there has been a steady decrease to 1.07 million tonnes in 2009. The Analysis of the reduction in fisheries data over the last 15 years (from 1994 to 2009) therefore indicates that global fishmeal and fish oil production from marine capture fisheries has been decreasing at an average rate of -1.7 percent per year and -2.6 percent per year since 1995, respectively.

21. The amount of the captured fish destined for non-food use has increased from 20.6 million tonnes in 1976 to 34.2 million tonnes in 1994 with proportion increasing from 31.5 to 37.1 percent of total catch during this period. Since 1995, the amount of the captured fish destined for non-food use have been decreasing both in absolute amounts as well in proportion of total catch. In 1995, 31.3 million tonnes of the global fish and shellfish landings were destined for non-food use (33.9 percent of total catch) and out of this total 27.2 million tonnes (29.5 percent of total catch) was reduced into fishmeal and fish oil, while in 2009, 22.8 million tonnes of the global landings were destined for non-food use (25.7 percent of total). Out of this total 17.9 million tonnes (20.2 percent of total) was reduced into fishmeal and fish oil. The amount of the captured fish destined for non-food use will probably decrease further in near future.

22. The reasons for this decrease in non-food use of captured fish are variable ranging from the increased use of feed fish for human consumption and decrease in dedicated feed fish catch due to tighter quota setting and additional controls on unregulated fishing. For example, there has been a notable increase of traditionally used feed fish (e.g., capelin, herring and blue whiting in Norway, herring and blue whiting in Denmark, jack mackerel and chub mackerel in Chile, anchovy in Peru) for human consumption. Specific reference may be made in case of Peru, where 190 000 tonnes (3 percent of total catch) of Peruvian anchovy went for human consumption in 2009. Similarly in Norway, about

90 percent of the almost 1 million tonnes of Norwegian spring spawning Atlantic herring (*Clupea harengus*) caught in 2010 was used for human consumption.

23. Although the above are having negative impact on global fishmeal and fish oil availability, these reductions are likely to be compensated to some extent by fishmeal/fish oil produced from fisheries/aquaculture by-products.

24. ***Fish/shellfish by-product meals and oils:*** In recent years increasing volumes of fishmeal and fish oil are originating from fisheries by-products (capture fisheries and aquaculture). It has been estimated that about 6 million tonnes of trimmings and rejects from food fish are currently used for fishmeal and fish oil production. Recent estimates have been made by the International Fishmeal and Fish Oil Organisation (IFFO) that approximately 25 percent of fishmeal production (1.23 million tonnes in 2008) came from fisheries by-products. This volume will grow as it becomes more and more viable to process this material.

25. The share of fishmeal from fish waste in total fishmeal trade has been also increasing from 1970s, seven percent of total fishmeal in 1976 to 20 percent in 2007. Accurate information on what proportion of by-product fishmeal and oil is produced from aquaculture processing waste is not available, although it is likely that significant volume of farmed fish wastes is contributing to the global fishmeal and fish oil produce. For example, in Chile, the production of 600 000 tonnes of salmon have reported to yield 270 000 tonnes of processing waste and farm mortalities, which in turn resulted in the production of 48 600 tonnes of salmon oil and 43 200 tonnes of salmon meal.

26. Similarly in Norway, most of the by-products from processing of farmed Atlantic salmon are immediately preserved into fish silage and the silage is subsequently processed into oil and fish protein concentrate (FPC). With a total Norwegian production volume of Atlantic salmon of about 0.85 million tonnes in 2009 and a yield of viscera of approximately 17 percent, this provides almost 145 000 tonnes which mostly are recycled and used in compound feed for pigs and poultry and for farmed fish other than salmon.

27. ***Zooplankton meals and oils:*** Although some of the marine zooplanktons have potential, and/or have been considered for use as feed ingredients for aquaculture, commercial operations only exist for the Antarctic krill (*Euphausia superba*) with a total landing of 118 124 tonnes in 2007. Although krill meal and krill oil are available in the marketplace, information concerning the total global production and market availability of these two products is currently unavailable. Studies have shown that krill meal may replace or supplement fishmeal in the diets for several fish and crustacean species. Although there are large biomasses of other zooplankton species in the oceans, it is probably unlikely that zooplankton meals will become a major protein ingredient in feed for farmed fish in the on-growing phase. It is however more reasonable to believe that relatively minor amounts of costly zooplankton meal may be used as a bioactive ingredient or attractant in aquafeed or in feed to fish larvae.

Terrestrial animal protein meals and fats

28. The major terrestrial animal protein meals and lipids commonly used in aquafeeds are: a) meat by-product meals (meat meal, and meat and bone meal) and fats, b) poultry by-product meal, hydrolysed feather meal and poultry oil, and c) blood meals. Although accurate information on the volumes produced is not available, it has been estimated that the global combined production of rendered animal protein meals and fats in 2008 was approximately 13.0 and 10.2 million tonnes, respectively.

Plant nutrient sources

29. The major plant dietary nutrient sources used in aquafeeds include; cereals, including by-product meals and oils; oilseed meals and oils; and pulses and protein concentrate meals.

30. ***Cereals and by-products:*** Total global cereal production was 2 489 million tonnes in 2009, with production growing at an average annual rate of 2.2 percent per year since 1995; maize totalling 817.1 million tonnes, or 32.8 percent of the total cereal crop in 2009, followed by wheat, rice paddy, and barley. Although FAO FAOSTAT Agriculture database on trade reports the country imports and exports of specifically traded cereal by-product meals and oils (excludes wheat millings/wheat pollard and by-products from corn ethanol production), information on the total global production of cereal by-product meals and oils are not available. According to the Renewable Fuels Association, ethanol biorefineries within the United States of America produced nearly 27 million tonnes of corn cereal by-products for use as animal feed in 2008.

31. ***Oilseed by-product meals and oils:*** In 2009, 415 million tonnes of oil seeds were produced, with soybean being the largest and fastest growing oilseed crop contributing little over 50 percent (210.9 million tonnes) to the total. In 2008/9 it was estimated that approximately 151.6 million tonnes of soybean meal was produced in 2008/09. Other major oilseed protein meals produced in 2008/09 included: rapeseed meal (30.8 million tonnes), cottonseed meal (14.4 million tonnes), sunflower seed meal (12.6 million tonnes), palm kernel meal (6.2 million tonnes), groundnut/peanut meal (6.0 million tonnes), and copra/coconut meal (1.9 million tonnes). However, no published information is currently available concerning the global production of oilseed protein concentrate meals. In terms of oil supply, palm oil was the top extracted oil produced in 2008/09 at 42.4 million tonnes. Other major oilseed oils produced in 2008/09, ranked in order of production volume, included rapeseed oil, sunflower seed oil, palm kernel oil, peanut/groundnut oil, cottonseed oil, copra oil, and olive oil.

32. ***Pulses and protein concentrate meals:*** Amongst pulses, protein concentrate meal from peas and lupins are commercially available for use within compounded animal feeds, including aquaculture feeds. The total global production of dry peas and lupins were 10.5 and 0.93 million tonnes respectively in 2009.

Microbial ingredient sources

33. Microbial derived feed ingredient sources for aquafeed include algae, yeasts, fungi, bacteria and/or mixed bacterial/microbial single cell protein (SCP) sources. So far the only microbial ingredient sources available in commercial quantities globally are yeast-derived products, including brewer’s yeast and extracted fermented yeast products with limited or no information concerning the total global production and market availability of these products. Because of the relatively low cost of some of these single cell proteins , these are probably most relevant as a major protein ingredient in fish feed or may at least partially replace fishmeal in feeds for some fish species. Although microbial and algal species are considered as innovative new protein sources for aquafeed, the cost of production will be an issue with the production of some these bacterial and algal protein sources.

34. Bacterial protein meal has been produced by the use of natural gas as a carbon source and it has been shown that it can replace some of the fishmeal in diets for Atlantic salmon. Photoautrophic microalgae have been reported to be mass produced by various sophisticated techniques and the total production has been estimated to be about 10 000 tonnes per year. The cost of production and processing is however currently so high that these are unlikely to become major protein contributors in the aquafeed. Products from micro algae may however be used as a source of high priced specific feed ingredients. An example is astaxanthin obtained from *Haematococcus* which is commercially used as a natural pigment in fish feed.

Current feed ingredient usage trends and constraints

Fish meals and oils

35. *Fishmeal and fish oil use in species/species-groups:* Within the animal husbandry subsectors, aquaculture is now the largest user of fishmeal and fish oil. Although the use of fishmeal and fish oil in aquafeeds is more prevalent for higher trophic level finfishes and crustaceans (fishmeal inclusion level varying between 17 and 65 percent and fish oil between 3 and 25 percent), low-trophic level finfish species/species groups (carps, tilapias, catfishes, milkfish, etc.) also use fishmeal and fish oil in varying amounts in their diets. The fishmeal use for these lower trophic fish species diets varies between 2 and 10 percent with the exception of tilapia and catfishes in few countries where >10-25 percent fishmeal use has been reported.

36. In total usage terms, the largest consumers of fishmeal in 2008 were shrimps (27.2 percent of total fishmeal used in compound aquafeeds), followed by marine fishes (18.8 percent), salmons (13.7 percent), carps (7.4 percent), freshwater crustaceans (6.4 percent), trouts (5.9 percent), catfishes (5.5 percent), tilapias (5.3 percent), eels (5.2 percent), miscellaneous freshwater fishes (3.9 percent) and milkfish (0.8 percent). Similarly, in total usage terms the largest consumers of fish oil in 2008 were salmons (36.6 percent total fish oil used in compound aquafeeds), followed by marine fishes (24.7 percent), trouts (16.9 percent), marine shrimps (12.9 percent), miscellaneous freshwater fishes (3.1 percent), freshwater crustaceans (2.6 percent), eels (2.6 percent), and milkfish (0.7 percent).

37. Although the global fishmeal and fish oil supplies have fluctuated between 4.57 and 7.48 million tonnes for the last 33 years and has now stabilized at approximately 5.0 - 6.0 million tonnes per year, amount of fishmeal and fish oil used in aquafeeds has grown from 1.87 million tonnes to 3.73 million tonnes and from 0.46 million tonnes to 0.78 million tonnes from 1995 to 2008, respectively. This has been possible at the expense of the land-animal sector, particularly from the pig and poultry sector, which is continuously reducing its use of fishmeal in poultry diets. In 1988, 80 percent of the world fishmeal production was used in feed for pigs and poultry while only 10 percent was included in aquaculture feed. In 2008 aquaculture used 60.8 percent of world fishmeal production and 73.8 percent of fish oil production and the remaining amount was used by all other sectors.

38. There is a wide variation in fishmeal and fish oil usage between major species/species groups with shrimp, marine fish and salmon being the largest combined users of fishmeal and fish oil. Overall, this variation reflects the differences in the selection and use by counties of fishmeal and fish oil replacers and the differences between countries in cost and availability of ingredients. One other factor is the increased use of land animal proteins and fats within feeds for high trophic level fish species and crustaceans within the Americas and Australia and for both high and low trophic level fish species and crustaceans within Asia. Use of land animal proteins (animal by products) in aquafeeds in Europe is restricted.

39. As mentioned earlier, low-value fish/trash fish are also increasingly used as aquafeeds for carnivorous species, particularly in Asia.

40. Increased use of fishmeal and fish oil and trash fish/low-value fish in aquaculture over the last 10-12 years has primarily been attributed to the increase in production of carnivorous species, particularly marine crustaceans, marine finfish, salmonids and other diadromous fishes, worldwide.

41. Although the aquaculture sector has continued to remain the largest user of fishmeal in the world, there has been a gradual reduction of fishmeal use in aquafeeds since 2006. In 2005, aquaculture consumed about 4.23 million tonnes (or 18.7 percent of total aquafeeds by weight) of fishmeal and it has gone down to 3.72 million tonnes in 2008 (or 12.8 percent of total aquafeeds by weight). It has been predicted that, even with increasing aquaculture production globally, the use of fishmeal for aquafeeds will decrease further to 3.63 million tonnes by 2015 (7.1 percent of total aquafeeds for that year) and to 3.49 million tonnes by 2020 (or 4.9 percent of total aquafeeds for that year).

42. The reasons for this decrease are the increasing market demand and prices, decreased supplies from tighter quota setting and additional controls on unregulated fishing, and increased use of more cost-effective dietary fishmeal replacers. Because of the limited amount of fishmeal available and the increasing price of this product, an impressive amount of studies have been carried out in recent decades both by research institutions and by the aquaculture feed industry itself, to reduce dependency on fishmeal.

43. All of these studies have given more detailed knowledge on the digestive processes and nutritional requirements of many farmed species and on the processing of feed raw materials to make these more suitable for use in feed. Results of these studies have led to an impressive reduction in the average inclusion of fishmeal in compound feed from 1995 to 2008 in major groups of farmed species. The increased knowledge has also resulted in improved feed conversion ratios (FCR) reducing the amount of waste from the industry.

44. Over the last 13 years (1995-2008), fishmeal inclusion in major fish diets has been reduced considerably; i.e., fed carps (fishmeal inclusion from 10 percent in 1995 to 3 percent in 2008); tilapia (10 to 5 percent), misc. freshwater fish (55 to 30 percent), salmonids (45 to 20 percent), milkfish (15 to 5 percent), eels (65 to 46 percent), marine fishes (50 to 26 percent), marine shrimps (28 to 20 percent), freshwater crustaceans (25 to 18 percent).

45. It is further projected that over the next 10-12 years, fishmeal inclusion in the diets of different carnivorous fish and crustacean species will be further reduced by 10-22 percent and from 7 to 1 percent for carps, tilapias and catfishes, from 25 to 12 percent for salmons and trouts, from 20 to 8 percent for marine shrimp, from 18 to 8 percent for freshwater crustaceans, from 26 to 12 percent for marine fishes, from 46 to 30 percent for eels and from 30 to 8 percent for miscellaneous freshwater fishes.

46. Moreover, with increased feed efficiency and better feed management, it is projected that there will be reduction of feed conversion ratios in the range between 0.1 and 0.4 for many aquaculture species (e.g., fed carps, catfishes, tilapias, milkfish, eel, marine fishes, marine shrimps and freshwater crustaceans) dependent on industrially manufactured compound aquafeeds. For example, the reported FCR of fed carps dependent upon industrial compound aquafeed is 1.8 in 2008 and it is expected to be reduced to 1.6 in 2020, for catfishes from 1.5 to 1.3 and milkfish from 2.0 to 1.6. If this materializes for the above species/species groups, it can be calculated that there will be about 6 percent reduction in the volume of fishmeal fish in spite of the projected 244 and 230 percent increase in the estimated total aquafeed and fed aquaculture production respectively.

47. Although it is projected that over the next ten years, fish oil inclusion in the diets for different carnivorous fish and crustacean species will also be reduced by 0.5-7.0 percent, the use of fish oil by the aquaculture sector will probably increase in the long run albeit slowly. The total usage will increase by over 16 percent by volume, from 782 000 tonnes (2.7 percent of total feeds by weight) in 2008 to 845 000 tonnes by 2015 (1.7 percent of total aquafeeds for that year) and to 908 000 tonnes (1.3 percent of total aquafeeds for that year) by 2020.

48. The reasons for the increase is due to the rising demand for these resources by the rapidly growing marine finfish and crustacean aquaculture sector and from the absence of cost-effective alternative sources of dietary lipids that are rich in long-chain, highly unsaturated fatty acids (HUFA), including eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3). There is also a growing demand for the use of fish oil for direct use as human supplements or pharmaceutical medicines.

49. Alternative lipid sources to fish oil are being used in greater amounts. Key alternatives include vegetable oils (e.g., linseed, soybean, canola, palm), preferably those with high omega-3 contents, and poultry oil. The use of oil from farmed fish offal is also a potential omega-3 source for other farmed fish.

50. Although reduction of dietary inclusion level of fish oil in aquafeed would not have any deleterious effect on the health of the farmed target species, there may be reduced health benefits of the final products imparted by HUFA, including EPA and DHA levels. Intensive research is therefore

required in order to find alternatives to fish oil, such as long chain (LC) omega-3 production from hydrocarbons by yeast fermentation, extraction from algal sources and/or genetic modification of plants to become LC omega-3 fatty acids producers.

51. The production of marine microalgae or bacteria with very high contents of highly unsaturated fatty acids is currently expensive for use in most aquaculture feeds, but more cost efficient production methods will change this. Research is being undertaken to retain health benefits in farmed fish by identifying suitable antioxidants to protect the highly unsaturated fatty acids from oxidation, and optimizing their inclusion levels and/or to phase the levels of marine oils in the feed across the growth stage, without compromising the health and welfare of the fish. Studies are also being undertaken to find out if fatty acid profile in certain microalgae are suitable to replace fish oil in feed for salmonids.

52. From the forgoing discussion, it is explicit that to keep pace with the fed aquaculture production, global aquafeed production will continue to grow and is expected to reach to 71.0 million tonnes by 2020. The above analysis also indicates that although the availability of fishmeal and probably fish oil over the ten year may not be a major constraining factor, other feed ingredient and input supply must grow at a similar rate if this growth is to be sustained and that has to be met from other sources (e.g., soybean, corn, rendered animal by-products etc.).

Terrestrial animal meals and oils

53. The use of terrestrial animal protein meals and oils in non-European countries is increasing within compound aquafeeds, for both high and low trophic level species/species groups (e.g., salmons, trouts, marine finfishes, marine shrimps, catfishes, tilapias, carps and mullets), although the type and level varies depending upon species/species groups. The inclusion level generally ranges between 2 and 30 percent for poultry by-product meal, 5–20 percent for hydrolysed feather meal, 1–10 percent for blood meal, 2–30 percent for meat meal, 5–30 percent for meat and bone meal, and 1–15 percent for poultry oil. Despite the apparent increasing trend, it is estimated that the total usage of terrestrial animal by-product meals and oils within compound aquafeeds ranges between 0.15 and 0.30 million tonnes, or less than 1 percent of the total global compound aquafeed feed production. Clearly, there is considerable room for further growth and expansion. As mentioned earlier, the use of animal by products in aquafeeds in Europe is restricted under the Community legislation.

Plant protein meals and oils

54. Plant protein meals commonly used in aquafeed include soybean meal, wheat gluten meal, corn gluten meal, rapeseed/canola meal, cottonseed meal, sunflower seed meal, groundnut/peanut meal, mustard oil cake, lupin kernel meal, faba bean meal and plant oils include rapeseed/canola oil, soybean oil, and palm oil. Plant proteins represent the major dietary protein source used within feeds for lower trophic level fish species (tilapias, carps, catfishes) and the second major source of dietary protein and lipid source after fishmeal and fish oil for marine shrimps and European high trophic level fish species (e.g., salmons, trouts, marine fishes, eels).

55. Other species/species groups that use substantial amount of plant protein meals and oils include milkfish, mullets, freshwater prawns, cachama and freshwater crayfishes. Depending upon the species/species groups, the inclusion levels are as follows: soybean meal (3–60 percent), wheat gluten meal (2–13 percent), corn gluten meal (2–40 percent), rapeseed/canola meal (2–40 percent), cottonseed meal (1–25 percent), groundnut/peanut meal (≈30 percent), mustard oil cake (≈10 percent), lupin kernel meal (5–30 percent), sunflower seed meal (5–9 percent), canola protein concentrate (10–15 percent), faba bean meal (5–8 percent), field pea meal (3–10 percent), rapeseed/canola oil (5–15 percent), soybean oil (1–10 percent), rapeseed/canola oil (5–15 percent).

56. Soybean meal is the most common source of plant protein used in compound aquafeeds and the most prominent protein ingredient substitute for fishmeal in aquaculture feeds, with feeds for herbivorous and omnivorous fish species and crustaceans usually containing from 15 to 45 percent soybean meal, with a mean of 25 percent in 2008. In global usage terms, and based on a total

compound aquafeed production of 29.3 million tonnes in 2008, it is estimated that the aquaculture feed sector is consuming about 6.8 million tonnes of soybean meal (23.2 percent of total compound aquafeeds by weight). Other plant proteins that are being increasingly used include corn products (such as corn gluten meal), pulses such as lupins and peas, oilseed meals (rapeseed meal, cottonseed, and sunflower) and protein from other cereals products such as wheat, rice and barley.

57. At present, plant protein/oil choice and selection are based upon a combination of local market availability and cost, and the nutritional profile (including antinutrient content and level) of the protein meal and/or plant oil in question. With the continued rise in the price of fishmeal, plant protein concentrates will gain more and more prominence over regular plant protein meals within aquafeeds for high trophic level cultured species and crustaceans (includes soybean protein concentrate, canola protein concentrate, pea protein concentrate and corn/wheat gluten meals). For example, the projected demand for soybean protein concentrates within aquafeeds is over 2.8 million tonnes by 2020.

Conclusion

58. Although the discussion on the availability and use of aquafeed ingredients often focuses on fishmeal and fish oil resources (including trash fish), considering the past trends and future predictions, sustainability of the aquaculture sector is more likely to be closely linked with the sustained supply of terrestrial animal and plant proteins, oils and carbohydrate sources for aquafeeds. Aquaculture sector should therefore place major emphasis to ensure sustainable supply of terrestrial and plant feed ingredients.

59. Apart from ensuring the sustained availability of feed ingredients (including fishmeal and fish oil) to meet the growing demand of aquaculture, the other important areas that need to looked into are:

- development of coping strategies and farmers' resilience to increase/fluctuation in raw material prices,
- addressing the poor supply chains of feed and feed ingredients, particularly in case of sub-Saharan countries so that the farmers/and small-scale feed manufacturers have better access to feed and feed ingredients,
- ensuring national quality standards for feed raw materials, feed additives and feeds,
- facilitating safe and appropriate use and reliable quality of aquafeeds produced by small-scale feed manufacturers,
- improving on-farm feeding and feed management practices and transfer of technology at farmers' level,
- feed formulation and production (e.g., farm-made feed, semi-commercial feed) at local level, and
- building the capacity of small-scale feed manufacturers and provision of support services to improve their production technology in countries of Asia and sub-Saharan Africa.

Issues to be addressed

Continued emphasis on alternatives to fishmeal and fish oil

60. Aquaculture should continue to search for alternative sources of affordable and high-quality plant and animal-based feed ingredients to replace fishmeal in aquafeeds. However, much of these researches have been carried out on plant feed ingredients to enhance their nutritional quality with significant successes; it is therefore imperative that equal priority should be given to improve quality of terrestrial products/by-products considering that total usage of terrestrial animal by-product meals and oils within compound aquafeeds is less than 1 percent of total global compound aquafeed feed production.

61. Continued research on fish oil substitute will be a priority to maintain the quality of farmed target species in respect of HUFAs in the final products as it is projected that the overall total usage of fish oil in aquaculture will increase although the fish oil inclusion level in different carnivorous fish and crustacean species is expected to decrease.

Reduce country dependence upon imported feed ingredient sources

62. Encourage to reduce developing country dependence upon imported feed ingredient and fertilizer sources within compound aquafeeds by encouraging outreach and training opportunities to maximize the use of locally available feed ingredient sources as feed inputs. Local knowledge complemented by research would help.

Give special attention to small-scale farmers using farm-made and semi-commercial aquafeeds and assist small-scale aquafeed producers

63. Merits and demerits aside of using farm-made and semi-commercial aquafeeds, there is an urgent need to assist and train the resource-poor farmers using farm-made and semi-commercial aquafeeds not only for improving feed formulation and minimizing the use of unnecessary feed additives and chemicals (including antibiotics), but also for improving feed management techniques. There are needs to further improve farm-made feeds through research and development programmes focusing on factors such as ingredient quality, seasonal variability, marketing and storage, and improvements in processing technology. The R&D efforts need to be supported by improved extension services. There is also a need for support services to build the capacity of small-scale aquafeed producers to improve their production processes.

Minimize environmental and ecosystem impact of feeds and feeding regimes

64. Minimize environmental and ecosystem impact of feeds and feeding regimes. This may include a) use of highly digestible feeds ingredient sources, b) integration of production with cultured species which can benefit from nutrient waste streams from the former and c) culture of fish under closed floc-based zero-water exchange culture conditions.

Diversification of feed and fertilizer resources

65. Promote the diversified utilization of feed and fertilizer resources through research, extension and information on nutritional requirements of farmed species and nutrient availability of the feed materials.

Guidance sought:

66. The Sub-Committee is requested to review the document, consider national situations and importance of addressing the issue of feeding future aquaculture at all levels, and guide and advise the Secretariat on how to improve FAO’s contribution in the field of feeding tomorrow’s fish towards improving the overall aquaculture sector sustainability, globally.