# Part II – Invited guest lectures

# Is feeding fish with fish a viable practice?

## Invited Guest Lecture 1

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## Abstract

The use of fish as feed for aquaculture is controversial. Some say that the practice should be reduced or stopped, arguing that it is not in the interest of consumers who otherwise would have eaten the fish used. Capture fisheries produces some 90–95 million tonnes of fish per year of which between 20 and 25 million tonnes are processed into fishmeal and oil. During the last two decades, a growing portion of the world's fishmeal and oil has been converted into fish and shrimp feed. Most of the 25–30 million tonnes are obtained by industrial fisheries in the North Atlantic and in the Pacific Ocean off South America. In Asia, by-catch, particularly from trawl fisheries for shrimp, is used as fish feed. It is believed that this may be on the order of 6 million tonnes/fish/year.

The farming of carnivorous fish and shrimp uses more fish as feed than is produced as finfish or shrimp. However, if the fish used as feed would not be consumed as food, then its use as feed might in the end lead to more food fish. Industrial fishing for forage species via manufacture of fishmeal and fish/shrimp feeds brings about a net contribution of food fish supplies without causing a systematic collapse of the exploited species. However, the practice of using bycatch as feed has apparently led to a decrease in the availability of fish as food for the very poor in some regions of Asia. Also, the ever-expanding demand for fish as feed is thought to endanger the long-term sustainability of targeted fish stocks.

Much of the "forage fish" used to produce fishmeal is edible. If this fish could be made available as low-cost food to the poor, no doubt their food security would improve. Aquaculture contributes about half of the world's seafood. Doubtlessly,

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the price of all fish would be substantially higher today if aquaculture did not exist. Most governments see unemployment as a problem; thus, jobs in feed fisheries, fishmeal/fish oil industries, fish/shrimp feed industries and aquaculture are positive contributions. In the absence of fishmeal/fish oil, most of these employment opportunities would likely not exist.

**KEY WORDS**: *Aquaculture, fish as feed, fishmeal, fish oil, forage fish, poverty eleviation, sustainability.*

## Introduction

### The issue and its context

The use of fish as feed for finfish and crustaceans is not uncontroversial. Many in the general public find it difficult to accept the practice of feeding fish to fish or shrimp instead of providing it as food to the poor and the starving. This feeling of unease is based on the idea that the practice reduces the quantity of food fish offered to the general public, as it is affirmed that more than one kilogram of fish – in the form of feed – is needed to grow one kilogram of carnivorous fish or shrimp in captivity. Also, the ever expanding demand for fish as feed is thought to endanger the long-term sustainability of fish stocks harvested to provide raw material for fishmeal and oil.

The author will analyse these arguments, focusing on feeds that are produced using fish landed by industrial fisheries and on those feeds that include fish obtained as bycatch. Consequences will be studied primarily in terms of (i) quantities of fish made available as food, and (ii) the employment that is created – or lost – in the process.

### Fish used as feed instead of as food

Not all fish is used directly as human food. Yearly, capture fisheries produce some 90 to 95[1] million tonnes. Of this, somewhere between 20 and 25 million tonnes of fish[2] are regularly processed into fishmeal and oil. During the last two decades, a growing portion of the world's fishmeal and oil has been bought by the fish/shrimp feed industries and converted into fish and shrimp feed[3]. Most of the fish provided to the fishmeal plants is obtained by industrial fisheries in the North Atlantic and in the Pacific Ocean off the west coast of South America.

[1] Unless otherwise stated, all data on fish landings and aquaculture production are taken from databases published by the Food and Agriculture Organization of the United Nations (FAO).

[2] FAO reports on the use of fish in two categories: "for human consumption" and "for other purposes". This second category in some contexts is broken down into: "reduction" and "miscellaneous purposes". The figures quoted above refer to fish used for "reduction", that is for processing into fishmeal and oil. The amounts of "bycatch" used as feed for fish would fall into the second category.

[3] The International Fishmeal and Fish Oil Organization has estimated that in 2008 about 59 percent of the world fishmeal production was used by aquaculture. The corresponding figure for fish oil was 77 percent.

In East, Southeast and South Asia, bycatch, particularly from shrimp fisheries, is used as fish feed. Although there are no official statistics quantifying the magnitude of this practice in the countries concerned, it is believed to be on the order of 5 to 6 million tonnes/fish/year (Tacon, Hasan and Subasinghe, 2006). Some of this fish is converted into fishmeal, often of a crude variety, but most is fed raw, as part of farm-made fish feeds.

Finally, whole or chopped fish is used in growing quantities to feed captured juveniles of bluefin tuna. This practice, which is found in the Mediterranean, off Baja California in Mexico and along Australia's south coast, uses on the order of 0.3 to 0.4 million tonnes of fish annually as feed.

## The argument

As mentioned above, there are two basic arguments against using fish as aquaculture feed: (i) it reduces the amount of fish available as food, particularly for the poor and (ii) the growing pressure for fish as feed will lead to overexploitation of forage species and threaten the future supply of fish.

The first argument – that the volume of fish as food falls as fish is used as feed – rests on the observation that frequently more fish is used as feed than is obtained as fish (or shrimp) on aquaculture farms; e.g. so many kilograms of fish (e.g. anchoveta) are used to produce a smaller quantity of salmon. The comparison implies that at the moment that the anchoveta (which is a small, delicate fish with a short shelf-life) or the menhaden is supplied to the fishmeal and oil plant, it could have been supplied to a local fish market and sold to waiting consumers. Ninety-nine times out of a 100 this is not the case. There is no market that could absorb, as food, the millions of tonnes of fish concerned. To put this another way: if there were no demand for fish as raw material for fishmeal and oil, the fishery for most forage species would stop.

Thus, it is important to understand that often even cheap fish (less than USD100 per tonne at dock-side) does not find its way into the diet of the poor. If we are concerned with supplying fish to the poor, we must of course be convinced that any additional fish we produce for that purpose actually finds its way to the food basket.

The first "basic" argument (above) is about how to maximize the quantity of fish that consumers will actually buy. It is not about maximizing the absolute amount of fish landed (in the long or short run) – it is about increasing the portion that is in fact accepted as human food. It will be seen that aquaculture, in fact, is an efficient method to transform unwanted fish into fish or shrimp acceptable as human food. It is a fact that until now the usual situation is that more fish is needed (in terms of live-weight equivalent) as feed than is obtained as food through the culture of shrimp or carnivorous fish. This fact would seem to clinch the argument that aquaculture reduces the availability of fish[4].

In its simplicity, the argument is appealing, but it ignores two fundamental facts: first, consumers must want to eat the fish (now used as fish feed) and second, they must have the money needed to pay the price the fisher and the processor/ trader requires to cover the cost of production in the long run. The consumer must have an income, preferably in the form of cash, as barter is cumbersome. There is no point in having food fish available if it is not purchased, as it will then be of value to no one. So we should rephrase the issue; the author understands a more precise formulation of the first issue to be "does the use of forage fish as fish feed continuously and consistently reduce the amount of fish available and purchased for human consumption?"

## How much food fish? viability measured by the quantities of food fish consistently made available (and purchased) through the use of fish as feed

### Industrial fisheries: effects on food supplies

Industrial fisheries exploit small pelagic species, of which raw material for fishmeal and fish oil comes from some 14 species. Let us classify these species into three groups: (i) forage species not eaten as food as "industrial-grade forage fish", (ii) species also marketed as food as "food-grade forage fish", and (iii) fish with a regular market as food but which at times is also processed into fishmeal and oil as "prime food fish" (Table 1).

#### *Industrial-grade forage fish*

There are several forage species not in demand as food that are virtually exclusively used as raw material in fishmeal and oil production. Among these, the most significant are the menhaden (*Brevoortia* spp.), fished off the southeastern United States of America, and sandeels (Ammodytidae), fished off the Danish west coast. During the period 2003–2007, the average landings amounted to 0.65 million tonnes for menhaden[5] (FAO, 2009a). Sandeel landings in Denmark amounted to about 0.6 million tonnes at the turn of the century, then fell drastically, but in 2009 had reached about 0.3 million tonnes[6].

[4] However, this is not a rule for each and every species. It is a rule that applies on the average. For some species and culture systems, it applies, for others, it does not. If 100 kg of anchoveta would produce 20 kg of fishmeal, this meal is used in a fish feed with an inclusion rate of 10 percent and the feed conversion ratio (FRC) is 1.6, then 100 kg of anchoveta would yield 125 kg of fish. The explanation is of course that only 10 percent of the feed is fish – the rest is also important. But in this discussion opportunity costs are not placed on ingredients other than those originating in fish. This is of course somewhat unrealistic.

[5] Gulf menhaden (*Brevoortia patronus*) and Atlantic menhaden (*B. tyrannus*).

[6] Danish Ministry of Fisheries, home page: www.Fvm.dk/English.

It seems to be beyond dispute that by converting these species to fishmeal and oil and then using part of that meal in fish feeds, the world ends up having more food fish than if this practice were not undertaken. The amount of industrial forage fish involved is on the order of 1.2 million tonnes per year; see Table 1). If 60 percent of the resulting meal would be used in fish feeds, the additional annual supply of food fish would be on the order of 0.7 million tonnes[7]. Equally, it is beyond doubt that if there were no fishmeal plants willing to use these species as raw material, the fisheries for them would cease.

**TABLE 1**
**Volume of fish landed and estimates of quantities converted to fishmeal and oil, average for 2001–2006 classified by degree of acceptability as human food, for 14 countries with largest fishmeal production**

| | Country reporting landings | Landings (tonnes) | % of landings converted into fishmeal & oil[1] | Tonnes converted into fishmeal & oil |
|---|---|---|---|---|
| | | Average 2001–2006[2] | | |
| **Industrial-grade forage fish** | | | | |
| Sandeels (*Ammodytes* spp.) | Denmark | 387 500 | 100 | |
| | Faeroe Islands | 7 000 | 100 | |
| | Sandeels | 92 000 | 100 | |
| Gulf menhaden (*Brevoortia patronus*) | USA | 479 000 | 100 | |
| Atlantic menhaden (*B. tyrannus*) | USA | 212 000 | 100 | |
| Norway pout (*Trisopterus esmarkii*) | Norway, Denmark, Faroe Islands | 52 000 | 100 | |
| **Total** | | **1 229 500** | **100** | **1 229 500** |
| | | | | |
| **Food-grade forage fish** | | | | |
| Anchoveta (*Engraulis ringens*) | Peru | 7 200 000 | 98 | 7 056 000 |
| | Chile | 1 268 000 | 98 | 1 243 000 |
| Japanese anchovy (*E. japonicus*) | China | 1 142 000 | *67* | 765 000 |
| | Japan | 425 000 | *50* | 212 500 |
| European anchovy (*E. encrasicolus*) | South Africa | 228 000 | *50* | 114 000 |
| | Morocco | 18 500 | *50* | 9 000 |
| Anchovies (Engraulidae) | Thailand | 155 000 | *50* | 77 500 |
| Sardinellas (*Sardinella* spp.) | Thailand | 128 000 | *50* | 64 000 |
| Capelin (*Mallotus villosus*) | Norway | 229 000 | 50 | 115 000 |
| | Iceland | 665 000 | 75[3] | 500 000 |
| | Faeroe Islands | 36 500 | 100 | 36 500 |
| | Canada | 28 000 | 0 | 0 |
| Blue whiting (*Micromesistius poutassou*) | Norway | 720 000 | 100 | 720 000 |
| | Iceland | 359 000 | 95[3] | 341 000 |
| | Denmark | 65 000 | 100 | 65 000 |
| | Faeroe Islands | 254 500 | 100 | 254 500 |
| European sprat (*Sprattus sprattus*) | Norway | 5 000 | 100 | 5 000 |
| | Denmark | 257 500 | 100 | 257 500 |
| **Total** | | **13 184 000** | **89.8** | **11 834 500** |

7 See Table 3 for the parameters.

**TABLE 1 (Continued)**

| | Country reporting landings | Landings (tonnes) | % of landings converted into fishmeal & oil[1] | Tonnes converted into fishmeal & oil |
|---|---|---|---|---|
| **Prime food fish** | | | | |
| Chilean jack mackerel (*Trachurus murphyi*) | Peru | 274 000 | | |
| | Chile | 1 475 000 | | |
| | China | 121 000 | | |
| Chub mackerel (*Scomber japonicus*) | Peru | 87 000 | | |
| | Chile | 418 000 | | |
| | China | 442 000 | | |
| | Japan | 432 500 | | |
| | Mexico | 24 000 | | |
| Japanese jack mackerel (*T. japonicus*) | China | 109 000 | | |
| | Japan | 211 000 | | |
| South American pilchard (*Sardinops sagax*) | China | 182 000 | | |
| | Japan | 68 500 | | |
| | South Africa | 263 000 | | |
| | USA | 85 000 | | |
| Pacific herring (*Clupea pallasii pallasii*) | China | 46 000 | | |
| | USA | 37 000 | | |
| | Japan | 4 000 | | |
| | Canada | 24 000 | | |
| Indian mackerel (*Rastrelliger kanagurta*) | Thailand | 155 000 | | |
| Atlantic herring (*C. harengus*) | USA | 96 000 | | |
| | Iceland | 238 000 | 50[3] | 119 000 |
| | Denmark | 135 500 | | |
| | Canada | 187 000 | | |
| | Mexico | 471 000 | | |
| Cape horse mackerel (*T. capensis*) | South Africa | 26 000 | | |
| European pilchard (*Sardina pilchardus*) | Morocco | 639 000 | | |
| **Total** | | **6 250 500** | | |

[1] Figures in italics are "guesstimates" by the author and should be verified.
[2] *Source*: Perón, Mittaine and Le Gallic (2010).
[3] *Source*: www.fisheries.is/main-species/pelagic-fishes

## *Food-grade forage fish*

The second category of fish used as raw material for fishmeal and oil production is the "food-grade forage fish". These are species that people eat, albeit for which demand is small and often localized. Generally, the quantities that can be harvested yearly by industrial fishing vessels far outstrip the demand for these species as human food. The most well-known example is the fishery for the anchoveta (*Engraulis ringens*). In the Pacific Ocean, anchoveta is the principal "food-grade forage species". During the period 2003–2007, the average landings of anchoveta were 8.3 million tonnes (landings in Peru and in Chile, Table 1).

Although it is a food-grade fish, only a very small amount is eaten. Peruvian consumers probably could eat somewhat more, but are not willing to do so, in spite of decade-long efforts by the public sector and the industry to develop alternative products and find new markets.

There is no realistic scenario under which the Peruvian population would be able to consume 7–8 million tonnes of anchovies in a year. The per capita consumption of anchoveta would need to reach about 0.75 kg/person/d. Peru has a well-established fish canning industry[8]. It is present on the world market, but has not, despite much effort, managed to create a significant international market for canned anchoveta.

Elsewhere, several species of anchovy (Engraulidae) have high-priced niche markets world-wide (salted, smoked or processed into paste, butter, cream, etc.), but in absolute terms the quantities handled in these niche markets are small.

In the North Atlantic, the three principal species in this category are European sprat (*Sprattus sprattus*), blue whiting (*Micromesistius poutassou*) and capelin (*Mallotus villosus*). Over the five year period 2003–2007, the average landings of sprat were about 0.6 million tonnes. In Sweden and Denmark, a few percent of landings are supplied as food, while in Finland, most of the landings are used as feed in mink farms (European Parliament, 2005). Blue whiting is processed into fishmeal or offered for human consumption, depending on where it is landed. In continental Europe (Netherlands, France, Germany, Spain and Portugal), the fishery is mainly for human consumption, while landings in the United Kingdom, Ireland and Denmark are traditionally destined for processing into fishmeal (EU Parliament, 2005). Canada, Norway, Iceland and the Faeroe Islands fish for capelin. During the period 2001–2006, their combined average landings were 0.93 million tonnes (Perón, Mittaine and Le Gallic, 2010). In both Iceland (FAO, 2009b) and Norway, the share used as food is slowly increasing.

In respect of "food grade forage fish", it does not seem as if the fishmeal industry is withdrawing fish that food fish markets could have absorbed. The reverse seems to be the case: fishmeal plants make use of fish that the fresh fish market and the fish processing industries cannot absorb. This is definitely the case for the 8–10 million tonnes of fish that are processed yearly into fishmeal in Peru and Chile. It also seems likely to be the case for several of the "food-grade forage species" caught elsewhere.

The 14 largest producer countries for fishmeal and oil during the period 2001–2006 seem to have been using about 12 million tonnes (see Table 1) of "food grade forage species" to produce fishmeal and oil. Accepting that 60 percent of

[8] In 2008, 73 canning factories processed 197 000 tonnes of fish (FAO Fishery Country Profile, Peru, in press).

the fishmeal is used by the aquaculture industry, this means that currently the industry provides at the very minimum about 7 million tonnes of aquaculture produce, which would not have been supplied in the absence of the world's fishmeal industries.

### *Prime food fish*

World-wide, species like sardines, herring and mackerel are considered as high-quality food fish, and there are well-established food fish markets for these species. Nevertheless, smaller or larger quantities of these species and other prime food fish intermittently end up as raw material in fishmeal and oil manufacture.

The manner in which prime food fish is exploited differs from region to region and is essentially a consequence of the nature of the market for the product in the region where the fish is landed. In regions with low population densities but with ample fish resources (e.g. west coast of South America, southwest coast of Africa) much of the fish ends up as raw material for fishmeal. In other regions (e.g. Europe, North Africa, the United States of America) where relatively large populations can be reached from fish landing centers, the fisheries are organized as food fisheries, and one could expect that the "prime food fish" should not end up as fishmeal[9].

There are two main reasons that it does: large fluctuations in landings and the extreme perishability of several of the species. The large fluctuations in landings mean that for economic reasons shore-based facilities are not constructed to a scale such that the largest of catches – which occur only for a short period each season – can be handled. So annually, there are periods when landings exceed the volumes that can be processed as food and, as they travel badly, the best alternative becomes processing them into fishmeal. This seems to happen regularly to landings of European pilchard (*Sardina pilchardus*) in Morocco[10].

During the period 2001–2006, the 14 main fishmeal and oil producing countries landed an average of 6.25 million tonnes of sardines, mackerel and herring. There are no comprehensive and global statistics indicating what proportion of these landings are regularly used as food.

[9] In fact, for this group of species, availability for industrial processing is likely to decline over time as demand for the species as food increases. An example is found in Norway "where 80 percent of herring catches were used for oil and meal some 20 to 25 years ago, while today the picture is reversed: 80–85 percent goes to human consumption and the remaining (bad quality) for oil and meal." (Bjørn Hersoug, personal communication, August 2009). However, during the second half of the first decade of the current century, the international fishmeal price trebled. This has increased prices paid for forage fish and reduced the volume of cheap fish available as food.

[10] Atmani, (2003) describes this situation for Morocco "When the raw material is at a low level, the canning plants work on a rotation basis as during the low season; when there is a glut of landings a considerable part of the catch goes to fishmeal."

## Why isn't more forage fish sold as food?

"Industrial-grade forage fish" has no viable markets as food. So fishing for them is viable only if the species is used as raw material for fishmeal and oil. "Food-grade forage fish" are generally considered low-quality fish, and consumers prefer other, more expensive species, when they can afford them. As these species are abundant, they provide a source of livelihood for fishermen, but then they rely on the fishmeal and oil industries to absorb most of the catches, even if prices at quay-side are low[11]. In densely populated and prosperous regions, "prime food fish" are exploited for the food market; but sardines, mackerels and herring are cheap fish compared to other marine prime food fish. Nevertheless, most skippers and owners of fishing vessels have an interest in selling "prime food fish" catches to the food markets, as prices in these markets generally are superior to those offered by fishmeal manufacturers[12] (Hasan and Halwart, 2009). Naturally, to sell into these markets, the fish usually has to be in better shape than what is demanded by the fishmeal and oil industries, and that may mean higher costs for the skipper/vessel owner.

## Other arguments against use of fish as feed

### *Leave the fish in the water*

There is another argument advanced against the use of forage species as fish or shrimp feed. It says: "Let all these forage species remain in the water. They are prey for other fish which consumers want to eat and which will be caught". It might be possible to catch a larger amount of the predators if industrial fishing ceased for key prey species, but as the conversion ratio in the wild is on the order of 10 kg of prey to 1 kg of food fish, the aquaculture alternative is much more productive. It provides at least about 6 kg[13] of additional fish for every 10 kg turned into fishmeal and oil (allowing for a 40 percent "loss" of fishmeal as feed for livestock and other uses).

### *It is morally wrong to feed fish to fish and crustaceans*

The last argument is ethical in nature. It affirms that it is not equitable that fish is fed to fish when people are starving. If so, then there is a moral obligation on those who catch and sell fish to provide it to those who need fish in order to have a nutritionally adequate diet.

It is often not clear whether this argument assumes that the poor shall receive the fish free of charge, at a subsidized price or pay the full costs. Providing large quantities of fish free of charge is expensive. If some 8 million tonnes of anchoveta were supplied yearly to the one billion hungry in the world, it would provide them with about 8 kg/person/year (live-weight equivalent). If the fish

[11] In Denmark, prices for forage fish fluctuated between Euro 80 and 130 per tonne during the period 1996–2002 (European Parliament, 2005).

[12] In Norway, capelin supplied as food pay better than capelin sold for reduction (www.nofima.no/marked/en/nyhet/2010/06/).

[13] See Table 3 for the parameters.

were to be supplied in the form of canned products, the annual cost would be on the order of USD25 billion per year[14]. This does not look like a financially feasible alternative[15], no matter how beneficial for the recipients. In addition, a subsidized product – canned or in another form – would, even if the quantities were much more modest, most likely be challenged under World Trade Organization (WTO) agreements; and this could happen even if the product did not enter international trade.

In summary, it seems clear that using fish landed by industrial fisheries in North America, Europe and on the west coast of South America as feed for food fish and crustaceans in the long run significantly expands the effective supply of fish for human consumption. The addition seems to be at least on the order of between 7 and 8 million tonnes of fish per year. If industrial fishing came to a halt world-wide, this would cause a closure of much of the fish feed and fishmeal and oil industries. It would also lead to an immediate annual loss of fish as food. In the long run, supplies of fish as food would increase, drawing upon the increase supplied from the fish now converted to fishmeal; however, this growth would be slow, as it would be dictated by population growth combined with rising living standards and would compensate for only a part of the fish lost.

If the global society wants to abruptly change the present pattern of using forage fish and ensure that "food-grade forage fish" is used as food upon capture instead of as feed, two actions would probably be necessary: (i) an agreement under the WTO that "food-grade" forage fish can be sold in subsidized form in specific countries; and (ii) a commitment that grants be provided in amounts required to subsidize fish processing companies dedicated to increasing the volumes of food produced from small pelagics. Such a decision would add to the supply of fish for human consumption, but the addition would be smaller than the amount of fish processed for human consumption, as a reduced supply of raw material for fishmeal and oil plants would result in a reduction in aquaculture production by an amount equal to between one quarter and one third of the fish processed as food.

## Industrial fisheries: long-term effects on sustainability

It is soon 40 years ago that a dramatic and rapid collapse of the Peruvian anchovy fishery supplying local fishmeal and oil factories drew the attention of the world to the effects of unregulated fishing. Since then all major industrial fisheries for small pelagic species have come under management. In the United States of America, authorities manage the fisheries for menhaden. In the Northeast Atlantic, the North Sea and in the Pacific off the west coast of South

[14] The "back-of-the-envelope" calculation: 10 kg of fish is equivalent to 3.3 kg in canned form. Each kg of canned product is retailed at the equivalent of USD1 per 100 g or USD10 per kg, so each individual receives canned fish worth USD26 per annum. For one billion poor, thus the total amount is USD26 billion.

[15] The annual budget of the World Food Programme for 2008 was USD2.9 billion

America, industrial fisheries[16] are all subject to an array of fishery management mechanisms (*inter alia*, total allowable catch (TAC), Area Catch Limits, minimum mesh size and satellite tracking) based on stock assessments carried out by the International Council for the Exploration of the Sea (ICES) (Europe), the Instituto del Mar del Perú (IMARPE) (Peru) and the Instituto de Fomento Pesquero (IFOP) (Chile).

These management measures, in and by themselves, will not undo what has been done in the past. Neither will their promulgation ensure sustainability of the stocks concerned. Many skippers participating in these fisheries are, like most capture fishermen, subject to perverse incentives. Therefore public resources must be deployed to enforce these regulations. However, the likelihood that stocks will collapse because of too much fishing effort has been drastically reduced during the past 40 years through the introduction of fisheries management. Also the fishmeal and oil industry needs a sustainable fishery. It is not served by a collapse of the fish stocks that it needs to harvest year after year. Thus, the industry can be counted on to be a moderating factor vis-à-vis the fleet sector.

## Farm-made feeds using bycatch: effect on food supplies

When bycatch has no or very low value, fishermen usually discard it back into the sea. This will also happen to commercial species if on-board storage space is a constraint or if management regulations dictate that only a certain quantity of fish can be caught and smaller specimens are worth less per kilogram than larger ones.

Traditionally, retained bycatch has provided food for the poor in and around fishing centers, particularly in Africa and Asia. Bycatch was either cured (salted, dried, smoked) or consumed fresh. This is still the situation in most of sub-Saharan Africa, as culture of marine shrimp and marine fish has not yet reached significant volumes in most coastal countries.

In Asia, the situation today is different. As culture of marine shrimp and marine fish spread, so did the practice of preparing farm-made feeds, and trash fish became a common ingredient (New, Tacon and Csavas, 1994). Estimates from the mid-1990s have placed the amount of low-value fish used in aquaculture at 5 to 6 million tonnes per year (Tacon, Hasan and Subasinghe, 2006). It is not clear how much of this low-value fish is converted into fishmeal and how much is fed directly to fish and shrimp. However, it seems that while bycatch of small pelagics (and trimmings) may be a source of raw material for the modern fishmeal and oil industry in Europe and South America, this is rarely the case in Africa and Asia. This is not to say that some bycatch in South, Southeast and

[16] For capelin, blue whiting, sandeel, sprat, herring, Norway pout, anchovy, jack mackerel and sardine (Fin Dossier, 2008).

East Asia (and then often not small pelagics) may not be reduced to fishmeal in artisanal fishmeal units. Such fishmeal, however, is not well suited as an ingredient in shrimp and fish feeds.

If stopping this practice would have the consequence that between 5 and 6 million tonnes of fish were added to the food market, then the practice causes a significant drain on food supplies. Also, it is not compensated by the aquaculture production that it will have generated[17], particularly as the produce (marine shrimp, prime finfish) will be priced well beyond what the poor can afford in fishermen communities and adjacent rural areas and towns.

However, not all of this low-value fish is bycatch; some is the product of directed fisheries. Apparently, the most important directed fisheries for low-value fish exists or existed in Viet Nam[18], yielding up to 0.6 million tonnes/year. In other fisheries, the crew may have retained bycatch that they would normally return to the sea, in order to sell it for feed use. The portion of the 5 to 6 million tonnes that has been made available because of this effect is not known. Although studies do not seem to be available, if the use of low-value fish or bycatch for aquaculture feed were to be stopped suddenly, it seems likely that in the long run the full 5 to 6 million tonnes would not be available as food. The amount that would become available would be somewhat lower, possibly between 4 and 5 million tonnes.

### Juveniles of commercial food fish: a bycatch component

Juveniles of commercial species are frequently part of the bycatch. If the use of bycatch as a source of low-cost fish for aquaculture feed does not lead to any modification of the fishing undertaken before this practice was started, then the use of fish as feed cannot be labelled as a cause of decreased commercial landings of the target species. However, if the use of bycatch as fish feed causes an increase in the fishing effort and possibly an increased targeting of the "bycatch" (including the juveniles), then it would seem appropriate to consider the net loss of food fish caused by this practice as equivalent to a net loss of food fish in the concerned fisheries, a loss that is likely to be several times the volume of cultured shrimp and fish obtained from fish feeds composed of juveniles. However, the author has not found quantitative data on this feature of bycatch, and it is not further considered here.

In summary, most likely, the practice of using low-value fish as fish and shrimp feed has led to a decrease in the availability of fish as food for the very poor but

[17] On the order of 3.0 million tonnes if the feed was used exclusively for shrimp and marine fish and the efficiency is similar to that obtained from industrial feeds incorporating the same amount of raw fish but in the form of fishmeal (between 2.8 and 3.4 million tonnes using parameters from Table 3). However, some dried fish/artisanal fishmeal is also used in traditional and semi-intensive culture of catfish and carps (Hasan, 2007).

[18] Source: Presentation given by M.S. Dao, V.T. Dang and D.B. Huynh Nguyen. Some information on low value trash fish in Vietnam,given at the Regional Workshop on Low Value and Trash Fish in the Asia Pacific Region. Hanoi, June. 2005.

possibly also for others in some regions of South, Southeast and East Asia. The quantities are significant; 4.5 million tonnes over a year could deprive 1 billion individuals of 4.5 kg fish/person/year (live weight equivalent)[19]. From the point of view of these consumers, this reduction is not compensated by the 3 million tonnes or so of aquaculture produce, as the species produced are generally priced far above what poor, local consumers can afford.

## Farm-made feeds using bycatch: long-term effects on resource sustainability

Bycatch (particularly from trawling) frequently includes immature specimens of commercial species. This is a fisheries management problem that is difficult to address, but partial remedies exist, and the problem can be contained and reduced in severity. If it is not, and the use of bycatch in farm-made feeds causes an increase in fishing effort[20] – in order to sell bycatch to those who make farm-made feeds – then aquaculture can be held responsible for jeopardizing the sustainability of the concerned food fisheries. The severity of this naturally varies from case to case and is a function of the initial status of the stocks and the intensity of the bycatch problem. Again, the question becomes empirical: what is the extent of this problem? The author has not found any reply to this question in the literature.

### Whole fish as feed for bluefin tuna: effects on food supplies

As farmed Atlantic bluefin tuna (*Thunnus thynnus*) is fed on fish, the conversion factor is low; reported FCRs varying from 1:7 to 1:20 (Tacon, Hasan and Subasinghe, 2006). In this discussion, the author will use an FCR of 1:15, meaning that, on average, 15 kg of raw fish would be needed to obtain 1 kg weight gain for the captive bluefin tuna.

No agreed statistics seem to exist as to the global production; however, just after the turn of the century, there seemed to be a consensus that production had reached about 20 000 tonnes/year (Halwart, Soto and Arthur, 2007) in the Mediterranean, which probably accounted at the time for about two-thirds of the global production. Global production has grown, but by how much? In order not to underestimate the amount, let us assume that production is 50 000 tonnes globally.

Tuna is fattened mostly on sardines, but also on horse mackerel, squid and other food-quality forage species. So, the "loss" of food fish is undisputable. To the author, it seems difficult to argue otherwise. The reason is that capture fisheries stagnate, while consumption of fish increases steadily by a few percent

[19] About the same as one quarter of the global average consumption for about 15 percent of the world's population.

[20] In the form of longer fishing hours or gear modifications intended to result in more bycatch, which then becomes target catch.

a year, thanks to aquaculture. No doubt in the long run, food-grade forage fish now fed to bluefin tuna could find markets as human food.

How much fish is used as feed? Although the size of tuna, both when stocked and harvested, varies considerably, except for a small Japanese production, other practices all seem to aim (at the most) to double the weight of the stocked species. That means that the weight gain for the industry as a whole might have been on the order of 25 000 tonnes and the amount of feed fish used, some 375 000 tonnes. By most measures, this is a significant amount of fish, if directed to the food fish market instead of used for tuna fattening.

### Whole fish as feed for bluefin tuna: effects on resource sustainability

The demand for forage fish as feed for bluefin tuna in pens will have two effects on fisheries for these species. The immediate consequence could be that fish is directed to feed instead of to food use. However, the extent of such a reaction depends in turn on both institutional factors and on the state of the concerned stocks. The second consequence is an increased overall fishing effort on the concerned stocks, or at least this will develop an incentive to increase the fishing effort. It is this incentive that can create problems where the stock is already fully fished and management is absent or ineffective. Given the volumes used to date and the geographical spread of the activity, the risk of a stock collapse seems low.

## Who can afford the fish?: viability measured by affordability

So far in this analysis, we have established: (i) that use of fish for producing fishmeal and oil on the whole increases the supply of food fish, and the order of magnitude is about 8 million tonnes/year; (ii) that the use of bycatch as aquaculture feed reduces the supply of fish as food by some 1 to 2 million tonnes annually; and, (iii) that fattening of bluefin tuna reduces the supply by some 0.4 million tonnes/year. Taken together, total food fish supply is increased. However, in the market fish has a price[21], so of paramount interest is “at what price is this additional fish made available?”, or phrased differently, “who will eat the ‘additional’ fish generated through the use of fish as feed for crustaceans and finfish?”

Most of the high-quality fattened bluefin tuna will be eaten in Japan in high-priced restaurants. However, the other products that rely heavily on fish protein (e.g. salmon, shrimp, seabass, seabream) are also not low-cost species. Although these species are not the high-cost items they used to be, it can be

[21] Even the World Food Programme’s (WFP) non-emergency food aid is usually delivered as part of pay packet – that is, not free of charge.

safely argued that as a rule the fish and shrimp produced by the aquaculture industry will not become part of the diet of the poor, and particularly not of the poor in developing countries.

On the other hand, aquaculture today contributes about half of all the seafood eaten in the world. Doubtlessly, the price of all fish would be substantially higher today if aquaculture did not exist. This will have also benefited the very poor. It is agreed naturally, that the merit of this development does not lie solely with the use of fish as feed, as not all aquaculture uses feed or fish in one form or another, as feed[22].

## Viability measured by employment (income earned)

So far the discussion has concerned the consumers. We have looked at the total supply of food fish and quickly, at who, among consumers, benefits or loses as the fish becomes cheaper or more expensive. However, there is another group of individuals involved: those whose livelihood is affected by activities linked to providing fish as feed. They may have found a way to secure their livelihood in aquaculture that depends on fish as feed, or they may have lost one, trading bycatch as food. How they are affected is at least as important as the implications for any other group in society. For many individual consumers, the effects are marginal[23]. They eat a little bit more or a little bit less fish. However, for the fisher, the fish factory worker or the fish trader, the consequences may be much more important; they may gain or lose a source of income and their livelihood.

In this context, it is fundamental to recall the pivotal role of income in the eradication of poverty. That income is important may sound like a truism – and maybe it is. But, what it means in this particular context is that for the poor – rural or urban – a steady source of income is more important in the long run than access to cheap fish or other cheap food (World Bank, 2007) made available in food help programmes, often of limited duration.

## Income earned from feeding fish to fish: industrial fishing

A large number of individuals of different professions have a role to play in the chain of activities that connects the fishery for forage species, via fish feed manufacture and the aquaculture farm, to the consumer. Unfortunately, the extent and nature of the employment that this chain of activities provides is not known with any precision. Few countries systematically collect data on employment for all the various components of the chain[24]. So there is no way of knowing with certainty what employment exists or can be created in this value

[22] With the exception of feed for salmonids, most aquaculture feeds contain more ingredients of plant origin than ingredients originating in marine fauna.

[23] Exceptions made for those among the very destitute who have bycatch as part of their survival diet.

[24] This situation exists in most countries, developed as well as developing.

chain. It seems that the best that can be done is to try to make reasonable estimates[25] based on a few examples.

### *First part of the value chain*

The main components of the "industrial fisheries" value chain are: (i) fishing for forage fish, (ii) converting the fish into fishmeal and oil, and (iii) producing industrial fish and shrimp feeds incorporating fishmeal/fish oil. These activities have in common that they are relatively capital intensive, or looked at from the perspective of labour, they employ relatively few workers. The first two take place at or close to the fishing grounds. The third is not necessarily located at the same place as the fishmeal/oil manufacture.

Industrial fishing for forage fish is productive, when measured in terms of tonnes landed per fisherman and year. In Peru the productivity is close to 100 tonnes per fisherman-year (Wijkström, 2009), while in the European Union (EU), it is on the order of 700 tonnes. The Peruvian fishmeal industry employs people at a rate of about 0.77 man-year per 1 000 tonnes of raw material (Wijkström, 2009). In the EU, total employment is on the order of 250 man-years, giving an employment rate of only 0.14 man-year per thousand tonnes of raw material[26].

The author has no information on the employment in the fish and shrimp feed manufacturing industries. However, although this is likely to be a mechanized activity, given that it takes place closer to the point of use of the food (particularly in Asia), the labour intensity is likely to be considerably higher than for the fishmeal and oil industry. A rate of one man-year per 1 000 tonnes of fish (or 220 tonnes of fishmeal) would give an additional employment of about 8 000 full time equivalents (FTEs) per year.

Thus, the additional employment created in the first part of the value chain by the additional 13 million tonnes of "additional" forage fish procured by the industrial fisheries will be on the order of  100 000 in terms of FTEs.

In summary, the first part of the value chain is not labour intensive. If it disappears, for whatever reason, the economies concerned will notice it, but it will not imply that a major industrial restructuring will follow.

### *Second part of the value chain*

The second part of the value chain starts with the aquaculture enterprise and ends with the retailing of the fish and shrimp produced. The economic

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25 One can build an estimate starting with examples of employment for different activities that are part of the chain. One can also infer a number by considering the value, at retail level, of the final product (aquaculture produce, forage fish sold to consumers, bycatch sold to consumers) and by knowing the cost structure of the various component activities, deduct the maximum number of direct employment that can be paid as a result.

26 See Fin Dossier (2008).

**TABLE 2**
**Additional employment in fishing, fishmeal manufacture and fish/shrimp feed manufacture generated by the processing of 13 million tonnes of forage fish into fishmeal and oil, and of 8 million tonnes of fishmeal into fish/shrimp feeds**

| | Man-years (FTE)[1] per 1 000 tonnes of forage fish | Quantities produced (million tonnes) | Total additional employment |
|---|---|---|---|
| Fishing | 6.25[2] | 13 | 81 000 |
| Fishmeal manufacture | 0.65[3] | 13 | 8 400 |
| Fish/shrimp feed manufacture | 1.0[4] | 8 | 8 000 |
| **Total** | | | **97 400** |

1 FTE = full time equivalent.
2 A weighted average of the productivity in Peru (100 tonnes/fisherman-year) and the EU (700 tonnes/fisherman-year).
3 A weighted average of the productivity in Peru (0.77 man-years to handle 1 000 tonnes of fish) and the EU (0.14).
4 Author's assumption.

characteristics of the culture system used by fish and shrimp farmers differ according to the location – and therefore the surrounding economy – of the activity. Salmon culture in Norway is capital intensive compared to shrimp farming in Southeast Asia, which is labour intensive. Direct employment in salmon culture is low per tonne produced. In the EU, the productivity is on the order of 100 tonnes per person (FTE) and year (SINTEF, 2005); in Norway, it is somewhat higher and in Chile lower[27].

However, indirect employment is considerable. In the EU, the productivity of the processing industries and associated indirect employment was on the order of 12 tonnes per person-year (FTE) (SINTEF 2005).

Information about employment in shrimp culture is spotty. The author has used (Wijkström, 2009) a figure of 1.33 man-years per tonne of shrimp produced. A large part of those employed are manual labourers. To this should be added employment in processing (freezing, canning), storage, transport and sales of shrimp products. These are likely to be considerable. The author has not found any published data on these employment effects and placed them, conservatively, he believes, at equal to those on the farm: 1.33 man-years per tonne of shrimp produced.

Earlier in this article, the author concluded that the industrial fisheries create an additional supply of food fish of some 7 million tonnes annually. The other side of this coin is that a number of individuals earn an income from this additional production.

27 The differences in labour productivity are considerable in the aquaculture sector. For example, fish farmers in Norway have an average production of 172 tonnes per person, while in Chile it is at about 72 tonnes, in China 6 tonnes and in India only 2 tonnes (FAO, 2010).

As can be seen in Tables 3 and 4, most of this employment is generated in labour-intensive aquaculture (shrimp culture) and relatively little in the fishing, fishmeal manufacture and fish and shrimp processing industries. Of the 3.7 million additional employment (FTE), some two thirds occur in shrimp culture. In this context, it is worth noting that while most of the employment takes place in developing, or emerging, economies, most of the fish and shrimp produced are consumed in Organisation for Economic Co-operation and Development (OECD) economies.

**TABLE 3**
**Additional employment in aquaculture (and downstream) enterprises using fish feeds that incorporate fishmeal obtained from processing 8 million tonnes of forage fish into fishmeal and oil[1]**

| | Share of global fishmeal in 2008 (%)[a] | Fishmeal inclusion rate in feed in 2007 (%)[b] | Total amount of feed produced (million tonnes) | Feed conversion ratio (feed produced/ cultured output) (2007)[b] | Total cultured output (million tonnes) | Labour productivity (tonnes/ man-year) | Total additional annual employment (8 million tonnes of forage fish[2]) |
|---|---|---|---|---|---|---|---|
| Salmon & trout | 29 | 24 | 2.67 | 1.2 | 2.22 | 100[c]<br>12[e] | 17 760<br>148 000 |
| Shrimp | 28 | 18 | 344 | 1.7 | 202 | 1.3[d]<br>1.3[e] | 1 240 000<br>1 240 000 |
| Marine fish | 21 | 30 | 153 | 1.9 | 81 | 5<br>10[e] | 129 600<br>65 000 |
| Other | 22 | 5 | 960 | 1.7 | 565 | 10<br>10[e] | 452 000<br>452 000 |
| **Total** | **100** | | **1 724** | | **1 070** | | **3 754 360** |

1 Source: [a]Andrew Jackson, personal communication, July 2009; [b]Tacon and Metian (2008); [c]SINTEF (2005); [d]Wijkström (2009); [e]The productivity existing in associated processing and indirect employment (see text above).

2 In 2008, just above 60 percent of world fishmeal production was used in aquaculture (FIN Dossier, 2008). So of the output produced from the 13.3 million tonnes "additional" forage fish made available to the fishmeal industry annually, some 60 percent would have been supplied to fish and shrimp aquaculture some years ago.

**TABLE 4**
**The employment effect per year of using fish as an ingredient in farm-made feeds: an exploratory calculation**

| | Effect | Volume of fish handled/year (million tonnes) | Labour productivity (tonnes/man-year) | Total employment (million man-years) |
|---|---|---|---|---|
| Directed fisheries | Increase | 1.0 | 10 | 0.1 |
| Preparation of aquaculture feeds | Increase | 6.0 | 15 | 0.4 |
| Curing and retailing low-value fish | Decrease | 5.0 | 7 | ( 0.7 ) |
| Aquaculture | Increase | 3.0 | 3 | 1.0 |
| **Total** | | | | **0.8** |

## Employment from feeding fish to fish: use of bycatch

The employment situation in the chain of activities that start with allocating bycatch to use as fish feed and ends with retail sale (or its equivalent) of the aquaculture produce is less documented than it is for the group of activities supplying fish as feed via preparation of fishmeal and oil.

### *First part of the value chain*

The first part of the value chain consists of the fishing, up to and including off-loading of the bycatch at quay-side (or its transshipment at sea). As has been stated above, employment on board, in terms of number of crew and their activities, does not change greatly because of the use of bycatch as feed. In most situations, the fishing patterns are not altered because of a new use for the bycatch, nor are activities on deck. The bycatch should be separated from the target catch under most circumstances. The same reasoning applies to those engaged in moving the bycatch on quay-side.

This means that once it has reached shore, the end use of the bycatch does not much affect either the number of individuals employed or what they do in the first part of the value chain. However, the fisheries dedicated to the catch of low-value fish to be used as fish feed have a positive employment effect. As these are high-volume fisheries, productivity, measured in tonnes landed per fisherman-year, will be higher than it is for the average Asian fisherman, about 2.5 tonnes/man-year (FAO, 2009b). Using a productivity of 10 tonnes/man-year would mean that 100 000 fishermen would be employed to land 1 million tonnes.

### *Second part of the value chain*

When low-value fish is sold as food, the value chain in its second part consists of transport of fish direct to retail markets and subsequent retailing; or, if direct marketing is deemed unfeasible, the fish is transported to fish-curing sites. In the latter case, labour is involved in the curing – a process lasting days or weeks – and subsequently in transporting (storing) and retailing the final cured product.

The bycatch bought as raw material for feed follows two value chains. It can be taken to fishmeal plants and processed. However, many such fishmeal plants in South and Southeast Asia are rudimentary, and the product frequently does not reach the standards demanded by shrimp and fish farmers. Much of the product is used as feed for chickens and ruminants.

Most of the bycatch or low-value species bought is but one of the ingredients in farm-made fish and shrimp feeds. This value chain includes the preparation of the feed, the subsequent aquaculture activity and ends with the processing and marketing of the aquaculture produce. The transport of bycatch, the preparation of farm-made feeds and the feeding itself are labour-intensive tasks. However, the author has not found any documented facts that permit a comparison of the employment generated by making farm-made feed with the use of labour as low-value fish is brought to markets to be sold as food, in fresh or cured form. His belief is that fish retailing – where mechanization is difficult – is considerably more labour intensive in terms of man-years of employment per unit of bycatch handled than the feed processing alternative – where mechanization is a distinct possibility.

The retailing of bycatch as food is of course not carried out in circumstances similar to those in which cultured fish or high-value finfish are retailed. Retailing of bycatch as food will be considerably more labour intensive. One reason is that the retailing of the aquaculture produce may occur thousands of miles from the place in which the fish or shrimp grew to market size, and where the low-value fish is retailed.

The culture of fish and shrimp constitutes the last part of the value chain. This activity generates employment, and the number of workers involved is considerable, given the large volume of low-value fish that is used. Does it generate more or less work on-farm than does the same amount of forage fish converted into fishmeal and industrially manufactured feeds? Given that the fish, when it arrives at the farm is four to five times heavier when it arrives there in the form of raw fish than as fishmeal, more work on-farm is needed with raw fish. For this same reason, larger aquaculture units soon find it necessary to mechanize the handling of feeds[28]. Also, by necessity manual labourers on farms are not strictly specialized, but perform more than one duty, particularly if they work full time

In summary, the use of low-value fish as feed probably has a positive overall effect on employment. The relatively large loss of employment in processing and retailing of low-value fish as food is compensated by increased employment in three distinct areas: (i) fisheries directed at low-value fish; (ii) the preparation of farm-made feeds (including raw fish), and (iii) increased aquaculture production. An exploratory calculation indicates that the additional employment, some years back, may have been approximately 0.8 million man-years (see Table 4).

## Some short-term consequences of the continued use of fish as feed

There is little doubt that fish will continue to be in demand. A growing population and increased popularity of fish will mean that global demand will grow faster than the global population. Most likely, aquaculture will continue to deliver

[28] It has been reported that even traditional catfish farms in Viet Nam have introduced machinery to facilitate the handling of trash fish (FAO, 2009b).

the additional quantities[29]; thus, there will also be a growing demand for fish feeds, and for such feeds to incorporate animal proteins or future equivalent ingredients.

On the one hand, it will be increasingly difficult for aquaculture to capture an even larger share of the total fishmeal supplies, and the price of fishmeal will continue to be high and may increase further. Fishmeal manufacturers will thus be able to afford prices much above the USD100 per tonne that seemed the standard during much of the end of the last century and the beginning of this century. When the fishmeal manufacturer can afford to pay USD300 per tonne of forage fish, then the industry will have the potential to purchase fish that today, under normal market conditions, would have been supplied to the food fish market. Such a trend is likely to cause much controversy.

In parallel with a growing demand for fish and for fishmeal, feed manufacturers and aquaculturists are putting considerable efforts into a search for alternatives to fishmeal and oil in fish and shrimp diets (Naylor *et al.*, 2009). As the price of fishmeal and oil increases, the economic space for replacing them will also grow, and during the coming decades, it seems more than likely that the aquaculture industry will make less use of fish as feed, per kg of seafood produced, than it does at present.

The use of bycatch as fish feed is likely to decrease during the next ten years. There are several reasons. One is economic – to transport and process the large volumes of fish involved is labour intensive, and as economies grow and salaries rise in Southeast and East Asia, the practice will rapidly become too costly. Simultaneously, there are health risks associated with the practice which will cause fish and shrimp farmers to prefer pelleted feeds. Lastly, managers of commercial fisheries are likely to have some success in their efforts to reduce bycatch generally.

If the future will be as just described, will the use of fish as feed continue to be viable? Let us look at the same "measuring rods" that we used to assess the situation today.

– *Sustainability of resources* – If fisheries management is going to become more effective, which seems likely, then there would be less grounds to expect that in the near future industrial fisheries will be a threat to the survival of feed fisheries or of fish stocks that are part of their ecosystem. Similarly, the bycatch problem – in terms of harmful quantities of juveniles – is being addressed; if anything, it will be better handled. This may lead to less bycatch but better sustainability for commercial food fish fisheries.

[29] During the decade 1995–2005, the per capita supply of fish in the world grew at an average annual rate of 1.0 percent (1.7 percent in the preceding decade), while aquaculture production during the same decade grew at an annual rate of 7.1 percent (11.8 percent in the preceding decade) (FAO, 2009b).

– *Volume of food fish supplied* – This is probably the big question mark. If the work on replacing fishmeal does not yield results, and therefore the price of fishmeal continues to rise, there is a considerable possibility that the search for raw material for fishmeal plants will lead to falling quantities of cheap forage fish on food fish markets. Measured in pure volume, such a development would doubtless lead to less food fish on the market overall. The same reasoning applies to tuna fattening based on raw fish. If we focus only on the volumes of food fish made available, tuna fattening can only be classified as a wasteful exercise.

– *Price level of food fish supplied* – As volumes of production grow for a species, its market price tends to come down. This is a well-established fact. However, at the global level, there may be a shift upwards in demand for fish. This may come about, on the one hand, because the general public realize the nutritional benefits of fish vis-à-vis other animal protein foods, and on the other hand, the public may perceive that the global warming effects of cultured fish are smaller, on a kilogram by kilogram basis, than are those of production of meat by ruminants.

– *Additional income earned and employment from using fish as fish feed* – Economic growth, with the accompanying technological growth, could lead to a slow fall in employment, without necessarily a parallel fall in total income.

## Conclusion

Given that overall: (i) the amount of fish available as food is larger when fish is used as feed than without this practice; (ii) that the price of fish globally is reduced because of aquaculture; (iii) that employment is larger with the practice than without it; (iv) that reduction fisheries can be, and increasingly are managed effectively, the practice of using fish as feed is viable, that is, use of fish as feed is capable of surviving as a practice during coming decades.

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