De Piscium Farinae et Olei Utilisatione in Aquacultura et de Rationis FIFO Calculatione

The Use of Fish Meal and Fish Oil in Aquaculture and Calculation of the Fish-In-Fish-Out (FIFO) Ratio

An Overview of Data from the Literature and the internet

Composit et Scripsit

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Summary

Fish meal and fish oil are important ingredients of fish feeds and aquaculture is thus highly dependent upon marine capture fisheries as a source for dietary ingredients. Most of the produced fish meal and fish oil is used for aquaculture (about 68 % and 88%, respectively in 2006, Tacon and Metian 2008). The dependency of aquaculture on marine capture fish or reduction fish can be described by the so called Fish-In-Fish-Out (FIFO) ratio, i.e. the amount of the equivalent of captured fish that is needed to generate 1 kg of cultured fish. There are various methods to calculate this FIFO ratio, One method is that of Tacon and Metian (2008) and another method that of Jackson (2009). Further, a combination of method of Jackson (2009) and the method of Tacon and Metian (2008) can be used. The combined method appears the most realistic and practical one and can be described by the simple formula:

FIFO = FCR *0.75 * 0.5 *[(% fish meal in feed / 22.5) + ((% fish oil in feed – 0.08 * % fish meal in feed) / 5)]

where the FIFO ratio is expressed in reduction fish equivalent and FCR is the feed conversion ratio (kg feed per kg fish). The yield of reduction fish is 22.5 % fish meal and 5 % fish oil. The factor 0.75 takes into account that about 25% of the fishmeal and fish oil is nowadays produced from fish slaughter byproducts and the factor 0.08 takes into account that fish meal contains 8 % fish oil. Some fish species have a high FIFO ratio, but these fish species account for only a small proportion of the total fish production. Conversely, there are also fish species with a low FIFO ratio; these fish species account for most of the cultured fish species, and as a consequence, the FIFO ratio of all the fish species taken together is nowadays considerably lower than 1. This low FIFO ratio that is smaller than 1 indicates that the aquaculture worldwide is a net producer of fish.

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1 Introduction.

Fish meal and fish oil are important ingredients of fish feeds, particularly for carnivorous fish species. There are various other sources of protein and oils that can be used, but fish feeds without any fish meal or fish oil result usually in a lower feed intake and lower growth performance. We will first give an overview of the amount of fish oil and fish meal that is worldwide produced and the amounts that are used for aquaculture. Subsequently, we will describe how the degree of dependency of fish feeds on fish meal and fish oil can be calculated and how much captured fish is needed to generate cultured fish, the so called Fish-In-Fish-Out ratio (FIFO). This FIFO ratio indicates how many kg captured fish is needed to grow 1 kg of fish and this ratio can be calculated for each specific species of cultured fish.

2 Fish meal and fish oil as ingredients of fish feeds.

About half of the fish products that are used for human consumption are nowadays derived from aquaculture (Figure 1, data from FAO 2008). The production of cultured fish is increasing exponentially with about 7-8% a year (doubling time of about 10 years). On the other hand, the capture of fish has reached now a maximum and has remained more or less the same during the last 10 years.

Fish meal and fish oil are major ingredients of fish feeds and aquaculture is thus highly dependent upon marine capture fisheries as a source for key dietary ingredients. Much efforts are done to replace fish meal an fish oil by alternative sources of protein and oil or fat. However, only about half of the fish meal protein in the feeds for carnivorous fish such as salmonids can be replaced by alternative protein sources without compromising the growth performance. The proportion of fish meal protein in feeds for omnivorous and herbivorous species can be reduced somewhat further, but some fish meal in the diet is still needed for a good growth performance. The fish oil in fish feeds can also be partially replaced by other sources of oil, but a minimum amount of fish oil in fish feeds is needed. Fish oil contains large amounts of the long chain fatty acids EPA (eicosapentaënoic acid) and DHA (docosahexaënoic acid). These fatty acids are essential for the fish, particularly for cold water or marine fish and to a lesser extent for warm or freshwater fish. Vegetable oils do not contain any EPA and DHA and animal oils contain only very small amounts. Aquaculture is thus still highly dependent on the use of fish meal and fish oil.

3 Databases related to fisheries and aquaculture

An important source of information is The Fisheries and Aquaculture Department of the Food and Agricultural Organization (FAO). A large body of data is given in the FAO report “The State of the World Fisheries and Aquaculture 2008 and 2012” and these reports can be downloaded from the internet. Further, many data related to fisheries and Aquaculture can be retrieved on line from the FAO website.

Another organization that gives information on the production and use of fish meal and fish oil is the International Fishmeal and Fish Oil Organisation (IFFO). This organization represents the fish oil and fish meal manufacturers and publishes a yearbook. The website of the IFFO also gives much information.

4 Production of fish meal and fish oil during the years

The production of fish meal and fish oil was in 1963 about 3 and 0.55 million tons, respectively (Figure 2). There was subsequently an increase in both the production of fish meal and fish oil to reach a maximum of about 7.5 million tons of fish meal in 1994 and about 1.6 milion tons of fish oil in 1986. Then, the production of both fish meal and oil decreased and was in 2009 about 5 and 1 million tons for fish meal and fish oil, respectively. The amounts in 2009 were considerably higher than in 1963, but comparable to those in the years around 1970 – 1980. The production of fish meal and fish oil will probably further decline in the future. There is a high pressure on the capture of fish and more of the captured fish that had been used for the production of fish meal and fish oil is nowadays used for human consumption.

Fish meal and fish oil are produced from so called reduction fish, i.e. fish that is not suitable or not attractive for human consumption, such as capelin, anchovis, blue whiting, and some types of mackerel and herring. Nowadays, fish meal and fish oil are also produced from fisheries by-products (i.e. offal of the fisheries industry). According to data from the IFFO (Chamberlain 2011) was the fish meal and fish oil production 4.942 and 1.032 million ton, respectively, in 2008 and these amounts were produced from 16.473 million ton of reduction fish and 5.491 million ton of fisheries by-products, a total of 21.964 million ton of raw materials. These data indicate that about 25% of the raw materials for the production of fish meal and fish oil are nowadays derived from fisheries by-products. Further, the yield of fish meal and oil from the 21.964 miljons ton of raw materials was 22.5 and 4.7% respectively, which is similar to the average yield of 5% fish oil and 22.5% fish meal from reduction fish (Tacon and Metain, 2008).

5 The use of fish meal and fish oil in Aquaculture

The largest consumer of fish meal and fish oil is aquaculture. Data from the IFFO (Jackson 2010) indicated that 59% of the fish meal production in 2008 was used for aquaculture whereas only 10% in 1980. Similarly, the IFFO reported that 80% of the fish oil production in 2010 was used for aquaculture whereas this percentage was only 16% in 1990. Thus, increasing proportions of fish meal and oil are used for aquaculture (Figure 2). Tacon and Metian (2008) calculated that 68% of the fish meal production and 88% of the fish oil production was used for aquaculture in 2006 and these estimates are thus somewhat higher than those of the IFFO.

Figure 2 shows that there is a strong increase in the use of fish meal and fish oil for aquaculture (Tacon and Metian 2008). This increase parallels the growth of aquaculture which is about 8% a year (Figure 1 and 2). The production of fish feeds also parallels the growth of aquaculture and was according to the calculations of Tacon and Metian about 25 million tons in 2006, about 4% of the total compound feed production. Tacon and Metian (2008) predict that the fish feed production will be about 66 million ton in 2020 when this strong growth of aquaculture will continue. These authors, however, further predict that the production of fish meal and fish oil will not increase and might even decrease (Figure 2). The inclusion levels of fish meal and fish oil in the various types of fish feeds is already declining, but has to reduce even more when this fast growth of aquaculture will continue (Figure 3).

6 Distribution of the use of fish meal and fish oil among the various cultured fish species.

Figure 4 gives an overview of the distribution of the use of fish meal and oil among the various cultured fish species. The total amount of fish cultured with compound feeds in

2006 was 23.9 million tons and the total production of compound fish feeds was 25.4 miljon tons (4% of the total compound feed production). The total usage of fish meal in aquaculture in 2006 was 3.7 miljon tons (68% of the total fish meal production in 2006) and the total usage of fish oil was 0.84 miljon tons (88% of the total fish oil production). All these data are from Tacon and Metian (2008). The largest consumer of the fish oil was the salmon culture; 43% of the total fish oil use in aquaculture was used for the production of salmon feeds, whereas the culture of salmon accounts for only 6% of the total fed fish production in aquaculture. Conversely, 11% of the fish meal use in aquaculture was consumed for the production of feeds for the chinese carp, whereas the culture of chinese carp accounts for 43% of the total fed fish production. The largest consumer of fish meal is the shrimp that consumes 27% of the total fish meal usage, whereas the culture of shrimp accounts for only 13%.

7 Fish meal protein dependency or utilization ratio

The dependency of fish feeds and aquaculture on fish meal and fish oil can be expressed in dependency or utilization ratios. The fish meal protein utilization ratio indicates the amount of fish meal protein (kg) in the feed that is needed to generate 1 kg of protein in the cultured fish. Similarly, the fish oil dependency or utilization ratio indicates the amount of fish oil (kg) in the feed that is needed to generate 1 kg of oil in the cultured fish. A utilization ratio smaller than 1 indicates that net protein or oil is generated in the fish.

We will use as an example a trout feed with 44% protein and half of the protein in this feed is derived from fish meal. We will assume that the feed conversion ratio of this feed is 0.80 which means that 0.80 kg of feed is needed to generate 1 kg of fish. Further, we assume that the protein content of a trout is 17%, and this protein level is rather constant for most fish species. Thus:

0.8 kg feed with 22% fish meal protein generates 1 kg fish
(0.8 x 0.22) = 0.176 kg fish meal protein generates (1 x 0.17) = 0.17 kg fish protein
The fish meal protein utilization ratio is then:
0.176 / 0.170 = 1.04

A fish meal protein dependency or utilization ratio of 1 indicates that we need 1 kg of fish meal protein to generate 1 kg of protein in the fish. Thus, we break even in this example. The general formula for this calculation is thus:

Fish meal protein utilization or dependency ratio is:

(FCR x % fish meal protein in feed) / 17

where FCR is the Feed Conversion Ratio and 17 is the percentage of protein in the fish. This number of 17% is rather constant for trout and most other fish species. Mostly, the percentage of fish meal rather than the percentage of protein that is derived from fish meal is given. Standard fish meal contains about 66% protein and the formule is then:

Fish meal protein utilization or dependency ratio is:

(FCR x % fish meal in feed x 0.66) / 17

where 0.66 is the fraction of protein in the fish meal. These numbers can be adjusted if necessary, e.g. when fish meal is used with a different protein content, such as fish meal LT (low temperature) that contains about 72% protein.

The amino acid composition of a fish and fish meal is rather constant and is not affected by the amino acid composition of the feed. The same is true for the amount of protein in the body (about 17% in the fish). Dietary proteins other than fish meal protein such as soy protein have a different amino acid composition than fish meal, but this difference will not change the amino acid composition of the fish. Thus, a fish protein utilization ratio smaller than 1 will truly indicate that net fish protein is generated that has the same amino acid composition and structure as fish protein that is exclusively generated from dietary fish meal protein.

8 Fish oil dependency or utilization ratio

We can similarly calculate the fish oil dependency or utilization ratio. The fish oil utilization ratio is amount of fish oil (kg) in the feed needed to generate 1 kg of oil in the fish and the general formula is then:

Fish oil utilization or dependency ratio is:

(FCR x % fish oil in feed) / (% oil in fish)

We can use as an example a trout feed with 22% fat and we assume that half of the oil in the feed (11%) is derived from fish oil and that the FCR is 0.80. Further, if we assume that the fat content of a trout is 10% . Then:

(0.80 x 11) / (10) = 0.88

This ratio is smaller than 1 and means that net oil in the fish is generated. Further replacing the fish oil in the feed by another oil will further improve the fish oil utilization ratio.

As discussed above, the amino acid composition of a fish is constant and is not affected by the amino acid composition of the feed. The fatty acid composition of the oil in the fish, however, is strongly affected by the fatty acid composition of the oils in the feed. Fish is appreciated by the consumer because of its high levels of the essential fatty acids EicosaPentaenoic Acid (EPA) and DocosaHexaonoic Acid (DHA) and fish is a major dietary source of these fatty acids. Feeding a fish with exclusively fish oil will result in a fish with higher EPA and DHA levels in the fat tissue than feeding a fish with other dietary oils. Fish oil is rich in the essential fatty acids EPA and DHA that are not present in vegetable oils and very little in animal fats. Therefore, the EPA and DHA utilization ratio may be a more useful ratio than just the fish oil ratio. The EPA and DHA utilization or dependency ratio indicates then how much EPA and DHA (kg) in the feed is needed to generate 1 kg of EPA and DHA in the fish. We can take as an example a trout diet with 22% fat that is exclusively derived from fish oil. Further, we assume that the fat content of a cultured trout is 10% and that the EPA and DHA concentration of the fish oil in the feed and in the trout is 20%. Thus, the EPA and DHA utilization ratio is:

(0.80 x 22 x 0.2) / (10 x 0.2) = 1.76

This calculation indicates that about 1.76 kg of EPA and DHA in the feed is needed to generate 1 kg of EPA and DHA in the trout. Thus, about 100*(1/1.76) = 57% of the EPA and DHA in the feed is retained in the fish and a loss of EPA and DHA takes place. When half of the fat in the diet is derived from fish oil (11%), the level of EPA and DHA in the raised fish will also be lower and we will assume that the oil in the cultured fish contains then only 15% EPA an DHA. The EPA and DHA utilization ratio will then be

(0.80 x 11 x 0.2) / (10 x 0.15) = 1.17

Thus, the EPA and DHA utilization ratio is now lower and improved, but still higher than 1 and again a loss of EPA and DHA takes place. The reason of this loss is that trout and other salmonids and marine fish have a very limited capability to generate EPA and DHA and all the EPA and DHA in the fish has to be derived from the feed. Therefore, a loss will take place, since a complete retention is not possible. Fresh water fish species such as tilapias, however, have a higher capability to synthesize EPA and DHA and the loss of EPA and DHA may be considerably less and these species may even generate net EPA and DHA.

9 Fish-In Fish-Out or FIFO ratios

We have in the previous paragraphs described how we can calculate the fish meal and fish oil utilization or dependency ratios of a fish feed. It is also possible to combine these two ratios and calculate how many captured or reduction fish is needed to grow 1 kg of fish. This ratio is called the Fish-In Fish-Out ratio. There are various methods to calculate this ratio. One is the method described by Tacon and Metian (2008) and the other is the method of Jackson (2009). We wil describe both methods and also a combination of the two methods

10 Calculation of the FIFO ratio according to the method of Tacon and Metian (2008)

We will first describe the FIFO ratio with the method of Tacon and Metian (2008). We will use as an example a trout feed with 20% fish meal and 10% (added) fish oil. The 10% fish oil is the oil added as such to the feed. The feed will actually contain more fish oil than the 10% added fish oil, since the fish meal in the feed also contains fish oil, fish meal contains about 8 - 10% fish oil. We need thus an amount 0.2 kg fish meal and 0.1 kg fish oil for a kilogram of feed. A kg of reduction fish has an average yield of 225 grams fish meal and 50 grams of fish oil (Tacon and Metian 2008). We need thus for this 0.2 kg fish meal in a kg feed an amount of 0.2 * (1000/225) = 0.9 kilograms reduction fish and for this 0.1 kg fish oil in a kg feed an amount of 0.1 * (1000/50) = 2.0 kilograms reduction fish. Thus, we need then at least an amount of 2 kg reduction fish to provide the necessary 0.2 kg fish meal and the 0.1 kg fish oil for the production of the 1 kg fish. When we assume that the feed conversion ratio is 0.8, then we need for growing 1 kg of fish an amount of 0.80 kg feed and we need for the production of this 0.8 kg feed an amount of 0.8 * 2.0 = 1.6 kg reduction fish. De FIFO ratio is dan 1.60.

Example:
We have a feed with 20% fish meal and 10% fish oil and a FCR of 0.80.
First we calculate the kg of reduction fish required for the fish meal protein in 1 kg of feed:
kg reduction fish required for the fish meal protein = (20 / 22.5) = 0.89 kg reduction fish
kg reduction fish for the fish oil = (10 / 5) = 2 kg reduction fish
Thus we need at least 2 kg reduction fish for 1 kg of feed
The FCR is 0.80. thus the **FIFO** = 2 * 0.80 = **1.60**

The disadvantage of these calculations is that we do not use all the fish meal that is supplied by this 1.60 kg reduction fish. In the example above, we need 2.0 kg reduction fish for the production of 1 kg of feed. This 2.0 kg of reduction fish provides us with 0.225 * 2.0 = 0.45 kg fish meal and we use only 0.2 kg fish meal. Thus we leave 0.45 – 0.20 = 0.25 kg fish meal unused, although this 0.25 kg fish meal can be used for the production of other fish feeds. With this method, Tacon and Metian (2008) have calculated the FIFO ratios of various species of cultured fish (Tacon and Metian 2008) (Figure 5).

11 Calculation of the FIFO ratio according to the method of Jackson (2009)

In order to circumvent the problem with the method of Tacon and Metian (2008) i.e. that not always all the fish meal and fish oil of the needed reduction fish is used, Jackson, the Technical Director of the IFFO, uses a different method for the calculation of the FIFO ratio. He uses a points system and each gram of fish meal and each gram of fish oil represents one point. The amount of reduction fish that is needed for growing 1 kilo of fish is then expressed in reduction fish equivalents. Thus, 1 kg of reduction fish with a yield of 225 gram of fish meal and 50 grams of fish oil supplies a total of 275 points and a fish feed with 20% fish meal and 10% fish oil consumes a total of 300 points. Thus, we need 300 / 275 = 1.1 kg reduction fish for the production of 1 kg feed. These calculations can be summarized with the formula:

$$\text{FIFO} = \text{FCR} * (\text{\% fish meal} + \text{\% fish oil in feed}) / (22.5 + 5.0)$$

This method appears to be more realistic since we assume with this method that all the fish meal and fish oil is eventually used for the production of fish feed. One fish species will use more fish meal whereas another fish species will use more fish oil. With this method, Jackson has calculated the FIFO ratios of various cultured fish species (that have been fed with compound feeds) and of the aquaculture as a whole (Jackson 2009) (Figure 5).

Example:
We have a feed with 20% fish meal and 10% fish oil and a FCR of 0.80. The FIFO factor is then:

$$\text{FIFO} = \text{FCR} * (\text{\% fish meal} + \text{\% fish oil in feed}) / (22.5 + 5.0)$$

$$\textbf{FIFO} = \text{FCR} * (20 + 10) / (22.5 + 5.0) = \textbf{0.87}$$

The disadvantage of the method of Jackson (2009) is that the fish oil and fish meal points from the reduction fish are lumped together and considered to be equivalent. A kg reduction fish, however, supplies 225 fish meal points, but only 50 fish oil points. Thus, more reduction fish is required for a fish oil point than for a fish meal point and a fish oil point should thus have a higher weighing factor than a fish meal point in terms of the FIFO calculations. The method of Jackson will thus underestimate the FIFO factor for the fish oil part of feeds and overestimate the FIFO factor for the fish meal part. The FIFO factor will be considerably underestimated for feeds with high fish oil inclusions and to a lesser extent overestimated for feeds with high fish meal inclusions.

12 Calculation of the FIFO ratio with a combination of the method of Jackson (2009) and Tacon and Metain (2008).

We can, however, combine the method of Tacon and Metian (2008) and the method of Jackson (2009) and circumvent the disadvantages of both the method of Tacon and Metian (2008) and Jackson (2009). Similarly, as with the method of Jackson (2009), the FIFO ratio can now also be expressed in reduction fish equivalents, but takes into account that reduction fish has a yield of 22.5% of fish meal, but only 5% of fish oil and that the fish oil and fish meal points have therefore a different weighing factor in terms of the FIFO calculations. First we can calculate the FIFO ratio for the protein part of the reduction fish and the fish feed and subsequently of the oil part and then combine these two FIFO ratios.

The FIFO ratio for the protein part is.

$$\text{FIFO}_{\text{protein}} = \text{FCR} * (\text{\% fish meal in feed} / 22.5) / 2$$

The FIFO ratio for the oil part is:

$$FIFO_{oil} = FCR * (\% \text{ fish oil in feed } / 5) / 2$$

where the term ½ in the formula indicates that only half of the reduction fish is used for either the protein or the oil part of the FIFO ratio. Then, the FIFO ratio for the protein and oil are combined:

$$FIFO = FCR * 0.5 *[(\% \text{ fish meal in feed } / 22.5) + (\% \text{ fish oil in feed } / 5)]$$

where the FIFO ratio is expressed in reduction fish equivalents.

Example: We have a feed with 20% fish meal and 10% fish oil and a FCR of 0.80. The FIFO factor is then:
FIFO = FCR * 0.5 *(% fish meal in feed / 22.5) + (% fish oil in feed / 5)
FIFO = 0.80 * 0.5 * (20 / 22.5) + (10) / 5) = **1.16**

We can also calculate somewhat differently the FIFO ratio by a combination of the method of Tacon and Metian (2008) and the method of Jackson (2009). A kg reduction fish has a yield of 225 grams of fish meal, but only 50 grams of fish oil. Thus, 1 gram fish oil requires 225 / 50 = 4.5 times more reduction fish than 1 grams of fish meal. When we assign 1 gram of fish meal a weighing factor of 1, then 1 gram of fish oil has a weighing factor of 4.5. When we take these weighing factors into account, then we can lump together the points for the fish meal and the points for the fish oil and a kg of reduction fish results in a total of 225 + (50 * 4.5) = 225 + 225 = 450 points. When we have a feed with 20% fish meal and 10% fish oil, then we need for a kg feed 200 points for the fish meal and 10 * 45 = 450 points for the fish oil, thus a total of 650 points. When we have a FCR of 0.80, then the FIFO factor is: 0.8 * (650 / 450) = 1.16. The general formula for the calculation of the FIFO ratio is:

$$FIFO = FCR * (\% \text{ fishmeal if feed } + \% \text{ fish oil in feed } * 4.5) / 45$$

and this formula will result in the same FIFO factor as with the formula for the FIFO factor above (see example below).

Example: We have a feed with 20% fish meal and 10% fish oil and a FCR of 0.80. The FIFO factor is then:
FIFO = FCR * (% fish meal in feed + % fish oil in feed * 4.5) / 45)
FIFO = 0.80 * (20 + 10 * 4.5) / 45 = **1.16**

The FIFO ratio calculated with the method of Tacon and Metian (2008) is similar to the FIFO ratio calculated with the method of Jackson (2009) and the combined calculation method when the ratio of fish meal to (added) fish oil in the diet is equal to the ratio of fish meal to fish oil in the reduction fish (22.5/5 = 4.5). However, when this ratio in the feed is different from 4.5 (either lower or higher), then the calculation method of Tacon and Metian (2008) results in higher FIFO ratios than both the method of Jackson and the combined method. Further, the method of Jackson results in a higher FIFO ratio than the combined method, when the ratio fish meal to (added) fish oil in the diet is higher than 4.5 and in a lower FIFO ratio when this ratio is lower than 4.5.

Examples:
(1) We have a feed with 22.5% fish meal and 5% fish oil and a FCR of 0.80.
The ratio (% fish meal / % fish oil) = 22.5 / 5.0 = 4.5
The FIFO ratio with the method of Tacon and Metian:

First we calculate the kg of reduction fish required for the fish meal protein in 1 kg of feed:
kg reduction fish required for the fish meal protein = (22.5 / 22.5) = 1 kg reduction fish
kg reduction fish for the fish oil = (5 / 5) = 1 kg reduction fish
Thus we need at least 1 kg reduction fish for 1 kg of feed The FCR is 0.80. Thus the
FIFO = 0.80 * 1 = **1.00**

The FIFO ratio is with the method of Jackson (2009) is:
FIFO = FCR * (% fish meal + % fish oil in feed) / (22.5 + 5.0)
FIFO = 0.80 * (22.5 + 5) / (22.5 + 5.0) = **0.80**

The FIFO ratio with the combination of the method of Tacon and Metian (2008) and Jackson is:
FIFO = FCR * 0.5 *(% fish meal in feed / 22.5) + (% fish oil in feed / 5)
FIFO = 0.80 * 0.5 *(22.5 / 22.5) + (5 / 5) = **0.80**

Thus, the method of Jackson and the combined method gives similar results.

(2) We have a feed with 30% fish meal and 5% fish oil and the a FCR of 0.80.
The ratio (% fish meal / % fish oil) = 30 / 5 = 6 and is > 4.5.
The FIFO ratio with the method of Tacon and Metian:
First we calculate the kg of reduction fish required for the fish meal protein in 1 kg of feed:
kg reduction fish required for the fish meal protein = (30 / 22.5) = 1.33 kg reduction fish
kg reduction fish for the fish oil = (5 / 5) = 1 kg reduction fish
Thus we need at least 1.33 kg reduction fish for 1 kg of feed The FCR is 0.80. Thus the
FIFO = 0.80 * 1.33 = **1.07**

The FIFO ratio is with the method of Jackson (2009) is:
FIFO = FCR * (% fish meal + % fish oil in feed) / (22.5 + 5.0)
FIFO = 0.80 * (30 + 5) / (22.5 + 5.0) = **1.02**

The FIFO ratio with the combination of the method of Tacon and Metian (2008) and Jackson is:
FIFO = FCR * 0.5 *(% fish meal in feed / 22.5) + (% fish oil in feed / 5)
FIFO = 0.80 * 0.5 *(30 / 22.5) + (5 / 5) = **0.93**

Thus, the method of Jackson overestimates the FIFO ratio as alculated with the combined method

(3) We have a feed with 22.5% fish meal and 10% fish oil and a FCR of 0.80.
The ratio (% fish meal / % fish oil) = 22.5 / 10 = 2.25 and is < 4.5
The FIFO ratio with the method of Tacon and Metian:
First we calculate the kg of reduction fish required for the fish meal protein in 1 kg of feed:
kg reduction fish required for the fish meal protein = (22.5 / 22.5) = 1.00 kg reduction fish
kg reduction fish for the fish oil = (10 / 5) = 2 kg reduction fish
Thus we need at least 2 kg reduction fish for 1 kg of feed The FCR is 0.80. Thus the
FIFO = 0.80 * 2.00 = **1.60**

The FIFO ratio is with the method of Jackson (2009) is:
FIFO = FCR * (% fish meal + % fish oil in feed) / (22.5 + 5.0)
FIFO = 0.80 * (22.5 + 10) / (22.5 + 5.0) = **0.95**

The FIFO ratio with the combination of the method of Tacon and Metian (2008) and Jackson is:
FIFO = FCR * 0.5 *(% fish meal in feed / 22.5) + (% fish oil in feed / 5)
FIFO = 0.80 * 0.5 *(22.5 / 22.5) + (10 / 5) = **1.20**

Thus the method of Jackson underestimates the FIFO ratio as calculated with the combined method.

Nowadays about 25% of the fish meal and fish oil production is derived from fish slaughter by-products (fish offal of the fish filleting industry, data from the IFFO 2011). Therefore, we can actually multiply the calculated FIFO ratio with 0.75. In addition, fish meal contains about 8 – 10% fish oil and we can make a correction for the fish oil in the fishmeal by subtracting the fish oil in the fishmeal from the *total* fish oil in the feeds. A correction is required when the fish oil in the feed represents the *total* fish oil in the feed, but no correction is required when the fish oil in the diet represents the *added* fish oil. For all the FIFO calculations in When we make a correction for both the 25% of fish meal and fish oil that is derived from fish offal and a correction for the 8% fish oil in the fish meal, then the formula for the calculation of the FIFO ratio becomes:

FIFO = FCR *0.75 * 0.5 *[(% fish meal in feed / 22.5) + ((% fish oil in feed – 0.08 * % fish meal in feed) / 5)]

or

FIFO = 0.75 * FCR * (% fishmeal in feed + (% fish oil in feed – 0.08 * % fish meal in feed) * 4.5) / 45

13 FIFO ratios of various fish species and aquaculture worldwide.

We have subsequently calculated the FIFO ratios of the various cultured fish species separately and of the total aquaculture production worldwide with the three calculation methods (Figure 5 and 6). The raw data used for these FIFO calculations are fom Tacon and Metian (2008). Figure 3 gives the inclusion levels of fish meal and fish oil and the feed conversion ratios of some typical fish species during the years. Feeds for carnivorous fish species such as salmon and trout have high levels of fish meal and fish oil whereas the feeds for omnivorous and herbivorous species have low inclusion levels. A high inclusion level of fish meal or fish oil will results in a high FIFO ratio.

As discussed above, when the ratio of the 5 fish meal / % fish oil in the feed is 4.5, then there are no differences anymore in the FIFO ratios calculated with the three described methods. The ratios of the worldwide usage of fish meal and fish for aquaculture feeds ranged from 4 to 5 and therefore, there were no major differences in the FIFO ratios calculated with the three methods for the worldwide production of cultured fish (Figure 6).

For the calculations of the FIFO ratios in Figures 5 and 6, we have assumed that the fish oil in the diet represents the *added* fish oil. Further, we have assumed with these calculations that all the fish meal and fish oil was derived from reduction fish and we have not taken into account that a proportion of the fish meal and fish oil may be also derived from fish offal. Nowadays about 25% of the fish meal and fish oil production is derived from fish offal, but we do not know how much that proportion was in the past (probably less) and how much that will be in the future (probably more).

We have only calculated the FIFO ratios of cultured fish that were fed with compound feeds (Figure 5 and 6). A large proportion of cultured fish is not fed with compound feeds, but with so called “trash fish”, i.e. freshly captured fish that is fed directly or fed with other by-products. The FAO estimated that an amount of 5 -6 million tons trash fish is used per year in aquaculture.

Figure 5 indicates that there are some fish species with a high FIFO ratio and some with a low FIFO ratio. The fish species with a high FIFO ratio, however, account for only a small proportion of the total aquaculture production (fish fed with compound feeds). Figure 5 indicates that cultured fish species such as the eel, salmon, trout and shrimp have a high FIFO ratio, but they account for only a small proportion of the total aquaculture production (Figure 4). On the other hand, the chinese carp accounts for 43% of the total aquaculture production, but has a low FIFO ratio and will thus lower considerably the FIFO ratio of the total aquaculture fish production worldwide. As a result, the FIFO ratio of all the cultured fish species together will still be low. The overall FIFO ratio is considerably smaller than 1 and this finding indicates that more fish is generated in aquaculture than is used worldwide.

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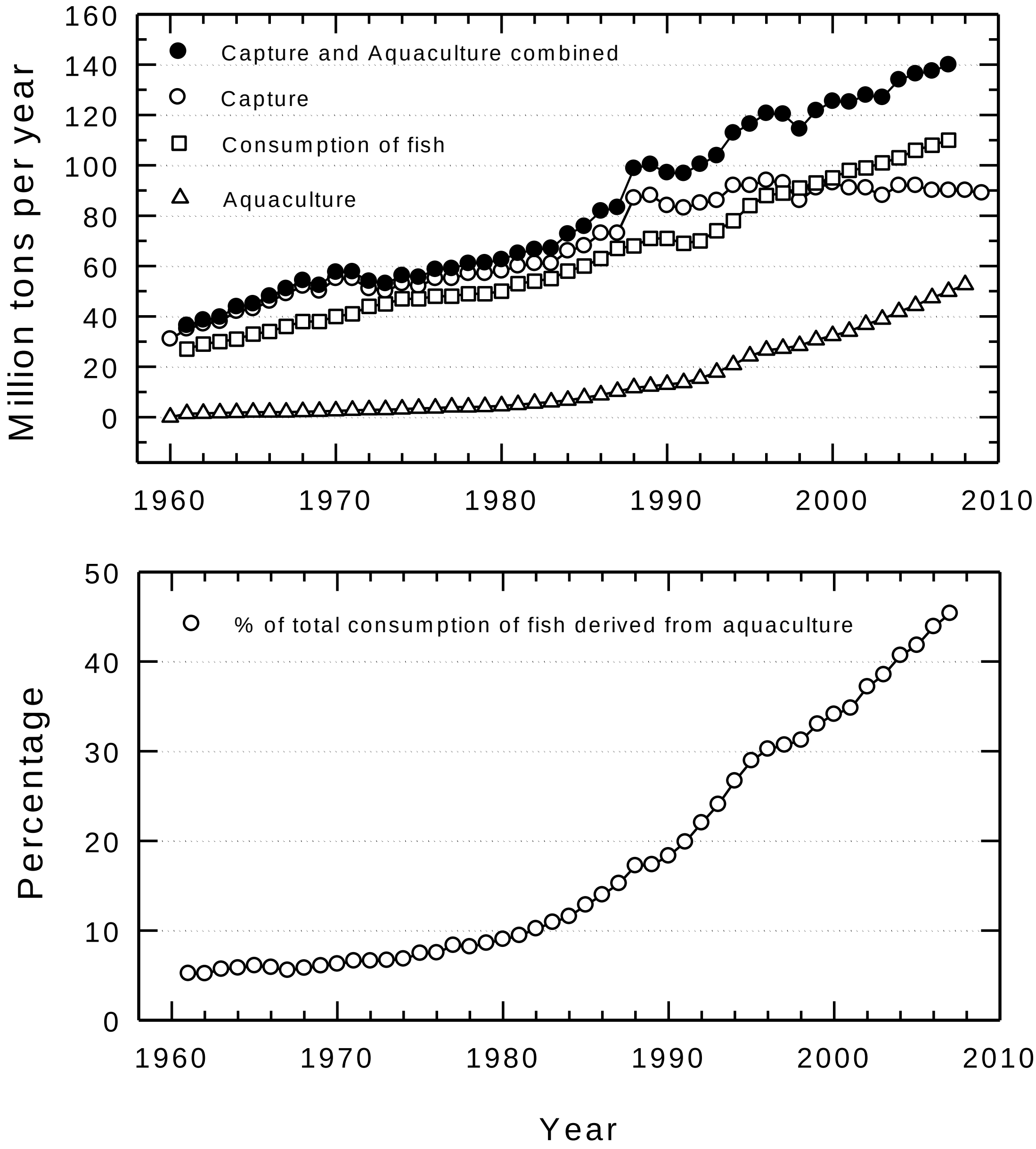

Figure 1
World fisheries and aquaculture production and fish consumption (data from FAO at the internet, 2008).

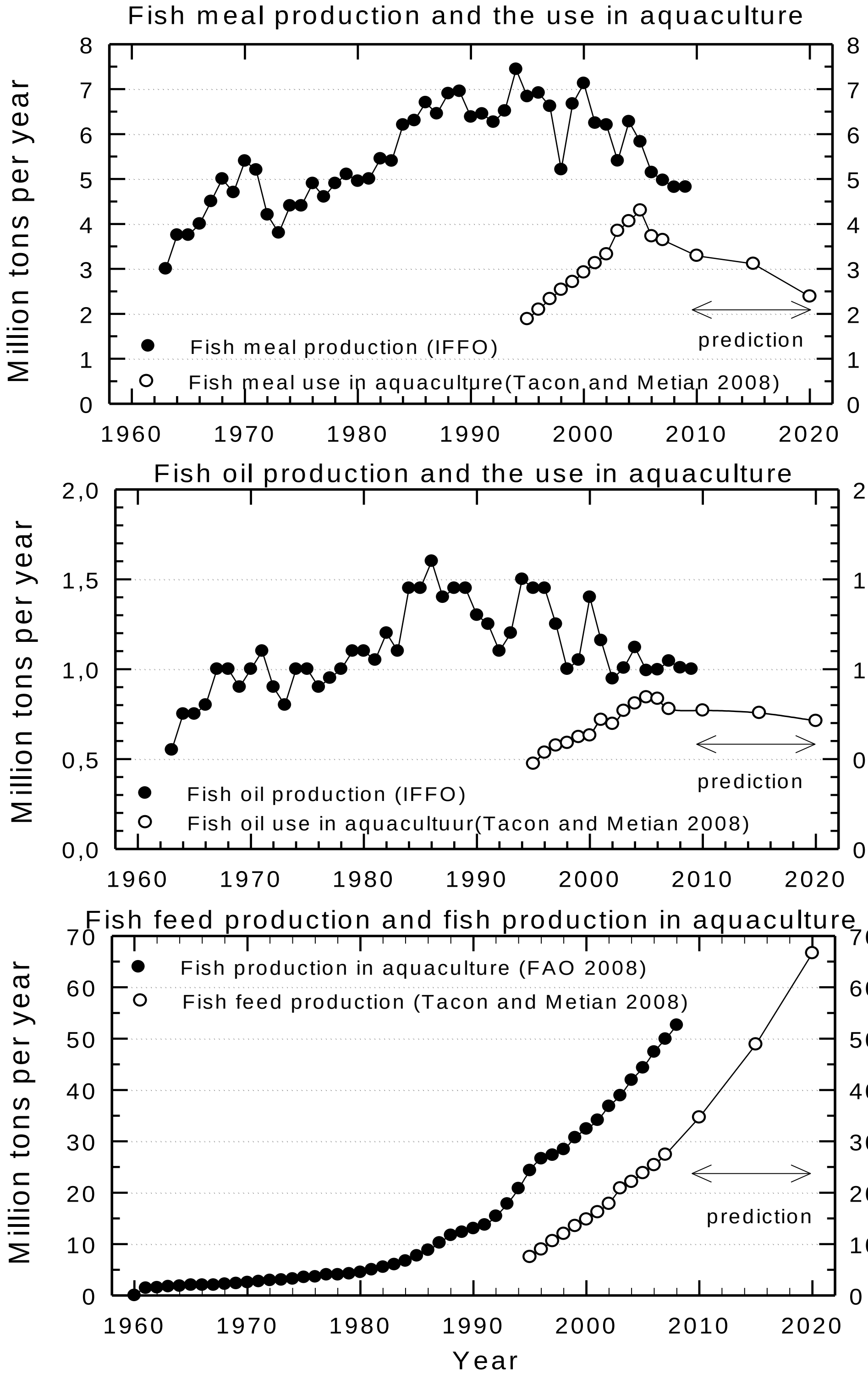

Figure 2
The production of fish meal and fish oil and the use in aquaculture.

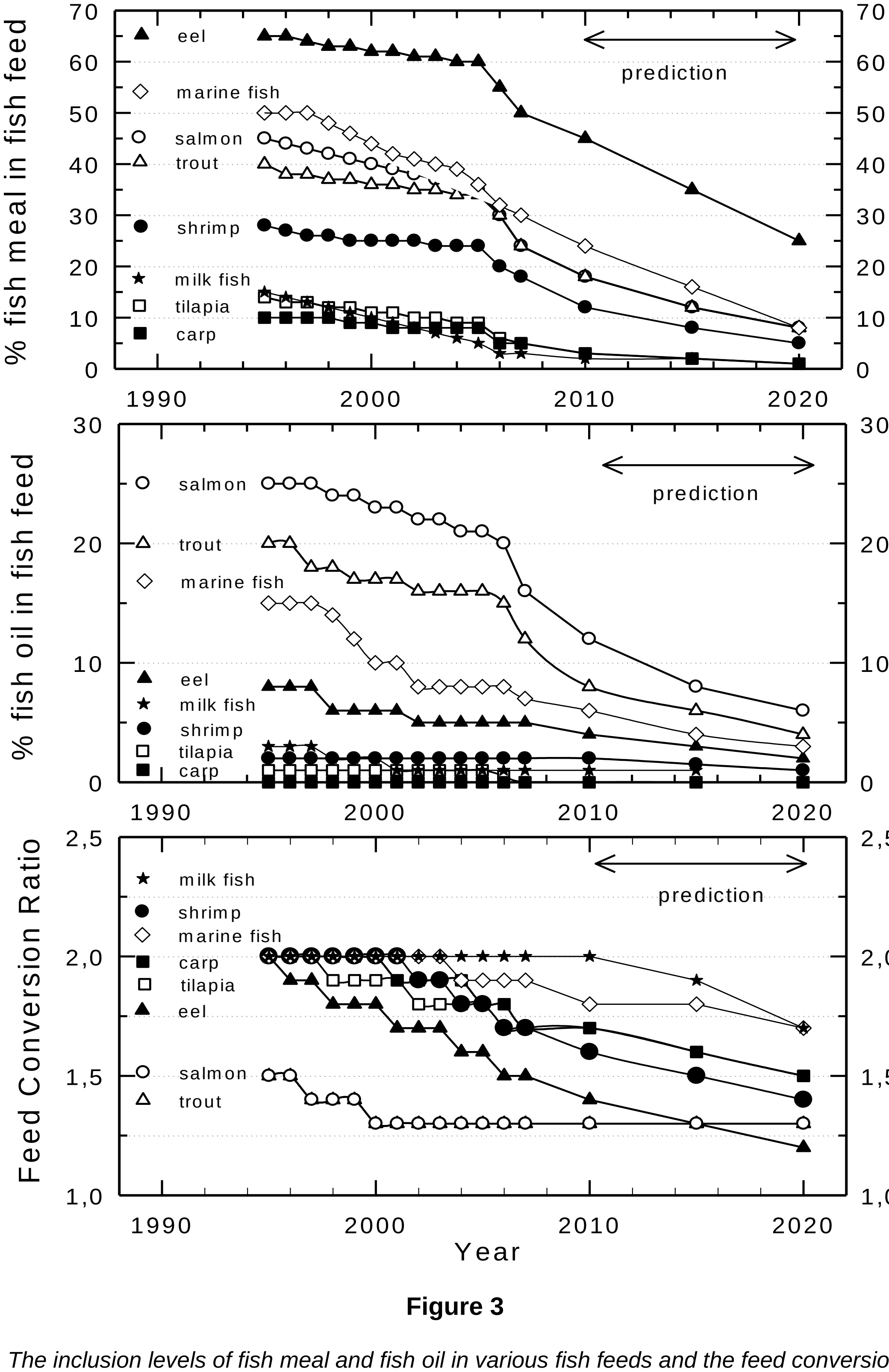

Figure 3

The inclusion levels of fish meal and fish oil in various fish feeds and the feed conversion ratios. Data from Tacon and Metian (2008, Table 4 of this article).

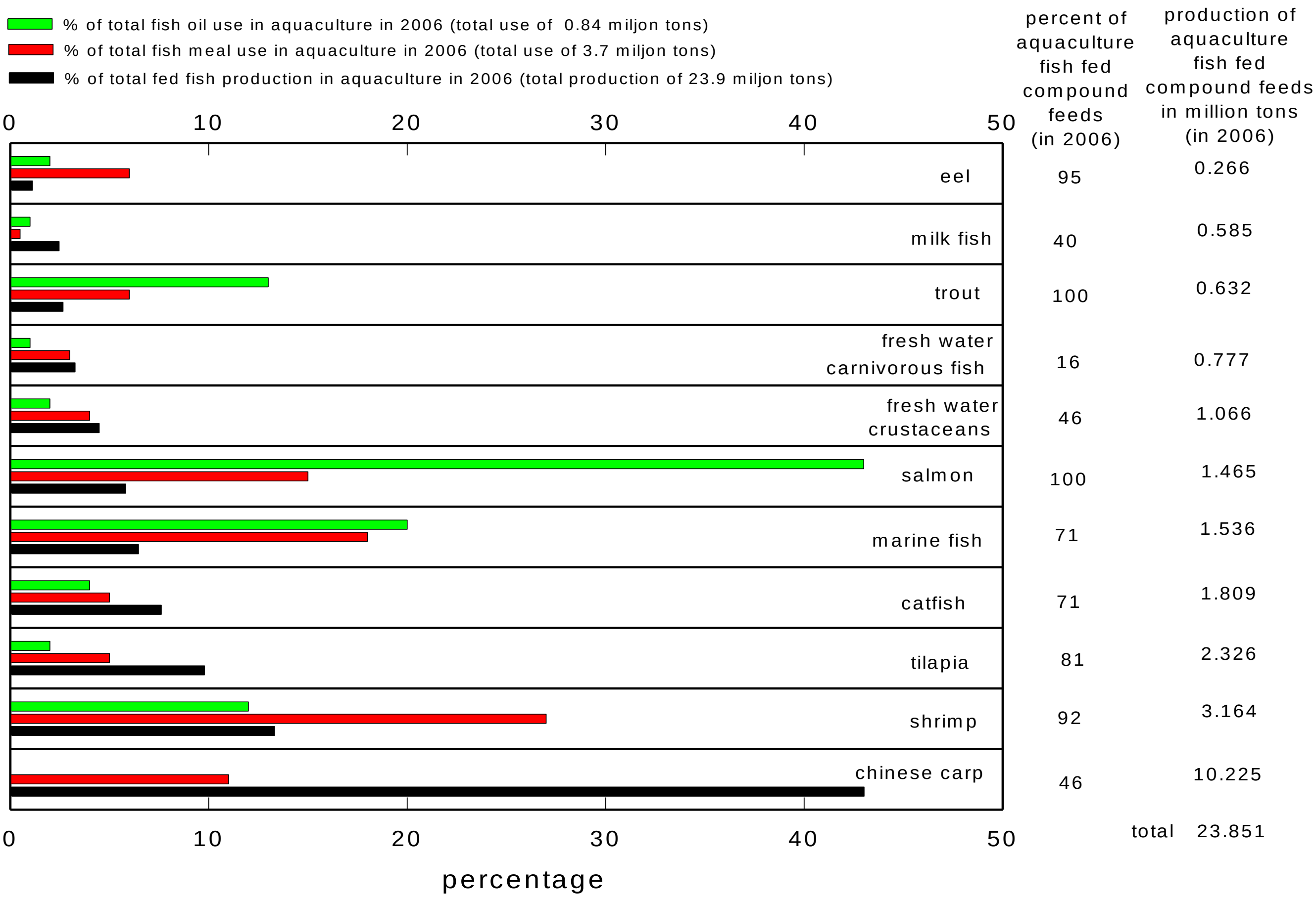

Figure 4

The use of fish meal and fish oil in various fish feeds and the total fed fish production in 2006 (expressed in percentages of the total use of fish meal and fish oil and calculated from the data in Table 4 of the article of Tacon and Metian, 2008).

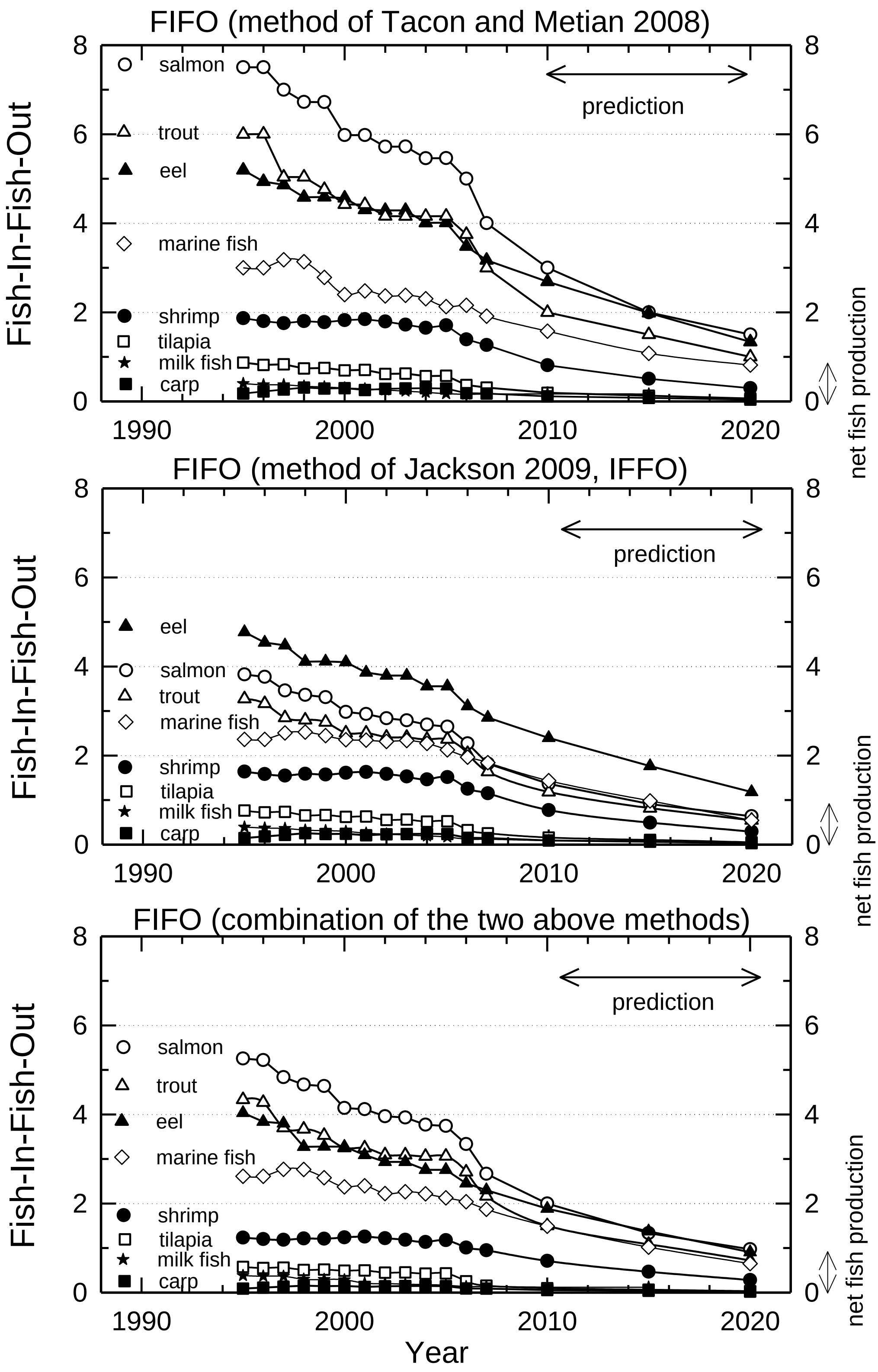

Figure 5
The Fish-in-Fish-out (FIFO) ratio calculated with different methods. The calculations are based on data from Tacon and Metian (2008, Table 4 of this article).

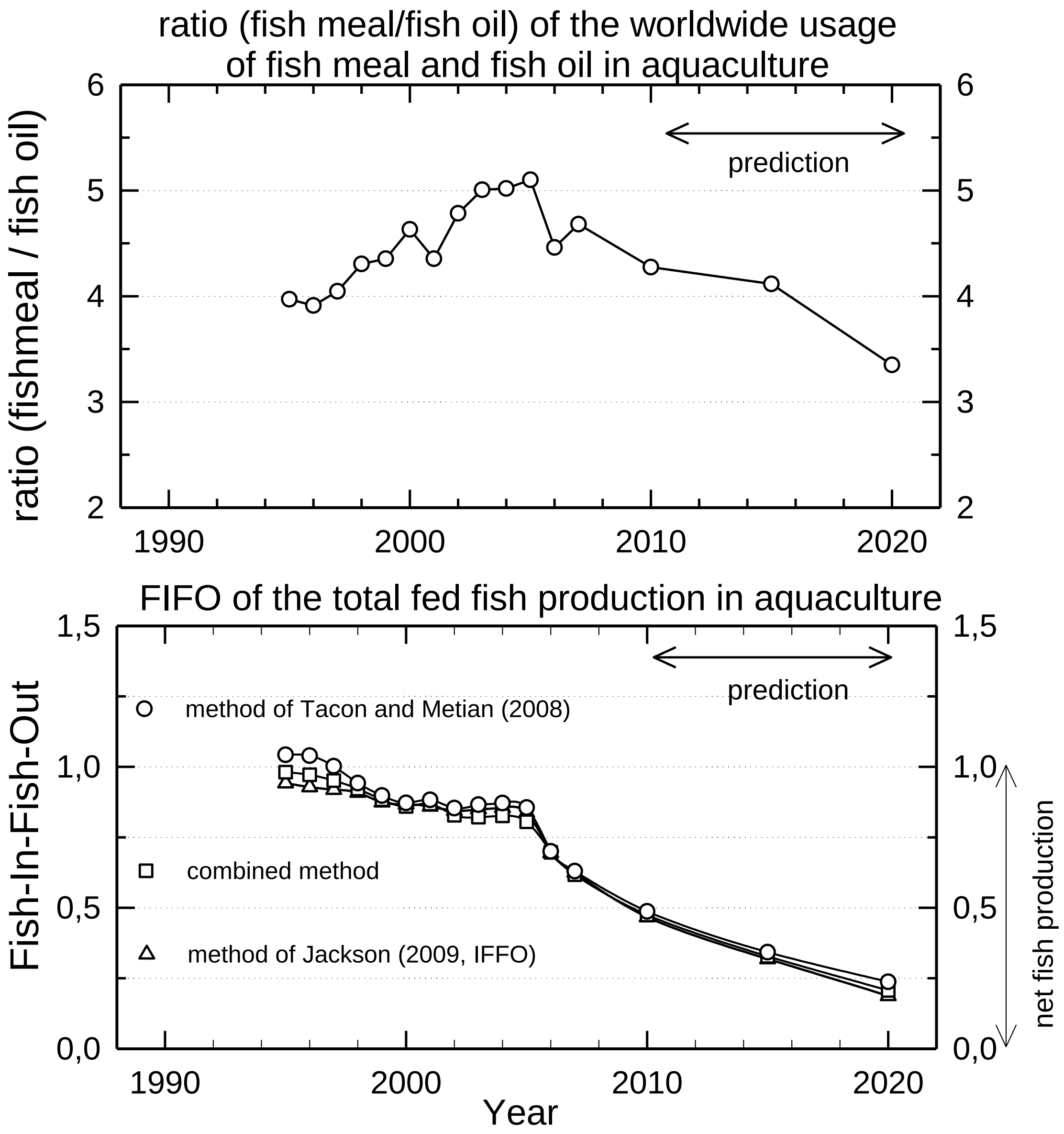

Figure 6

The Fish-in-Fish-out (FIFO) ratio of the worldwide cultured fish production calculated with various methods. The calculations are based on data from Tacon and Metian (2008, Table 4 of this article).