Estimating the Number of Farmed Fish Killed in Global Aquaculture Each Year

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1. Summary

Estimating the numbers of farm animals is important for animal welfare assessment, since the magnitude of an animal welfare problem may be evaluated as the product of the *severity of suffering*, its *duration* and the *numbers of animals affected*. This study estimates the number of farmed fish slaughtered for food in 2010 to be between 37 and 120 billion[1] individuals (for which the midpoint is around 80 billion), and the annual numbers are rising. This compares with the 63 billion farmed mammals and birds killed globally for food that year. Assuming the true figure is likely to fall nearer the midpoint than at either end of the estimated range, it therefore seems probable that the number of fish slaughtered globally each year now exceeds the figures for other farmed vertebrates. This great number of farmed fish multiplies the welfare problems prevalent in their slaughter, transport, handling and rearing, for which the severity and duration of distress will often be high.

EU fish farming is dominated by intensive farming of trout and marine fish. Their numbers are estimated at between 460 million and 1,700 million, for which the midpoint (1.1 billion) equals about 15% of the number of other farmed vertebrates slaughtered for food in 2010, these being mainly (86%) chickens. However, since farmed fish generally live for many months and often for over a year, whereas chickens are slaughtered at the age of around six weeks, the numbers of fish alive at any one time (and living under intensive conditions) may be greater than all other EU farmed vertebrate species combined.

Despite the EU's recognition of fish sentience and the inclusion of fish into OIE animal welfare recommendations, farmed fish are often killed using inhumane methods, which cause prolonged pain and distress, within the European Union and elsewhere. It is likely that most of the world's farmed fish are handled and killed by methods that do not meet the welfare recommendations laid out by the OIE. Other handling practices and transport are also stressful, as can be the environmental conditions under which the fish are reared. Farmed fish can experience high stocking densities leading to poor water quality, increased susceptibility to disease, competition for food and aggression. Lack of cover and hiding places is a problem for some species of farmed fish, according to their ethological needs, and artificial breeding processes also impact on welfare.

The FAO reports farmed fish production in 2010 for as many as 244 fish species categories. It is considered that greater understanding and consideration of their ethological needs and behaviours are needed in order to develop farming with good welfare. The suitability of different species for such farming, and questions such as the extent to which migratory species such as salmon suffer from

[1] Estimated range 36,734 million to 121,757 million (midpoint 79,246 million) rounded to 2 significant figures.

confinement in sea cages, and to which solitary species such as halibut suffer from crowding, need to be addressed.

Aquaculture production tonnage statistics published by the Food and Agriculture Organisation of the United Nations (FAO) for 2010 were used, along with estimates of mean weights at harvest for different species, to estimate the numbers of fish represented by global farmed fish production. These estimated mean weights were based on, and extrapolated from, fish size data for individual fish species obtained from a range of internet sources.

The estimated mean weights (EMWs) obtained in this study, and the fish number estimates based on them, will vary in their accuracy owing to the variability of fish slaughter weights and the limitations of the fish size data available. This study has sought to obtain the best estimate within these limitations. Issues of accuracy and representativeness are addressed as far as possible by including all fish size references for the most reliable types of data available while excluding those that are less reliable.

88% of fish production tonnage had a corresponding EMW (including single and multi species categories) with the corresponding numbers estimated at between 32 billion and 110 billion individuals. Extrapolating EMW data to estimate fish numbers for species without an EMW gave a total estimate of 37-120 (midpoint 79) billion. The full results of this estimate are available on web pages and in two excel spreadsheets, one of which shows estimated numbers separately for each country/group of countries and/or family, and by year for 2000-2010.

This estimated range is based entirely on the data used; the probability that the actual figure lies within this range has not been calculated, but it is considered unlikely that the number represented by FAO production tonnages will fall outside it. It is also considered that that the true number is more likely to lie towards the midpoint (around 80 billion) than at either end of the range. The most reliable estimates of fish numbers are likely to be those based on average/normal/general fish weight ranges taken from more than one reference (covering more than one country or the highest producing one) or taken from data provided by the FAO *Cultured Aquatic Species Information Programme* for the highest producing country or global production. These together total 24-89 (midpoint 56) billion and account for 76% of fish production tonnage.

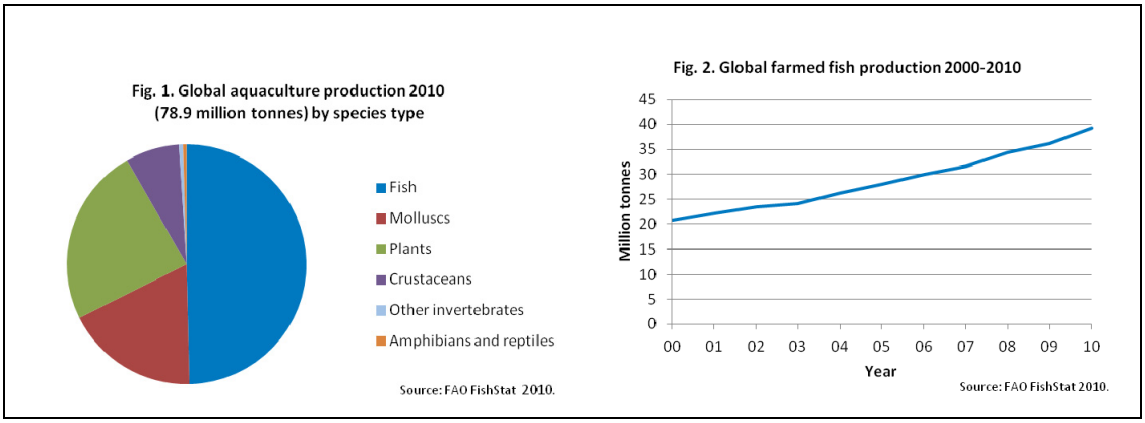
This estimate does not include the numbers of fish farmed for bait and it does not include fish mortalities arising in fish farms prior to harvest; from environmental impacts on surrounding wildlife; in the capture of wild fish for re-stocking or for feed – the latter of which is discussed. It is elsewhere reported that the use of fish oil and fish meal in aquaculture accounted for respectively 88.5% and 68.2% of total global fish oil and fishmeal production in 2006, with respectively 76% and 47% of global production fed to farmed fish species. According to a cautious estimate by the first current author, global fish oil and fishmeal production entailed the capture of an estimated 450-1,000 billion wild fish. It is estimated from this that respectively 340-780 and 210-480 billion feed fish were used to make the fish oil and fishmeal fed to farmed fish that year. It is also estimated that an additional 140-490 billion wild fish were fed directly to farmed fish and crustaceans in 2006. From this the number of wild fish used entirely for aquaculture feeds is estimated at 440-1,200 billion. Farmed trout and marine fish consumed three quarters of the total oil, and one third of the total

fishmeal, consumed by aquaculture that year, while contributing only 11% of farmed fish and crustacean production.

The welfare of farmed fish represents a major animal welfare issue. Fish welfare during slaughter, transport and rearing urgently needs to be addressed in the EU and elsewhere to prevent further large scale suffering.

2. Introduction

This study follows on from a previous study by the same authors (Mood and Brooke, 2010) to estimate the numbers of fish caught from wild each year. Using similar methods, the global numbers of farmed fish slaughtered[2] for food are estimated for 2010 and the ten previous years.



Fish farming accounts for half of global aquaculture production tonnage (see Fig.1.) and is increasing rapidly, almost doubling in the years 2000-2010 (Fig. 2. NB non fish species such as crustaceans are not included).

Fish sentience and welfare issues in fish farming are discussed in section 5.3. Farmed fish are often killed using inhumane methods. Other handling practices and transport are also stressful, as can be the environmental conditions under which the fish are reared. The natural ethology and welfare needs of many species are poorly understood. The magnitude of these animal welfare problems will be multiplied by the numbers of animals affected.

It is unfortunate that the numbers of fish slaughtered for food each year are not published by the FAO, as they are for farmed mammals and birds, and that the FAO does not systematically publish data on mean weights of farmed fish that would enable fish numbers to be calculated quickly. This study uses farmed fish production tonnages reported by the FAO, together with estimated mean weights for farmed fish that were obtained from a range of sources, to estimate these numbers.

[2] The term "slaughtered" is used throughout this document to mean killed for food, but it should be noted that fish are often not slaughtered actively, but die at some stage after harvesting, often of asphyxia

3. Methods

Aquaculture production statistics published by the FAO (2012a) were used, along with estimates of mean weight at harvest for different farmed fish species, to estimate the global number of farmed fish killed for food annually. The data used were as follows:

- Fisheries aquaculture production tonnage by species category for 2010 (and each of the 10 previous years) (FAO, 2012a)
- The species (or group of species) to which each fish species category above referred was identified from the "ASFIS List of Species for Fishery Statistics Purposes" published by the FAO (FAO, 2011)
- An estimate of the mean weight at harvest for each fish species category above was obtained, or extrapolated from, fish size data collected from a range of internet sources.

According to the range of data available, both a lower and an upper estimated number of farmed fish produced annually were calculated for each species or group of species. Note that the estimate does not include invertebrates, for which production tonnage is a significant proportion of total aquaculture production (see Fig. 1).

FAO data varies in its specificity. Tonnages of farmed fish production are listed by single species categories (e.g. Nile tilapia), by multi-species categories (e.g. "tilapias nei[3]") or in generic categories without species information ("freshwater fishes nei" and "marine fishes nei"). Estimated mean weights were obtained for as many species categories as was both possible and practicable for species-identifiable categories, beginning with those categories comprising the highest tonnages.

3.1. Estimating mean weight at harvest for farmed fish species categories

To estimate the average weight at harvest for a fish species, "harvest" and/or "market" and/or "table" and/or "grow out" size data were obtained from interent searches e.g. harvest size range, average market size. In addition to these different size types, the fish size data obtained also varied in how the size was measured e.g. average weight, typical weight. In this study, the different types of fish size measurement used to estimate mean weights are called "estimating methods" and are given in Table 1.

Table 1. Methods Used to Estimate Mean Weight (EMW) for Fish Single Species Categories

Method id	Method (Type of Data)	Reliability Ranking
1	Average weight or weight range[4]	1
2	Normal/usual weight or weight range	
3	Weight or weight range	
4	Typical or common (or "frequent") weight	2

[3] Nei (not elsewhere included) means fish recorded without species information.

[4] In the special case where a reference document gives a weight range for a species (method 2 or 3) together with an average weight (method 1) specifically for that weight range (as in the case of rainbow trout), then only the average weight is used. More generally, cited average weights and cited weight ranges are combined.

From Table 1 it can be seen that methods 1-3 involving taking a cited general or average weight, while method 4 involves use of a typical or common. Methods 1-3 were judged to be more reliable than method 4. The methods were each assigned a "reliability ranking", shown in Table 1, to indicate the judged relative reliability of the estimating method.

The reliability ranking affects how the data is used. Only data for the highest ranking method or methods available for each species were used in calculating estimated mean weights (EMWs). In doing this, the lower and upper end of the EMW range were considered separately since fish size references may sometimes only apply to one end of the range. References pertaining to the same reliability ranking were treated as if equally reliable whether they referred to a harvest, market, table or grow out size. Of the 103 fish size references[5] obtained for the study (relating to 51 species categories), five were not used as a result of this process of selection by reliability ranking.

EMWs are more often expressed as a weight range, from an estimated lower mean weight to an estimated upper mean weight, for reasons as follows:

- Many references state weights as a range
- Where more than one reference is available at a particular reliability ranking, the lowest and highest figures available are used to give a range
- Some references indicate a minimum or maximum figure for the weight (e.g. "Eels are harvested at a weight varying from 150 g to several kilograms") in which case separate references would be required for the lower and upper value and would most likely produce a range.

Table 2. Percentage of Results Obtained by Different Methods of Estimating Mean Weight (EMW) for Fish Species

Reliability Ranking[1] of the EMW	Farmed fish production 2010 (t)[2]	% Fish Cap-ture	Estimated Number Lower (Millions)	Estimated Number Upper (Millions)	% of Total Number (Lower)	% of Total Number (Upper)
1	32,235,298	82	29,924	100,666	81	83
2	171,000	<1	613	862	2	1
Multi-species categories	1,890,819	5	1,601	4,950	4	4
Total production with EMWs	34,297,117	88	32,138	106,477	87	87
Total production without EMWs[3]	4,877,181	12	4,596	15,280	13	13
Total farmed fish production	39,174,297	100	36,734	121,757	100	100
Total aquaculture production[4]	78,943,002					

1. See Table 1 for the methods that correspond to each reliability ranking.
2. Source of production tonnages: FAO FishStat Plus "Aquaculture Production 1950-2010 (Release Date: March 2012)" (FAO, 2012a).
3. See Table 3.
4. Includes invertebrates e.g. crustaceans.

Percentages of fish numbers estimated by methods at each ranking level are recorded in Table 2. Note that where the upper and lower ends of an EMW have a different reliability ranking, the

[5] Counting fish size data for a given species and country in a given reference document once.

reliability ranking indicated in Table 2 will be the lower ranking of the two, i.e. the highest number. It can be seen that 88% of farmed fish production tonnage had a corresponding mean weight estimated for it with 87% of estimated fish numbers based on this. 82% of total farmed fish production tonnage had an estimated mean weight based on data with a "reliability ranking" of 1.

All data were held on a MySQL database. The overall method used in this estimate of global farmed fish numbers is essentially the same as that used for the previous estimate of wild-caught fish numbers by the same authors (Mood and Brooke, 2010), but with a small change to reliability ranking scores, and fewer estimating methods, as discussed in Appendix A. After estimating total fish numbers for 2010, the same method and EMWs were then used to estimate numbers of farmed fish in global aquaculture production for each of the years 2000-2009 and in European Union aquaculture production for 2010.

Multi-species categories

Mean weights were estimated for two multi-species categories, namely "tilapias nei" and "Pangas catfishes nei". For multi-species categories, the estimated mean weight was derived from those for the estimated smallest and largest relevant species in the group, combined as a range. These were judged from maximum sizes given on fishbase.org (Froese and Pauly, 2011) together with any estimated mean weight data for relevant species. Relevant species are those that are, according to fishbase.org or other references, used in aquaculture.

Estimates for species categories with insufficient size data available

For some species categories (12% by weight, see Table 2), a mean weight estimate was not obtained. The aquaculture production tonnage for which no corresponding estimated mean weights were obtained included the generic categories "freshwater fishes nei" and "marine fishes nei" whose production tonnages accounted for 3% and 1% respectively of total fish production tonnage. It also included the category "Cyprinids nei", for which searches failed to obtain sufficient fish size data on which to base an estimate and whose production tonnage accounted for less than 2% of total production. The remaining aquaculture production tonnage for which no corresponding EMWs were obtained comprised a further 190 single and multi-species categories for which each production tonnage accounted for less than 1% of the total farmed fish production tonnage (179 of them accounting for less than 0.1% of total tonnage each).

Estimated fish numbers for species categories without an estimated mean weight were calculated by extrapolation. A generic estimated mean weight for farmed fish was calculated from the total tonnage and total estimated numbers for single species categories for which a mean weight had been obtained (see Table 3 of section 4).

4. Results

Table 3. Estimated Numbers of Farmed Fish Slaughtered Globally Each Year for FAO Species Categories with an Estimated Mean Weight (EMW) Obtained in this Study.

FAO Category Type	Farmed fish production 2010 (t)[1]	Estimated numbers lower (millions)[2]	Estimated numbers upper (millions)[2]	Generic mean weight (g)[3]
Single species	32,406,298	31,000	100,000	319-1,061
Multi-species	1,890,819	1,600	5,000	
All with EMW	34,297,117	32,000	110,000	
All without EMW[4]	4,877,181	4,600	15,000	319-1,061
Total farmed fish production	39,174,297	37,000	120,000	

1. Source of production tonnages: FAO FishStat Plus "Aquaculture Production 1950-2010 (Release Date: March 2012)" (FAO, 2012a).
2. Estimated numbers for each FAO species category were obtained by dividing production tonnage for the category by its EMW (see text). Figures are given to 2 significant figures.
3. Generic mean weight (g) was obtained for single species categories by dividing Farmed fish production 2010 (t) by Estimated numbers upper (millions) and Estimated numbers lower (millions).
4. Estimated numbers (millions) were obtained by dividing Farmed fish production 2010 (t) by Generic mean weight (g).

Table 4. Top 20 Fish Species Categories by Aquaculture Production Tonnage Reported by FAO

Species	Farmed fish production 2010 (t)[1]	Estimated mean weight (g)[2]	Generic mean weight (g)[3]	Estimated numbers (millions)[4]
Grass carp(=White amur) (*Ctenopharyngodon idellus*)	4,337,114	500- 2,500		1,700- 8,700
Silver carp (*Hypophthalmichthys molitrix*)	4,116,835	300- 1,500		2,700- 14,000
Catla (*Catla catla*)	3,869,984	300- 2,000		1,900- 13,000
Common carp (*Cyprinus carpio*)	3,444,203	500- 2,500		1,400- 6,900
Bighead carp (*Hypophthalmichthys nobilis*)	2,585,963	500- 1,500		1,700- 5,200
Nile tilapia (*Oreochromis niloticus*)	2,538,052	250- 800		3,200- 10,000
Crucian carp (*Carassius carassius*)	2,217,799	150- 400		5,500- 15,000
Atlantic salmon (*Salmo salar*)	1,425,968	3,614- 8,434		170- 390
Pangas catfishes nei (*Pangasius spp*)	1,306,838	500- 1,500		870- 2,600
Freshwater fishes nei (*Osteichthyes*)	1,266,868		319-1,061	1,200- 4,000
Roho labeo (*Labeo rohita*)	1,167,315	300- 1,500		780- 3,900
Milkfish (*Chanos chanos*)	808,559	250- 500		1,600- 3,200
Rainbow trout (*Oncorhynchus mykiss*)	728,448	210- 5,000		150- 3,500
Wuchang bream (*Megalobrama amblycephala*)	652,215	450- 500	319-1,061	1,300- 1,400
Cyprinids nei (*Cyprinidae*)	630,208		319-1,061	600- 2,000
Tilapias nei (*Oreochromis*(=Tilapia) spp)	583,981	250- 800		730- 2,300
Marine fishes nei (*Osteichthyes*)	468,858		319-1,061	440- 1,500
Channel catfish (*Ictalurus punctatus*)	444,937	340- 680		650- 1,300
Black carp (*Mylopharyngodon piceus*)	424,487	2000- 3000		140- 210
Amur catfish (*Silurus asotus*)	379,691		319-1,061	360- 1,200

1. Source of production tonnages: FAO FishStat Plus "Aquaculture Production 1950-2010 (Release Date: March 2012)" (FAO, 2012a).
2. Based on fish size data from various sources (see text).
3. See Table 3 for derivation of generic mean weight range.
4. Estimated numbers are given to 2 significant figures.

The total estimated numbers for fish species both with and without estimated mean weights are shown in Table 3, which gives the total estimated fish numbers for fish aquaculture production in 2010 as between 37 billion and 120 (midpoint 79) billion individuals.

Table 4 shows the 20 FAO fish species categories with the highest aquaculture production tonnages for 2010 (see also Fig. 3) and the estimated numbers of fish for each. The full results, including details of all estimated mean weights, are presented on a number of web pages, and three excel spreadsheets, available from the fishcount.org.uk website (2012a). The spreadsheets show the data used and calculations performed to produce the results shown on these web pages and in Tables 3 and 4 for global farmed fish production. They also include a spreadsheet to show the estimated numbers separately for each country or group of countries[6], by family and by year for 2000-2010 (Tables 5 and 6).

The top 20 FAO species categories with the highest estimated numbers (i.e. highest upper figure for the estimated range) based on EMWs are shown in fig. 4. For comparison, the top 20 FAO species categories with the highest production tonnages are shown in fig. 3. Note that not all species with the highest tonnages shown in fig. 3 appear in fig. 4. This is either because they did not have an EMW calculated for them or because the number of fish calculated were not as high as for the 20 species shown.

Figs. 5 and 6 show similar graphs for the top nine farmed fish species in the Europe Union (see footnote 5). There is a very noticeably wide range in estimated numbers for rainbow trout. This is because they can be both farmed at sea, where they can grow to several kg, and held in fresh water where they tend to be harvested at less than 1 kg (Lines and Spence, 2012). The estimated mean weight range for this species was based on an average weight for rainbow trout farmed in fresh water in Turkey, equal to 210 g (Bozoğlu *et al*., 2007), combined with an optimal market size of 3-5 kg for marine cages in Canada, Norway, Chile, Sweden and Finland (Cowx, 2005). In the UK, the harvesting size is reported to be 300-400g (British Trout Association, 2012) while reported numbers for Norway (Bergersen, 2011) indicate an average harvest size closer to 3 kg.

Table 5 shows the total farmed fish production tonnage and estimated numbers the years 2000-2010, based on estimated mean weights (EMWs) obtained in this study. Production tonnage increased by 88% in this period, while estimated numbers have increased by more than 90%.

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[6] Note that the estimated fish numbers for individual countries in this spreadsheet, and for Figs. 5 and 6, are based on the estimated mean weight ranges derived for global fish farming. These may be unduly wide in respect of the specific country or countries in question, which may not rear fish at the smaller or larger end of the global range. The estimated mean weights in the spreadsheet obtainable from the fishcount.org.uk website (fishcount.org.uk, 2012a) can be amended (and estimated numbers automatically recalculated) with the user's own estimated mean weights for a given species and country.

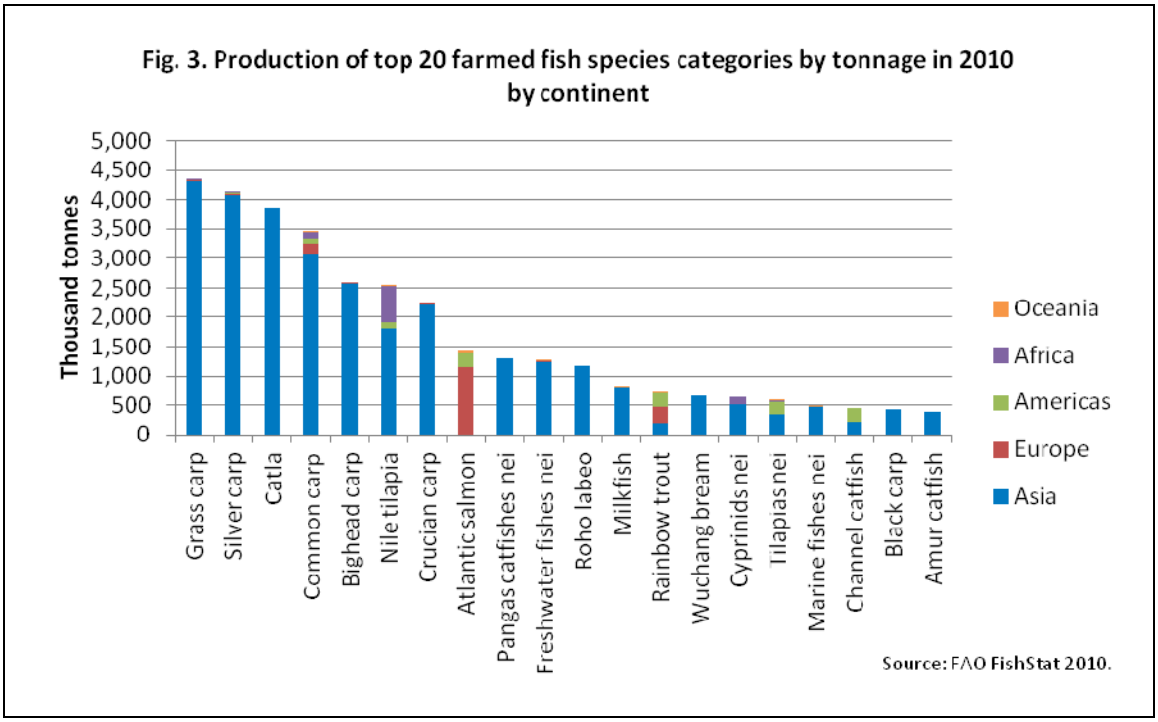

Fig. 3 shows the top 20 farmed fish species with the highest production tonnages in 2010. These comprise 33.4 of the total 39.2 million tonnes (85%) of global farmed fish production.

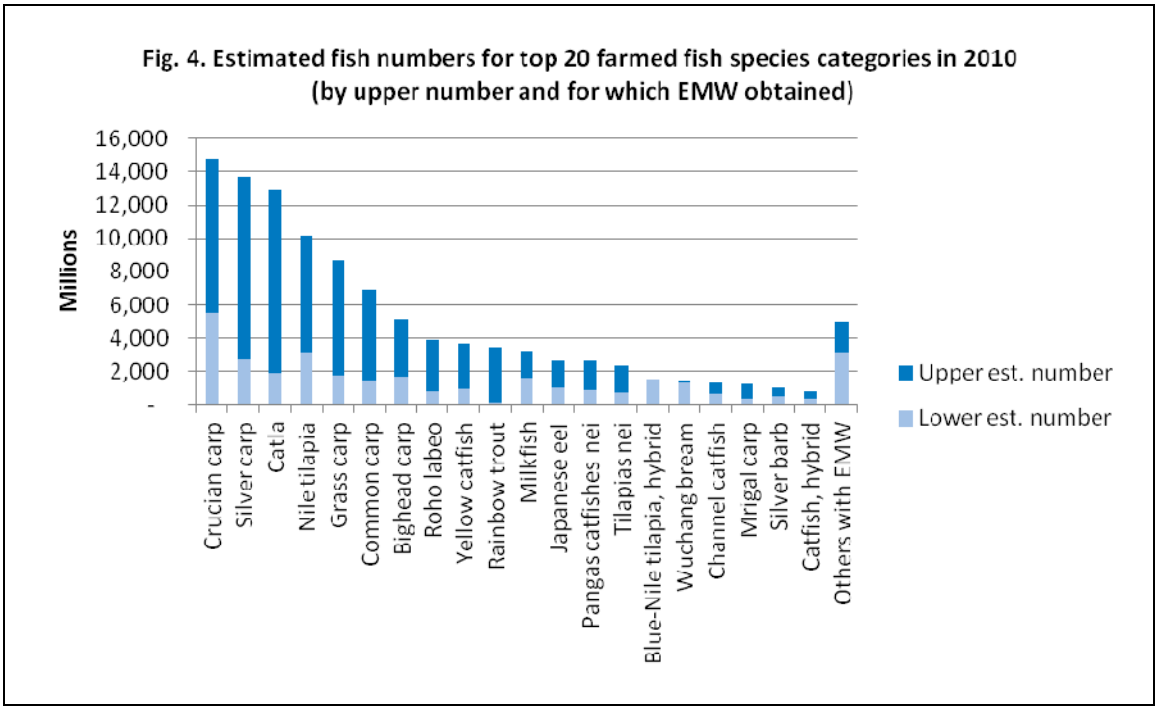

Fig. 4 shows the top 20 FAO fish species categories for which an estimated mean weight (EMW) was obtained with the highest estimated numbers for 2010. Together these 20 species comprise 77% of total fish tonnage and 29-100 billion individuals.

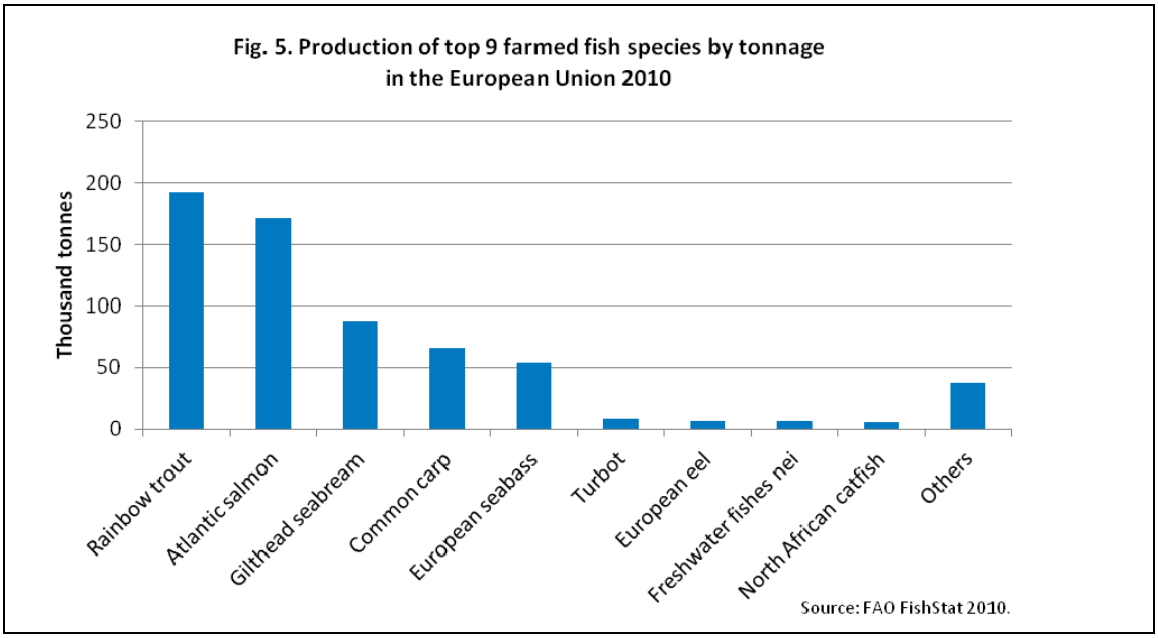

Fig. 5 shows the top nine farmed fish species with the highest production tonnages in the Europe Union (i.e. EU 27 countries) for 2010. These comprise 599 thousand of the total 636 thousand tonnes (94%) of farmed fish production in the Europe Union. EU farmed fish production accounts for 34% of European[7] production. Norway, which is outside the EU, accounts for 53%, most of which is Atlantic salmon (92%) with some rainbow trout (5%) and Atlantic cod (2%).

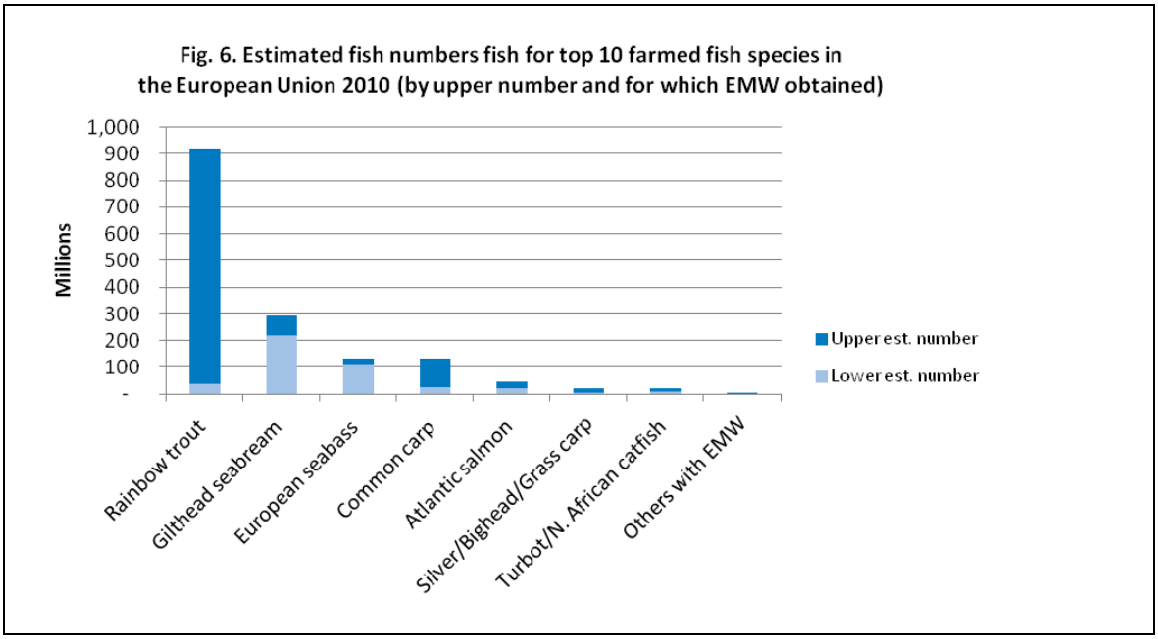

Fig. 6 shows the top ten FAO fish species categories with the highest estimated numbers based on estimated mean weights (EMWs) for 2010 in Europe (EU 27). Together these ten species comprise 93% of total EU farmed fish production tonnage and 420-1,600 million individuals. Estimated fish numbers for the EU, Norway and Europe as a whole are respectively 460-1,700, 130–530 and 710-2,700 million individuals. The wide range for rainbow trout reflects the production of both small freshwater trout and large trout on-grown at sea, hence a wide EMW range.

[7] Europe as defined by FAO FishStat. The countries that FishStat includes under "Europe" may be viewed from its online query panels (FAO, 2012e) and in Spreadsheet5_emws_country_year.xls available at fishcount.org.uk (2012a).

Table 5. Estimated Numbers of Farmed Fish Slaughtered by Year, 2000-2010

Year	Farmed fish production		Estimated Number Lower		Estimated Number Upper	
	Yearly Total (t)[1]	% increase since 2000	Yearly Total (Billions)[2]	% increase since 2000	Yearly Total (Billions)[2]	% increase since 2000
2000	20,813,393	0	19	0	63	0
2001	22,165,104	6	20	5	66	6
2002	23,515,769	13	21	13	71	13
2003	24,229,157	16	22	19	73	17
2004	26,305,679	26	24	30	81	29
2005	27,978,853	34	26	39	86	37
2006	29,929,232	44	27	48	92	46
2007	31,601,160	52	30	63	98	56
2008	34,305,881	65	32	74	110	68
2009	36,134,604	74	34	84	110	78
2010	39,174,297	88	37	98	120	94

1. Source of production tonnages: FAO FishStat Plus "Aquaculture Production 1950-2010 (Release Date: March 2012)" (FAO, 2012a).
2. See text for estimating method. Estimated numbers are given to 2 significant figures.

5. Discussion

The accuracy of this estimate will depend on accuracy of the FAO FishStat data and on the reliability of mean weight estimates for single and multi species categories, which is discussed in 5.1 below. Aquaculture related fish mortalities not included and the animal welfare implications of the estimate are discussed in 5.2 and 5.3.

5.1. Reliability of estimated mean weights

5.1.1. Estimating numbers for single species categories

The accuracy of the estimated numbers of fish for single species categories of farmed fish with an estimated mean weight (EMW) will depend on the accuracy and representativeness of the fish sizes on which the EMWs were based, and on the accuracy of FAO production tonnages.

This overall method has sought to obtain the best estimate within the limitations of the data available. Where estimated weights were obtained from several cited fish sizes combined, the full outside range was used in order to be fully inclusive of the fish size data used.

Representativeness, accuracy and bias.

The final estimated number of farmed fish of 37-120 billion is a wide range, with the upper figure approximately three times the lower figure, reflecting the variability of fish harvest size in fish farming both within and between producing countries, for which climatic conditions and optimal market sizes differ. Average slaughter weights vary for a range of reasons. These may be affected by:

- Levels of stocking density and food supply, especially in extensive systems
- Provision of supplementary feeding
- Age at killing
- Other habitat factors (e.g. temperature, salt or freshwater for trout (as mentioned earlier))
- Market requirements.

In Asia, higher market prices can often be obtained for larger fish due to consumer preference and, conversely, there is also a market for smaller cheaper fish amongst poorer communities (Ahmed, 2010). Had more harvest size data been available for this study, and more time to process it, a more precise estimate could probably have been obtained by deriving separate EMWs and estimated fish numbers for each country and combining the results. (Note that researchers wishing to estimate fish numbers for their own country may find that local internet searches produce data from which they can derive their own EMWs for that country. The spreadsheet published with this study, available from the fishcount.org.uk website (2012a) can then be used to recalculate fish numbers for these country-specific EMWs).

Estimated numbers for single species categories are likely to be more accurate where they were based on fish size data of reliability ranking equal to 1 i.e. general and average fish weights or weight ranges. From Table 2 it can be seen that around 82% of estimated fish numbers were calculated from single species category EMWs based on rank 1 data, corresponding to 82% of total fish production tonnage and 30-100 billion individuals.

EMWs will be more reliable when based on more than one rank 1 reference and when based on references that apply to the highest producing countries or globally. Single species EMWs based on two or more rank 1 references (excluding those EMWs where all references pertained to the same country other than the highest producing one) accounted for 69% of total tonnage. Single species EMWs based on a global fish weight range, or a weight range for the top producing country, provided by the FAO *Cultured Aquatic Species Information Programme* webpages accounted for 44% total tonnage. These global/highest producing country FAO reference and multi-reference EMWs together corresponded to 76% total fish tonnage and respectively 66% and 73% of the lower and upper total estimated number range i.e. to 24-89 (midpoint 56) billion individuals. More detailed analysis of the different types of fish size data used and their corresponding impact on the calculation of total estimated numbers are given in Appendix B.

5.1.2. Estimating numbers for multi-species categories

Estimating the numbers of farmed fish for multi-species categories with an EMW is more speculative because the precise species composition is unknown. Estimates were made for two such species categories, namely “tilapias nei” and “pangas catfishes nei”.

The method used to was to take the estimated mean weight for the smallest and largest species for the category that are used in aquaculture, and combine them as a range. In the case of pangas catfishes, references indicated only two species are farmed significantly (Corsin, 2008). For tilapias, determining the smallest and largest species of the several farmed species was itself an estimate based mainly on “maximum published size” data from fishbase.org, and it was assumed that the smallest and largest tilapia species in terms of respective harvest sizes are those species with the lowest and highest maximum published weights, which is not necessarily the case. However, because the method aims at the outside range it does give a wider margin for error, with the total number of fish estimated for tilapias nei at 730-2,300 million and for pangas catfishes nei at 870-2,600 million, and it seems less likely that that the true numbers of fish represented by these categories will fall outside these estimated ranges.

5.1.3. Estimating numbers for species without an estimated mean weight

The extrapolation of generic mean weights to estimate fish numbers for species categories without an EMW is inevitably speculative and may therefore have produced an underestimate or overestimate of the numbers of farmed fish of these species. The method assumes that the overall average weight for species categories without an EMW is similar to the extrapolated generic mean weight, which was used to estimate their numbers.

5.2. Fish mortalities not included in this estimate

This estimate of fish numbers includes only those represented by FAO recorded farmed fish production statistics for 2010. It does NOT include the following:

- Marine or freshwater invertebrates
- Amphibians or reptiles
- Farmed fish that die before harvest
- Farmed fish culled for disease control purposes
- Farmed fish removed and killed for stock population control purposes
- Farmed fish killed by predator fish stocked with them to control numbers
- Small farmed fish fed live to predatory farmed fish
- Fish killed to extract hormones for breeding purposes
- An accurate estimate of numbers of fish farmed for bait
- Fish farm escapees
- Fish killed during capture for farm re-stocking
- Mortalities amongst, or culls of, wrasse fish kept to control parasites on salmon
- Fish released from hatcheries
- Culling of unwanted fish species in fish culture ponds
- Wild fish killed by environmental impacts of fish farms e.g. increased sea lice
- Reduced survivability in offspring from wild fish/fish farm escapee interbreeding
- Wild animals killed as a result of predator control measures
- Fish caught from the wild to feed to farmed fish.

The estimate does not include farmed non fish aquatic species such as crustaceans (e.g. prawns, shrimps, lobsters and crabs) or molluscs (e.g. mussels or oysters), for which the numbers may be great (see Fig.1.), or frogs. It excludes the mammals, birds and fish killed on fish farms deliberately (by shooting) or unintentionally (e.g. entangled in poorly fitted nets and drowned) by predator control measures.

The estimate does not include the farmed fish that die, are culled or escape before harvest since, although these may be recorded by the farmer, they are not included in FAO aquaculture production statistics. Mortalities can be caused by disease, algal blooms, predation, accidents (e.g. chemical contamination), during transport or from other unintended causes. In Scotland, for example, average survival rates tend to be below 80 per cent (Stevenson, 2007). As discussed in section 5.3, farmed fish can be attacked by external predators such as seals and birds, attacked by lice, by predators stocked with them to control numbers and can also suffer cannibalism.

In China, the predatory mandarin fish are sometimes stocked in polyculture with species such as crucian carp and/or tilapia whose offspring provide food for the mandarins. Mandarin fish are also reared in monoculture, in which case fry and fingerlings of other farmed fish, such as tilapia or a range of carp species, are added regularly as live food for the mandarins (Kuanhong, 2006).

Fish are farmed for bait as well as for food. Whilst these fish should be included in FAO farmed fish tonnage statistics (Table 6) it has been assumed, for the purposes of this estimate, that the total weight of farmed production of bait (and ornamental) fish is not a significant fraction of total farmed fish production and EMWs have been based on food fish sizes. However, since bait fish are very much smaller, they may represent additional large numbers of individuals. For example, according the US Department of Agriculture Census in 2005 (USDA, 2006), the live weights given for bait fish add up to 12 million pounds, or 5 thousand metric tonnes, compared to a total US farmed fish production tonnage 330 thousand tonnes in 2005. The numbers of bait fish given for farmed baitfish sold comprise over 940 million fathead minnows, 335 million feeder goldfish and nearly 560 million golden shiners, with an average weight of between 2-4 grams. Milkfish fingerlings have been used also as bait, either alive or frozen, for long-line tuna fishing (FitzGerald, 2004). Milkfish have been favoured for live bait as a species since they have the misfortune to be hardy enough to be able to survive both the crowded conditions in a live bait well on board ship and being impaled on hooks and sunk to depths, even to the extent that they could often be used more than once.

Sometimes fish farms are re-stocked with fry caught from the wild, the bycatch of which constitutes unaccounted fish deaths relating to fish farming activity. It is reported that capture of milkfish fry for aquaculture in inshore seine nets incurs 85% bycatch - fry of other species which are discarded on the beach to die (Naylor *et al*., 2000). Nor does the estimate include the numbers of wrasse "cleaner" fish that are caught from the wild and caged with farmed salmon to eat sea lice. Those surviving the stress of capture and transport to the farm can suffer starvation and predation from larger salmon, and they are generally killed after each production cycle to prevent disease transfer from one salmon batch to another (Stevenson, 2007). The estimate does not include the fish deaths incurred in the rearing and release of young fish from hatcheries with the aim of increasing numbers of fish in rivers and along coasts, as discussed by Braithwaite and Salvanes (2010). The numbers of wild fish that are deliberately killed by fish farmers as with some systems in China, for example, where unwanted fish species occupying a pond are sometimes killed with bleach before a pond is restocked with the preferred species (Gregory, 2007), are also beyond the scope of this estimate.

Environmental impacts of fish farming are likely to cause further unaccounted wild fish deaths. Salmon farms can increase the presence of diseases and parasites that may then be transmitted to nearby wild populations and escapees interbreed with wild fish to produce hybrids with low survival (Ford and Myers, 2008). It is reported that hundreds of thousands of hectares of mangroves and coastal wetlands have been transformed into milkfish and shrimp ponds, resulting in loss of fish nursery habitat (Naylor *et al*., 2000).

The greatest welfare impact on wild animals attributable to fish farming may be the tremendous numbers of small fish that are caught from the wild for use as feed, either as wet fish, in farm-made feeds or as fishmeal/fish oil. These again are not included in this estimate but are discussed in section 5.2.1. below.

5.2.1. Use of fish for non-food purposes

Fish have been caught from the wild for non-food purposes at least since the 1800s (Tacon & Metian, 2009), when the oil was extracted for industrial purposes (e.g. soaps and paints) and the remaining cake was used as a fertilizer. In the 20th century the solid fraction was rendered into fishmeal to provide a high-protein feed for pigs and poultry which, within the last 20 years, has been diverted mainly to aquaculture. The oil came to be used to make cheap margarine but is now similarly used mainly in aquaculture. It is a high value commodity supplying energy and essential fatty-acids, including long-chain omega-3, for farmed fish and, to a lesser extent, crustaceans. Separate non-food fisheries have also developed to provide fresh fish, partly for bait and pet-food, but mainly for direct use in aquaculture.

Estimated numbers of feed fish used in aquaculture

The total tonnages of wild-caught feed fish used for reduction to fishmeal and fisheries production for other non-food purposes are shown in Table 6[8]. These together average 23,681 thousand tonnes each year for 2005-9 and equal 31% of average total fish capture for that period at 76,986 thousand tonnes per year (FAO, 2012b).

Table 6. Fisheries capture for reduction and fishery production for other non-food uses.

Year	Fisheries capture for reduction (1000 t)	Fisheries production for other non-food uses* (1000 t)
2005	22,391	4,417
2006	18,239	4,578
2007	17,914	4,955
2008	18,186	4,900
2009	17,917	4,910
Average of above	18,929	4,752

Source: FAO yearbook. Fishery and Aquaculture Statistics. 2009 (FAO, 2009).
* Includes use of aquatic products for feed and bait, for ornamental purposes, withdrawals from markets and any other non-food use of fish production (e.g. fertilizers, medical uses). The extent to which this includes aquaculture production and non fish species is not clear.

It can be seen that an average of 18.9 million tonnes of wild-caught fish were used each year to make fishmeal and fish oil for the period 2005-9. The numbers of fish represented by this tonnage is more difficult to estimate because the species composition is not published, and a more cautious estimate has been made by the current authors of between **450** billion and **1,000** billion[9] individuals. This estimate is based on the numbers of fish caught for species that are reportedly mainly used for reduction, and corresponds to an overall mean weight of 18-41g for these "industrial" species (fishcount.org.uk, 2012b).

In addition to these, feed fish are often fed directly to farmed fish and crustaceans, either being fed alone or processed into farm-made feeds. The FAO currently reports that a further 4.75 million tonnes (Table 6) of wild-caught fish are used for feed, bait and other non-food purposes on average

[8] Note that figures for 2005-7 are lower than as given in Table 6 of the current authors' previous study (Mood and Brooke, 2010), taken from FAO data for 2007 (FAO yearbook. Fishery and Aquaculture Statistics 2007). The FAO has since revised downwards the non-food estimates for China's consumption to reflect improved national information on the sector.
[9] Between 448,819 and 1,025,575 million rounded to 2 significant figures.

each year. A higher figure is given by Tacon and Metian (2009) who estimate, based on a range of data sources, that between 5.6 million and 8.8 million (for which the mean is 7.2 million) tonnes of wild feed fish were used in aquaculture as direct feed, or for farm-made feed, in 2006[10] (mostly in Asia). These species include small pelagic fish as well as other fish of low commercial value (sometimes termed "trash" fish, a pejorative term indicative of a mindset which places no value on sentient wildlife) and juveniles of commercially important species. If Tacon and Metian's figures are correct, and if it is assumed that the average weight of all these feed fish is similar to that of the key industrial species, estimated at 18-41g (as discussed above), then the numbers for these additional feed fish are estimated by the current authors to be between **140** billion and **490** billion[11].

The proportions of feed fish consumed as fish oil and fishmeal in aquaculture are estimated by Tacon and Metian (2009) at respectively 88.5% and 68.2% of global fish oil and fishmeal prod-uction (Table 7). Those consumed as fish oil and fishmeal specifically by farmed fish are estimated at respectively 76.4% and 47.2% of global production (Table 7). If the proportions by numbers are similar to the proportions by meal/oil tonnage, this suggests that respectively 400-910 and 310-700 billion feed fish are used to make fish oil and fishmeal for aquaculture each year from the estimated total 450-1,000 billion fish used for reduction. Of these, respectively 340-780 and 210-480 billion feed fish are used to make fish oil and fishmeal fed to farmed fish. This estimate ignores any differences in oil and fishmeal yields between different feed fish species and the fact that some farmed species groups may be fed particular feed fish species. Combining the estimated 310-700 billion feed fish used for fishmeal consumed in aquaculture (which are also used for fish oil) with the estimated 140-490 billion fish fed directly to farmed fish and crustaceans gives a total range of 440-1,200 billion wild fish used entirely as aquaculture feeds.

As discussed in the section on rearing, with the exception of extensive aquaculture, farmed fish are provided with at least some feed which may be entirely of vegetable origin or may include some wild fish. Farmed marine fishes are largely dependent on fish meal and/or fish oil feed and include Atlantic salmon, gilthead seabeam and European seabass which, together with intensively farmed rainbow trout, dominate farmed fish production in the EU (see Fig. 5.) and Norway. As discussed below it is these species, which together form a relatively small proportion of farmed fish production tonnage, that consume a large part of the global fish oil and fish meal consumed by aquaculture.

Feeding purpose-caught wild fish to farmed fish is controversial. Many of the species caught for feed are also eaten by people (Shepherd *et al*., 2005; Froese and Pauly, 2011; fishcount.org.uk, 2012b) and using them for feed is therefore wasteful of scarce resources. Since most fish cannot manufacture essential fatty-acids (Kaya & Turan, 2008), but do metabolise them, it would seem a more efficient use of limited supplies of long-chain omega-3 fatty-acids for people to eat these fish, or to take the fish oil as supplements, rather than consume them indirectly as farmed salmon.

[10] Interpretation of this data is complicated by the fact that at the time of this study by Tacon and Metian, their figure was within the figure reported by the FAO for other non-food uses of fishery production besides reduction to fishmeal and fish oil, which it reported at 13.14 million tonnes for 2006 in the *FAO Yearbook Fishery and Aquaculture Statistics 2006* (FAO, 2006). However, in the following year's publication, the figure had been revised downward to 6.02 million tonnes for 2006 in the *FAO Yearbook Fishery and Aquaculture Statistics 2007* (FAO, 2007), equating to a 54% decrease. The FAO have advised that the bulk of the change was linked to the revision of data for China. (FAO, 2012, personal communication).
[11] Between 136,585 and 488,889 million rounded to 2 significant figures.

Some feed fish species, such as blue whiting (Institute of Marine Research, 2011), are being fished beyond sustainable limits for the species and the wider ecosystem impacts of removing large numbers of these feed fish from the marine food web are a cause for concern since the impact is uncertain (Huntington, 2004; Watson *et al*., 2006). If more of them were left in the sea, these small fish would provide ecosystem services, forming part of the diet of other commercial fish as well as of marine birds and mammals.

Another controversial issue is the capture of juveniles of commercially important species along with the target feed fish catch. Young herring shoal with sprats (Hopkins, 1986) and young whiting and haddock shoal with Norway pout (Huse *et al*., 2003; Eliasen, 2003) and fishery closures are often timed to try to reduce this bycatch. In addition, according an FAO publication, it has been estimated that between 18-32% of "trash fish" caught off the Gulf of Thailand were juveniles of commercially important species (Funge-Smith *et al*., 2005).

Use of fish meal and oil to feed farmed fish

Fishmeal and fish oil are produced from purpose-caught "industrial" feed fish combined with trimmings from food fish. According to the International Fishmeal and Fish Oil Association (IFFO, 2011), the total raw material going into fishmeal and fish oil production is about 21 million tonnes per year of which about 5 million tonnes, or 25%, comprises trimmings from whole fish and crustaceans landed for human consumption.

Currently most fishmeal and fish oil are fed to farmed fish or shrimps, with most other fishmeal being fed to farmed pigs and poultry and most other fish oil consumed as food (Pike, 2005 cited in Tacon *et al*., 2006). Tacon and Metian (2008) conducted a study into the use of fish oil and fishmeal in industrially formulated feeds for farmed fish and crustaceans in 2006. They estimated that 68.2% of global fishmeal production and 88.5%[12] of global fish oil production was used for this purpose (Table 7). They calculated that this consumption of fish oil and fishmeal in 2006 was equivalent to 16.6 million tonnes of small pelagic forage fish. Note that this tonnage represents about 70% of the total wild fish consumed in aquaculture feeds in 2006 (taking the total to be this 16.6 million tonnes together with Tacon and Metians's (2009) estimated 5.6-8.8 million (for which the mean is 7.2 million) tonnes of feed fish that were fed directly to farmed fish, as discussed earlier).

As shown in Table 7, in 2006 farmed trout, salmon and other marine fish, comprising just over one tenth (10.6%) of total farmed fish and crustacean production tonnage, consumed three quarters (76%) of the total fish oil used in aquaculture. They also consumed over one third (39%) of the total fishmeal used in aquaculture. Farmed salmon species, comprising just 4.3% of the total farmed fish and crustacean production, consumed 43% of total fish oil, and 15% of total fishmeal, used by aquaculture.

In the same 2008 paper, Tacon & Metian also discovered a wide range in the rates at which fishmeal and oil were used in the diet (Table 8). Unsurprisingly, the highest levels on inclusion of fishmeal

[12] Figures used by Tacon and Metian for total global fishmeal and fish oil production in 2006 are as reported by the FAO. In more recently issued FAO data (FAO, 2012c), these figures are slightly revised at respectively 5,452 and 956 thousand tonnes of fishmeal and fish oil. Using these revised figures would give the amount of fishmeal and fish oil consumed in industrially formulated aquaculture feeds in 2006 as respectively 68.3% and 87.4% of global production.

Table 7. Percentage estimated global consumption of fishmeal and fish oil in formulated aquaculture feed by species (after Tacon & Metian (2008)).

Reported species group in Tacon & Metian study[1]	Aquaculture production 2006		% of consumption of global **fish oil** used in industrially formulated aquaculture feeds		% of consumption of global **fishmeal** used in industrially formulated aquaculture feeds		% of consumption of global **fish oil** 2006	% of consumption of global **fishmeal** 2006
	From FAO[2]. ('000 tonnes)	*% total farmed fish & crustacean production[3]*	*2006 data from Tacon & Metian study[1]*	*From IFFO[4]*	*2006 data from Tacon & Metian study[1]*	*From IFFO[4]*	*Extrapolated from Tacon & Metian study[1]*	*Extrapolated from Tacon & Metian study[1]*
Salmon (incl. Atantic, coho, chinook)	1,465	4	43	45	15	17	38	10
Marine fish excl. salmon	1,536	5	20	14	18	23	18	12
Trout (incl. rainbow, sea, brook)	632	2	13	11	6	6	12	4
Marine shrimp	3,164	9	12	10	27	24	10	18
Catfish	1,809	5	4	1	5	1	3	4
Eel	266	1	2	1	6	5	2	4
Tilapia	2,326	7	2	3	5	2	2	4
Freshwater crustaceans	1,066	3	2	1	4	5	2	3
Misc. freshwater carnivore fishes	777	2	1	<1	3	<1	1	2
Milkfish	585	2	1	1	<1	1	1	<1
Chinese carps	10,225	30	0	13	11	17	0	8
Total of above	23,851	70	100	100	100	100	**88.5**	**68.2**

1. Estimations from Tacon and Metian study (Tacon and Metian, 2008).
2. FAO FishStat data given by Tacon and Metian (2008).
3. Total production of farmed fish and crustaceans equated to 34,194 thousand tonnes in 2006 (FAO, 2012a).
4. IFFO estimations (Jackson, 2007) cited in Tacon and Metian(2008).

Table 8. Global inclusion rates for fishmeal and oil in compound feeds in aquaculture (after Tacon & Metian (2008))

Species group	Fish oil inclusion		Fishmeal inclusion	
	Range (%)	Average (%)	Range (%)	Average (%)
Salmon	9 - 35	20	20 - 50	30
Trout	3 - 40	15	15 - 55	30
Marine finfish	1 - 15	8	7 - 70	32
Eel	0 - 24	5	40 - 80	55
Shrimp	0.5 - 10	2	5 - 40	20
Catfish	0 - 15	1.7	3 - 40	10
Freshwater crustaceans	0 - 3	0.75	5 - 25	15
Tilapia	0 - 10	0.5	0 - 20	6
Non-filter feeding Carp	0 - 2	0	0 - 20	5

and fish oil in compound feeds are for carnivorous species such as salmon, trout, eel, other marine finfish and for some species of shrimp. Notably even the lowest diets for salmon had at least a minimum content of 29% for fishmeal and fish oil combined. Fishmeal and oil are also included in the diets of omnivorous and herbivorous species of tilapia and carp, but notably diets for at least some species of these groups contained none at all.

The authors go on to argue that substituting fishmeal and oil with alternative ingredients will be easier to achieve with herbivorous and omnivorous species. They also suggest that trimmings from aquaculture may become a more important source of fishmeal and oil in the future.

Table 9. Numbers of animals killed for food globally each year

Species	Killed for food each year worldwide		Killed for food each year in the European Union	
	Weight (t)	Numbers (millions)	Weight (t)	Numbers (millions)
Pigs	109,215,302	1,375	22,821,180	255
Rabbits	1,693,022	1,196	479,209	327
Sheep	8,532,257	538	899,759	61
Goats	5,168,151	426	94,291	9
Cattle	62,325,464	296	8,140,506	29
Total mammals	**194,731,109**	**3,933**	**32,732,853**	**681**
Chickens	86,205,014	55,334	9,687,909	6,357
Ducks	3,980,136	2,708	490,138	166
Turkeys	5,292,778	632	1,686,289	197
Total birds	**98,089,870**	**59,371**	**11,931,430**	**6,740**
Farmed fish (estimated numbers)*:				
Carp family (*cyprinidae*)	24,031,913	19,000 - 72,000	79,160	36 - 170
Tilapias (*cichlidae*)	3,497,391	5,500 - 14,000	248	<=1
Catfish families (Siluriformes)	3,205,031	3,800 - 12,000	7,605	5 - 18
Salmon, trouts, chars (*salmonidae*)	2,366,567	410 - 4,200	373,601	68 - 1,000
Milkfish (*chanidae*)	808,559	1,600 - 3,200		
Seabreams, porgies (*sparidae*)	263,190	580 - 810	88,021	220 - 290
Seabasses, Striped bass (*moronidae*)	130,126	260 - 320	54,038	110 - 130
Total farmed fish	**39,174,297**	**37,000 - 120,000**	**635,822**	**460 - 1,700**
Wild fish (estimated numbers)*:				
Caught for fishmeal & fish oil	18,929,000	450,000 - 1,000,000		
Fed directly to farmed fish & shrimp	7,200,000	140,000 - 490,000		
Total wild fish	**77,388,322**	**970,000 - 2,700,000**		

Source: Farmed mammals and birds - FAOSTAT data for 2010, website accessed 9 April 2012 (FAO, 2012d).

Farmed fish - Figures available in Spreadsheet5_emws_country_year.xls from fishcount.org.uk (2012a).

Wild fish caught for fishmeal and oil - Average annual tonnage and numbers 2005-2009 (Table 6 and fishcount.org.uk (2012b))

Wild fish fed directly to farmed fish & crustaceans - Tonnage for 2006 (Tacon and Metian, 2009). Numbers based on 2006 tonnage (see text).

Total wild fish - Average annual tonnage and numbers 1999-2007 (Mood and Brooke, 2010).

* Estimated fish numbers are given to 2 significant figures.

5.3. Animal welfare implications

The increasing global number of farmed fish slaughtered for food each year, estimated for 2010 at between 37-120 (midpoint around 80) billion, may already exceed the number of farmed mammals and birds reported by the FAO (63 billion in 2010), as shown in Table 9. In the EU, farmed fish numbers are lower but represent a significant proportion of farmed vertebrates slaughtered each year. EU farmed fish numbers are estimated at 460 million to 1,700 million, for which the midpoint of 1.1 billion equates to 15% of total EU farmed birds and mammals slaughtered in 2010 (most of these (86%) being chickens).

The magnitude of an animal welfare problem may be assessed as the product of the *severity of suffering*, its *duration* and the *numbers of animals affected* (WSPA, 2003). The large numbers of fish farmed multiply the prevalent welfare problems in their slaughter, transport, handling and rearing, for which the severity and duration of distress will often be high (as discussed later in this section).

Though this study focuses on numbers, it is also worth noting that the welfare impact of chronic stress resulting from poor environmental conditions during the animal's lifetime will also be multiplied by the greater *duration* of rearing for farmed fish as compared to other species. Fish farming in the EU is dominated by the intensive farming of trout and marine species. Farmed fish in Europe are generally reared to several months and often over a year, whereas chickens reared for meat in Europe are typically slaughtered at around six weeks of age (for example, the market size for rainbow trout can be reached in 9 months but fish may be harvested after 12-18 months (Cowx, 2005); European seabass and gilthead seabream farmed in cages in the Mediterranean take respectively 15-20 months and 12-18 months to grow to market size (Halwart *et al*., 2007) and the total production cycle for Atlantic salmon generally takes 2-3 years (Marine Harvest, 2010)). Therefore, although the numbers of farmed fish killed for food each year in the EU is around one sixth the total of all other vertebrates, the numbers of farmed animals alive (and those living under intensive conditions) at any one time in the EU may well be greater for fish than for mammals and birds combined.

Note that the following section is not intended to be a review of global farmed fish welfare, but rather seeks to outline some major welfare issues with reference to some reviews; scientific opinions and some general concerns of animal welfare organisations, beginning with a brief discussion of the acceptance of fish sentience and the inclusion of fish into animal welfare codes and regulation. The feeding of wild-caught fish to farmed fish is a separate, but related, environmental and animal welfare issue, and is discussed at the end of this section.

Acceptance of fish sentience

There is now widespread acceptance that fish species are capable of experiencing pain and distress and that their use in farming entails a responsibility for their welfare. In 2009 the Animal Health and Welfare scientific panel (the "AHAW" panel) commissioned by the EU's European Food Safety Authority adopted its "*General approach to fish welfare and to the concept of sentience in fish*" (EFSA, 2009a) in which, having examined the research that has been conducted for some fish species (a relatively small number of species have been studied), concluded that the balance of the evidence indicates that some fish species have the capacity to experience pain and fear. In "*Do fish feel pain?",* Braithwaite (2010) describes the many different pieces of evidence that together build up a

picture of fish as animals that, she concludes, have the mental capacity to feel pain. This evidence includes:

- The presence of nociceptors (pain receptors) in fish that are activated by noxious stimuli e.g. high temperature
- Activity in the brain during nociception
- Long lasting changes in behaviour following nociception including alteration to normal fear response
- The effect of analgesics (painkillers) on behavioural response to nociception
- Impressive mental abilities in fish (spatial learning, logical deduction, cooperative hunting).

There is enough evidence to at least to give fish the benefit of the doubt.

The policy statement of the World Organisation for Animal Health (OIE, 2010a) states: "*The use of fish carries with it an ethical responsibility to ensure the welfare of such animals to the greatest extent practicable.*" and it has published welfare guidelines on the transport (OIE, 2010b) and slaughter (OIE, 2010c) of farmed fish.

In the EU, fish are included in the minimum standards for the protection of animals bred or kept for farming purposes, as laid down in Council Directive 98/58/EC but these contain no detail on permissible rearing conditions such as stocking density or enrichment. Similarly, fish are included in the general minimum standards for farm animal slaughter (Council Directive 1099/2009 and 93/119/EC, which it replaces in 2013) but these contain no detail on permissible killing methods, and current practice (as discussed below) causes considerable suffering to fishes. However, the European Commission is due to report to the European Parliament and the Council by the end of 2014 on the possibility of introducing certain specific requirements for fish welfare at slaughter (Council Directive 1099/2009).

The EU's AHAW panel has published scientific opinions on the animal welfare aspects of husbandry systems for six farmed fish species (Atlantic salmon (EFSA, 2008a), trout (EFSA, 2008b), eel (EFSA, 2008c), common carp (EFSA, 2008d), seabass and seabream (EFSA, 2008e)) and, as discussed below, on the welfare aspects of the main systems of stunning and killing of eight farmed fish species (the above species, turbot and tuna). Two EFSA reports into the welfare of animals at slaughter (EFSA, 2004a) and during transport (EFSA, 2004b) both include a section on fish, also discussed below.

Elsewhere in Europe, Norway (see below) and Switzerland have passed legislation for the humane slaughter of farmed fish. In the UK, all key supermarkets have adopted humane slaughter standards for salmon and trout (Compassion in World Farming, 2012, personal communication). The certification of farmed fish in the Soil Association, RSPCA Freedom Food and Code of Good Practice for Scottish Finfish Aquaculture (CoGP) UK farm assurance schemes has also brought some welfare benefits and these have been compared for salmon by Compassion in World Farming and Onekind (2012). For example, the Soil Association and RSPCA Freedom Foods schemes require lower stocking densities than standard industry ones and set higher standards for water quality. All three schemes prohibit the use of genetically modified fish and require humane slaughter methods to be used. The Soil Association scheme also covers farmed trout and carp, while CoGP covers all

finfish aquaculture species. A Norwegian consumer survey has shown that consumers are prepared to pay more for better farmed fish welfare (Olesen *et al*., 2010).

Slaughter

Inhumane methods of fish slaughter are still widespread, if not predominant, in the EU and elsewhere. According to Gregory (2007), the traditional method for killing farmed fish is to allow them to asphyxiate in air or on ice, which is slow and distressing. Fish take a long time to lose consciousness when taken out of water to die of asphyxia, as compared to mammals and birds deprived of air, and this is particularly true of species adapted to low oxygen conditions. For example, in one study, EEG tests for brain function on trawl-caught cod that had been stored out of water for two hours and appeared motionless, showed signs of consciousness in all fish (fishcount.org.uk, 2012c). Some species, such as carp, that have the misfortune to be able to survive long periods out of water, are often transported without water (see section on transport). Fish species also take a long time to lose consciousness when killed by cutting major blood vessels without prior stunning, as compared to mammals and birds, and this will sometimes take 15 minutes or more (EFSA, 2004a).

Most of the world's farmed fish are produced in Asia and, in most Asian countries, the transport, handling and killing of fish usually does not conform to the OIE fish welfare guidelines (Leaño and Mohan, 2011).

In Europe, in a report on the welfare aspects of stunning and killing of commercial species, the EU's AHAW panel of scientists concluded that many existing commercial killing methods expose fish to substantial suffering over a prolonged period of time and that for many species, there is not a commercially acceptable method that can kill fish humanely (EFSA, 2004a). In 2009, the AHAW panel produced Scientific Opinions on the species-specific welfare aspects of the main systems of stunning and killing of the following fish species: Atlantic salmon (EFSA, 2009b); rainbow trout (EFSA, 2009c); carp (EFSA, 2009d); eels (EFSA, 2009e); seabass and seabream (EFSA, 2009f); turbot (EFSA, 2009g) and tuna (EFSA, 2009h). Inhumane, i.e. slow and painful and/or distressing, commercial methods of killing farmed fish include the following:

- Asphyxiation in air or on ice (carp, seabream, seabass, trout, turbot)
- Asphyxiation followed by percussive stun (carp)
- Carbon dioxide stunning (salmon, trout)
- Live chilling (carp, salmon, seabream, seabass, trout)
- Gill-cutting without prior stunning and allowing the fish to bleed to death (turbot)
- Eels are immersed in salt and gutted while many are likely to still be alive.

According to EFSA (2009g), turbot are not stunned prior to slaughter under commercial farming conditions and the most common method for killing turbot is asphyxia on ice. Turbot lying at the bottom can be subjected to considerable pressure due to the weight of ice and fish until death occurs and this may cause further pain and distress. In the commercial method of slaughtering carp, the fish are removed from water for a period of up to 20 minutes or longer before being percussively stunned with a priest.

By contrast, humane methods of killing fish are ones that cause an instant death or render fish instantly insensible to pain until dead. Potentially humane methods of killing fish include percussive and electrical stunning machines; percussive stunning with a club; spiking the brain and spiking combined with food-grade fish sedatives (licensed for use in New Zealand, Australia and Chile). Fish should be killed by gill-cutting immediately after stunning, to ensure death occurs before consciousness returns. To achieve humane slaughter these methods must be properly designed for the species in question and effectively carried out.

The AHAW panel believe that the majority of carp in the EU are sold alive or as a whole fish by supermarkets and minor retailers (a market sale or at the farm) and that less than 15 % of carp that are produced for human consumption are processed in commercial processing plants. Fish slaughtered at home may suffer prolonged transport without water, asphyxia, temperature shock, excessive handling, and ineffective stunning. Carp may be often kept alive for few days in homes in ad hoc water tanks, in which case, serious welfare deterioration may be expected (EFSA, 2009d). This treatment of live fishes is likely to be widespread throughout the rest of the world, where live marketing is also common, especially in Asia where most fish farming occurs. For example, of the two globally most numerous farmed species according to this study (Fig. 4 and Table 4), crucian carp is sold "entirely live or fresh" (Weimin, 2004a) and silver carp are normally bought live (Yang, 2005). Footage of commercial processing of pangasius catfish in Vietnam is available on YouTube (Cadovimex II, 2012). The fish are bled to death by cutting blood vessels through the gills arches on one side without prior stunning. Cutting blood vessels on one side only, is likely to result in a slower bleed-out and a slower death than cutting both. Prior to gill-cutting, the pangasius have experienced removal from water for some time, storage in baskets (fish piled on top of each other) and rough handling by the conveyor belt machinery. The processing operation appears to have been designed without any consideration of fish welfare, though the company targets the EU market and claims to have a number of EU certificates for food quality and safety, including recognition for BRC (British Retail Consortium) by SGS United Kingdom.

One positive development is the ban on the use of carbon dioxide stunning throughout Norway, which came into effect in January 2010 (HSA, 2010), by which time, 80% of fish abattoirs had installed either percussive or electrical stunning equipment. This shift to more humane stunning methods would not have occurred without the new legislative requirements (Bergersen, 2011). Swiss Animal Protection Law (Swiss Federal Council, 2011) prohibits all the inhumane slaughter methods listed above and prescribes that fish must be stunned before slaughter (by electrical stunning, blow to the head or spiking). There is one exception to this which is that cervical dislocation (neck breaking) is permitted instead of stunning (cervical dislocation is inhumane since it does not cause an immediate loss of consciousness). This seems to be mainly used by professional fishermen on wild perch caught in gillnets, rather than on farmed fish (Billo Heinzpeter Studer, 2012, personal communication). Switzerland is possibly unique in that its wild-caught fish are also covered by some animal welfare regulation during fishing.

Lines and Spence (2012) provide a short overview on the welfare of farmed fish at harvest and argue that, for most species, this could be improved by adopting and adapting existing procedures.

Rearing

Fish farming is commonly described as being extensive, semi-intensive or intensive. These terms are not sharply defined but generally relate to the level of inputs of feed and/or fertiliser and to stocking density. In extensive fish farming, which has been practised for many centuries, the fish feed entirely from the food web within the pond. This may be enhanced by the addition of fertilizer or manure to promote the growth of simple plants, in order to increase the yield of fish produced.

From this developed semi-intensive fish farming, in which the fish still obtain significant nutrition from the food web within their pond but are given some supplementary feed to improve their growth and permit a greater stocking density.

The end of the last century saw the development of intensive fish farming; high input systems with high stocking densities. High stocking densities mean that the fish do not obtain significant amounts of feed from their environment but are dependent on feed provided, and water must be replenished at a high rate to maintain oxygen levels and remove waste. Fish feeds may be of vegetable origin but nowadays typically include wild fish (discussed later in this section), which form an especially high proportion of the diet of intensively farmed carnivorous species. As with farmed mammals and birds, stocking densities are a key concern for animal welfare.

A review of the welfare issues in global aquaculture is given in *Animal Welfare and Meat Production* (Gregory, 2007). Methods of fish farming vary in how the fish are held, how the water is managed as well as the level of feed inputs. Holding systems include natural water resources e.g. a pond or part of a river, manmade ponds, tanks, concrete raceways and cages. In some systems the water flows through unaided, e.g. floating cages in an estuary or raceways through which water is diverted from a stream. In other systems the water is filtered using biological or mechanical filters and reused.

Welfare issues concerning rearing conditions are broadly summarised below:

- High stocking density (leading to poor water quality (lack of oxygen, build up of ammonia), crowding, increased susceptibility to disease and parasites)
- Social stresses (aggression leading to chronic stress and injury such as fin erosion, competition for food, cannibalism)
- Other environmental stresses (inappropriate temperature/salinity, insufficient hiding places/cover/protection, cage noise).

Fish confined in cages or ponds are unable to escape causes of fear and distress, such as low oxygen, cage noise generated in rough weather by the impact of waves and aggression from larger fish which can lead to injury, inability to feed and cannibalism. Most farmed fish species display cannibalism under certain conditions, with the exception of species with small mouths and some cichlid species such as tilapia that show a high degree of parental care (Gregory, 2007).

Crowding fish together encourages the spread of disease and of parasites which are a common cause of irritation. Sea lice feed on the skin and blood or fish, leading to ulceration, reduced growth and sometimes open wounds on the back of the head.

Besides cannibalism and parasites, farmed fish can also be attacked by predators (such as birds, seals, jellyfish). A study of farmed carp in the EU identifies predation as a very serious welfare issue, particularly in the pond environment where cormorants can induce stress in the fish, manifested by behavioural changes and associated reduction in feeding, and the birds may also inflict injury (EFSA, 2008d). Sometimes there is intentional predation by predators stocked with the main species to control their numbers, since uncontrolled natural breeding can be a problem for farmers. Non predatory fish (including tilapia) in mixed sex culture, that reach sexual maturity before reaching slaughter size and that will breed naturally in ponds, can produce offspring that compete for food with the parent generation, severely reducing growth rates. Tilapia are sometimes stocked with predator fish, such as catfish, to prevent this stunting. Tilapia that have become stunted are often removed to reduce densities, so the rest of the fish can grow larger, and discarded or converted to fish feed (Fagbenro, 2004).

Fish handling procedures, such as transferring fish between pens; grading (separating fish by size); vaccination by injection and chemical treatments to prevent disease/parasites, are further sources of stress which can result in injury that may lead to fatal infection.

The welfare problems in the intensive farming of Atlantic salmon, rainbow trout and Atlantic halibut are discussed a report by Compassion in World Farming and the World Society for the Protection of Animals, *Closed Waters: The Welfare Of Farmed Atlantic Salmon, Rainbow Trout, Atlantic Cod & Atlantic Halibut*, which also raises concern for the prevalence of cataracts, soft tissue malformations, skeletal abnormalities, pre-slaughter starvation; the impact of confinement on migratory species; of subjecting fish to prolonged periods of artificial light; high mortalities; the welfare of wrasse fish caged with salmon (see section 5.2); predator control measures and the welfare threats from possible increased use of tagging, by selective breeding for fast growth and genetic modification of fish (see below).

A similar range of welfare concerns (including water quality, stocking density, disease and parasites, genetic manipulation, handling, transport and inhumane slaughter) are raised in reports by the Humane Society of the United States (HSUS, 2009a and 2009b). In the United States, channel catfish make up over 80% of farmed fish production tonnage (81% in 2010) with most of the rest comprising Atlantic salmon, rainbow trout and tilapias. According to a source cited in an HSUS report (2009a), in the U.S. catfish industry mortality due to infectious disease can approach 30% of the population (Maurer, 2007). The HSUS states the importance of outcome based assessments of farmed fish welfare, including the use of directly observable indicators to measure fish welfare (as explained by FSBI, 2002) which include changes in skin or eye color; changes in ventilation rate; changes in swimming performance; reduced food intake; loss of body condition or impaired growth and increased incidence of disease).

In Vietnam, highly intensive farming of pangasius catfish has greatly expanded in the last decade to 1.1 million tonnes in 2010 (i.e. 78% global FAO reported *pangasius spp.* and *pangasius hypophthalmus* production, for which total estimated fish numbers are 1-2 billion), whereby pangasius are reportedly stocked at densities of 40-60 fish per m^2 in ponds and net pens, and even higher at 100-150 fish per m^2 in net cages (Griffiths *et al*., 2010). These extremely high stocking densities are made possible by a high rate of water exchange (net cages and pens being sited on river tributaries; ponds exchanging water with nearby tributaries by pumping or tidal exchange) and by the

ability of pangasius catfish to breathe atmospheric oxygen, which makes them able to tolerate low levels of dissolved oxygen and highly polluted water. According to one study by Belton *et al* (2011), mortality rates for the Vietnamese intensive pond system (stocked at 44 fish per m^2) are 25%, and are significantly higher than those in the much less intensive Bangladeshi pond system which equal 10%. The Bangladeshi pond system has lower stocking densities (6 pangasius fish per m^2 together with 10–20% filter-feeding carps kept as pond cleaners to eat up algae), maintains cleaner water (as indicated by the presence of these carp which have less ability to tolerate low oxygen pond conditions) and there is a lower propensity to use antibiotics for disease control (*Ibid*.).

The Swiss fish welfare group, Fair-fish, stresses the need for greater understanding of the natural ethology of fish in order to be able to design and manage systems with good welfare. There are now many species of fish being farmed (the FAO reports farmed fish production in 2010 for 244 fish species categories). Fair-fish is concerned that, although there is growing research which studies farmed fish in cages to assess their welfare, there seem to be few studies of these species in the wild aimed at understanding their natural needs and behaviour*"* (Billo Heinzpeter Studer, 2012, personal communication).

Fair-fish has developed a standard which aims to promote less intensive, more humane and environmentally friendly fish farming. This includes requirements for humane slaughter, careful handling, transport, breeding techniques (use of genetically modified and triploid fish are not permitted) and maximum allowed stocking densities. In addition, the stocking density at which fish are farmed must not impair their health and welfare, nor oblige the fish to shoal unnaturally. The installation must be designed to enable fish to perform the natural behaviours of the species, especially with regards to social interaction; to sheltering from light, current and from other fish; and to feed intake. The Fair-fish standard also restricts the amount of purpose-caught wild fish that may be used as feed (fair-fish, 2012).

Live Transport

Transportation of fish involves capture, loading, transport, unloading and stocking and so can induce large stress responses that can affect fish over a prolonged recovery period (Ashley, 2006). Poor conditions during transport, such as overcrowding and inadequate water quality due to insufficient oxygen and/or accumulation of carbon dioxide and ammonia, may result in irreparable damage to the fish and mortality (Håstein, 2004; Rosten, 2005 cited in Stevenson, 2007).

In 2004, EFSA (2004b) published a report on the welfare of fish during transport. In the EU, there are five main methods used to transport fish: well-boats, towing of cages by tugs, helicopter transport of open bins, insulated tanks and sealed plastic bags in insulated boxes, of which tanks and plastic bags are probably the most commonly used.

Fish transportation exposes fish to a range of stressful stimuli during pre-transport treatment (e.g. draining of ponds, pre-transport starvation to clear the gut); during loading and during the journey (inadequately maintained water quality leading to low oxygen levels and build up of CO_2 and excretory products). Fish have a stress physiology which is directly comparable to that of mammals and birds (EFSA, 2009a) and stressful stimuli have been shown to produce a wide variety of effects on transported fish such as metabolic hormonal and behavioural alterations. Immunosuppressive

effects and osmoregulatory problems can activate latent disease organisms and are the major cause of death when fish are handled and transported.

It has been shown for a number of species, that the initial loading of fish into the container is the most stressful component of transport. The skin surface of all fishes is extremely delicate and fish can suffer damage from netting which is the most widely used procedure. Use of pumps and transfer in water pipe systems can greatly reduce skin trauma and cortisone levels associated with such transfer.

Lowering the temperature under which fish are transported increases the stocking density that the fish can tolerate, since lower temperature slows the metabolism, but abrupt temperature changes are stressful to fish. Temperature changes to which fish are exposed during transport was highlighted as a major fish welfare problem in transport in a forum organized by the Humane Slaughter Association (HSA, 2006), as were the transfer of smolt to seawater before they are capable of coping physiologically, and mechanical breakdowns, which result in "significant mortalities" during transport.

Anaesthetics can help reduce stress but none are currently licensed in Europe for food fish. EFSA expresses concern that the use of anaesthetics and other welfare related compounds in the EU is currently greatly constrained by drug licensing arrangements. This means that compounds of generic availability or low cost are not legally available for use because of the high cost of licensing of all veterinary therapeutics.

Some species, such as pangasius, carp, tilapia and eel, are routinely transported by land without water. Though these species are able to survive such conditions, they are likely to be very stressed by lack of oxygen, by physical vibration, pressure and temperature (Lines and Spence, 2012).

Breeding and genetics

Artificial breeding processes and genetic manipulation can have serious welfare impacts on fish. Many species of farmed carp do not breed naturally in captive conditions and in consequence, it is common practice to induce production of sperm or eggs by injecting hormones (Weimin, 2004b). These are usually obtained by removing the pituitary glands of other breeding carp (Yang, 2005) which are "sacrificed" for the purpose. Even with species such as common carp which can breed naturally in ponds, hormone injection is often applied to control the time of spawning and maximise production (frontfish.co.uk, 2012). While natural spawning is sometimes allowed for breeding fish, many species are commonly stripped by hand to remove eggs and sperm (e.g. Peteri, 2004, frontfish.co.uk, 2012). Welfare certification schemes, such as the Soil Association, require salmonid broodstock to be anaesthetized or humanely slaughtered before stripping them (Soil Association, 2011) in order to mitigate the welfare impact of removing eggs artificially.

Uncontrolled natural breeding, on the other hand, of farmed fish species that do breed naturally in ponds generates another set of welfare issues as can methods of controlling such breeding. As discussed earlier, overpopulation of tilapia may be controlled by polyculture with predator fish. Other measures to control overpopulation include rearing mono-sex stock or breeding sterile fish using triploidy (see below).

Selective breeding for fast growth has created serious health and welfare for terrestrial farmed animals, and therefore presents the risk of analogous welfare problems being developed in farmed fish. The development of transgenic fish genetically modified, for example, to grow faster or to withstand harsh conditions, threatens to develop new welfare problems – two examples of which are given by Gregory (2007). Welfare problems in salmon genetically engineered with a growth hormone gene have included impaired immune function, enlarged head and bulging operculum sufficient to cause breathing difficulties in some individuals. Fish genetically engineered for tolerance to salinity could be caused suffering where the gene is under expressed in a proportion of individuals, especially if this results in a slow death.

Triploidy is a method of producing sterile fish with three sets of chromosome instead of the usual two, by subjecting newly-fertilised eggs to heat or pressure shock. The breeding of triploid salmon in aquaculture is used for reasons of preventing interbreeding with wild fish if the salmon escape and for improving flesh quality and growth rates, which are impaired by sexual development. Triploids are, however, susceptible to a range of health and welfare problems, including higher levels of spinal deformities, eye cataracts, poorer growth and lower survival rates (Stevenson, 2007).

Suitability for farming

Some fish species may be unsuitable for farming. For example, according to Gregory, eels are a solitary animal much of their lives. Under farm conditions, the dominant individuals are "feeders" and continue to grow whereas subordinates become "non feeders" and show signs of stress such as gastric ulcers, and there are frequent confrontations between them. The extent to which migratory species such as salmon suffer from confinement in sea cages, and to which solitary species such as halibut suffer from crowding, are questions that need to be addressed. It has been suggested that Atlantic cod may be more suitable for husbandry than Atlantic salmon since it may be less easily stressed (Huntingford and Kadri, 2009). Compassion in World Farming and the World Society for the Protection of Animals have argued for a moratorium on the introduction of new species into fish farming before humane rearing, transport and slaughter methods have been developed for that species (Stevenson, 2007).

The farming of carnivorous species, such as salmon and trout, has also attracted controversy on account of their requirement to consume more fish than they produce, predominantly met by feeding them wild-caught fish (in the form of fish oil and fishmeal) (see next section).

In addition to a requirement that fish reared must be suited to a diet that can be produced sustainably with limits on use of fishmeal and fish oil, the Fairfish standard discussed earlier requires that species to be farmed must be suited both to the local climate and to the system in which they are reared.

Feeding wild-caught fish to farmed fish

As discussed in section 5.2.1., the numbers of fish caught from the wild to produce fishmeal and oil, of which most is used to feed to farmed fish and shrimp, has been elsewhere estimated by the first current author at between 450 billion and 1,000 billion individuals (fishcount.org.uk, 2012b) for an average yearly tonnage of 18.9 million tonnes (Table 6), with a further estimated 5.6 million to 8.8 million tonnes fed directly to farmed fish and crustaceans (Tacon and Metian, 2009). From an animal

welfare perspective, this multiplies the welfare impact of fish farming many times over, since wild fish are caught and killed inhumanely (Mood, 2010).

The following calculations demonstrate the high animal welfare impact of raising farmed salmon on wild-caught fish. Calculating the weight of fish meat obtained per unit weight of wild fish consumed depends on which "fish-in-fish-out" ratio is used. The fish-in-fish-out ratio for salmon has been calculated at 4.9:1 by Tacon and Metian (2008), based on their high requirement for fish oil, whereas the fishmeal industry calculates a lower figure of 2.27:1 (Jackson, 2009).[13] Based on these, a typical 20g anchovy fed to a farmed salmon will suffer a stressful capture and death to produce just 4-9 g of salmon meat. Based on the estimate of fish numbers for species mainly used for reduction to fishmeal and fish oil, the feed fish used for reduction vary in size from 10 to 1000g with an average weight range of between 18 and 41g (fishcount.org.uk, 2012b). Depending on the species processed to make the fishmeal, a single 3.5 kg farmed salmon will entail the inhumane killing of tens or, more probably, hundreds of feed fish, even allowing for 25% of the diet based on trimmings. Farming of carnivorous fish therefore raises further ethical questions of proportionality, in addition to the environmental concerns more often discussed.

The continued capture of fish for non-food purposes, comprising over 30% of total wild fish capture tonnage, is widely controversial. It raises environmental concerns about the impact on wild fish populations, marine birds and mammals and the diversion of edible fish species to animal feed (see section 5.2.1). Since most fish caught for non-food purposes are consumed as feed in aquaculture, and since they represent large numbers of animals that are caught and killed by inhumane methods, this source of fish feed also greatly multiplies the animal welfare impact of fish farming. Reducing the amount of feed fish fed to farmed fish and crustaceans, by increased use of fish trimmings from capture fisheries and aquaculture, use of alternative feeds and/or farming fewer carnivorous species, could greatly reduce the welfare impact of fish farming if this is turn permitted a reduction in fishing pressure on species used for feed.

5.4. Conclusion

It has been estimated from FAO reported production tonnages, together with fish size data accessed from the internet, that the number of fish slaughtered each year is 37-120 billion, for which the midpoint is around 80 billion. This estimated range is based entirely on the data used; the probability that the actual figure lies within this range has not been calculated, but it is considered unlikely that the number represented by FAO production tonnages will fall outside it. It is also considered that that the true number is more likely to lie towards the midpoint than at either end of the estimated range.

The estimated numbers are based on estimated mean weights for fish species comprising 88% total farmed fish production tonnage. The most reliable estimates of fish numbers are likely to be those based on average weight/weight range data taken from more than one rank 1 reference (covering more than one country or the highest producing one) or from an FAO fish size reference that pertains to global aquaculture or the highest producing country. These total 24-89 (midpoint 56) billion and account for 76% of fish capture tonnage.

[13] Figures vary according to whether fish oil is seen as the limiting resource or whether fishmeal and oil should be seen as equally important.

These results suggest that the rising number of farmed fish slaughtered for food each year (for which both tonnage and estimated numbers have nearly doubled in the last ten years (Table 5)) has probably already overtaken the number of other vertebrate farm animals combined at 63 billion (Table 9). This estimate does not include the fish mortalities arising in fish farms prior to harvest, in wild fish capture for restocking or, in tremendous number, for feed. It also excludes environmental impacts on surrounding wildlife.

In the EU the estimated numbers of farmed fish, at 460 million to 1,700 million, are only about 15% of the number of other farmed vertebrate animals (86% of which are chickens) slaughtered for food each year. However, since EU fish farming is dominated by intensive farming of trout and marine fish and since farmed fish generally live for many months compared to the typical six week lifespan of a farmed chicken, the numbers of fish alive at any one time in the EU (and living under intensive conditions) may be greater than all other farmed vertebrate species combined.

There are serious welfare problems in the farming of fish in Europe and elsewhere, including inhumane slaughter methods, live marketing and the rearing of fish in intensive conditions with little understanding of their ethological needs. The magnitude of this welfare problem is multiplied by the great numbers of animals involved.

Appendix A

Comparison with previous study to estimate numbers of wild-caught fish

The overall method used in this estimate of farmed fish slaughtered globally each year is essentially the same as that used for the previous estimate of wild fish capture by the same authors (Mood and Brooke, 2010) but with fewer methods used to calculate estimated mean weights (EMWs) for farmed fish. In the previous estimate certain other methods (with a reliability ranking number greater than 2), often including fish lengths, were used to estimate a mean capture weight where fish capture weights were not available. In this current estimate, all EMWs are based on cited weight ranges, average weight ranges or common weights (i.e. data of reliability ranking 1 or 2). Overall, fewer species categories had EMWs calculated for them. Fewer fish size references were obtained and it was not necessary to eliminate any, as in the previous study, for size references that lacked credibility compared to other references. In the previous estimate, in order to estimate numbers for species without an EMW, a generic mean weight was obtained for each class of fish species. In this study only one generic mean weight range was obtained as there were no farmed species identified as being of any class other than "Actinopterygii".

Of the estimating methods used in this study, there is one difference in the reliability ranking scoring compared to the previous estimate. In this study, cited general and normal weight ranges have a reliability ranking of 1 compared to the previous study in which this was 2.

It had originally been intended that method 1, for EMWs based on cited average weights (see Table 1), would have a higher ranking than methods 2 and 3 (cited normal or general weight ranges). This would mean that if both a cited average weight and a cited general weight range were both obtained for a species, then only the average weight would be used to obtain an EMW on the basis that this is likely to be more precise. Had this been the case then narrower EMW ranges would have been obtained for six species (grass carp, catla, Atlantic salmon, rainbow trout, channel catfish and North African catfish) and the resulting total estimate would have been 39-100 (midpoint 71) billion individuals, i.e. the lower and upper ends of the estimated number range would have increased by 6% and decreased by 16% respectively. However, taking into account the geographical regions to which the cited fish weight/average weight ranges obtained for these species corresponded, it was considered generally more representative to include them all. Therefore the ranking for average weights and weight ranges were both assigned a ranking of 1.

Appendix B

Analysis of different types of fish size data used to estimate mean weights (EMWs).
This section details the analysis performed on the fish size data used in this study to estimate mean weights. The purpose of this analysis was to identify possible biases in the data, and the respective assumptions made, in obtaining EMWs for single species categories.

Table 10 shows different types of fish size data used in obtaining single species EMWs and their corresponding impact on the calculation of total estimated numbers. Each cited fish size data used for a given species affects the EMW for that species and thereby the numbers of fish estimated for it. Each cited fish size data also affects the generic estimated mean weight, since this is calculated from EMWs and capture tonnages. For simplicity the impacts of the different types of fish size data shown in Table 10 on the generic mean weight range and extrapolated numbers are ignored.

Table 10 Analysis of types of fish size data used to calculate EMWs for single species categories

	Type of reference	Single-species categories with EMWs based on this type of reference data		
		% of production	% of total numbers (lower)	% of total number (upper)
1	All types	83	83	83
2	Rank 1 refs.	82	81	83
3	Rank 2 refs.	<1	2	1
	EMWs based on rank 1 refs:			
4	> 1 ref.	71	54	64
5	> 1 ref. (for highest producing country or >1 country)	69	48	60
6	FAO *Cultured Aquatic Species Information Programme* weight range ref. for global aquaculture or highest producing country	44	44	50
7	> 1 ref. (for highest producing country or >1 country) and/or FAO *Cultured Aquatic Species Information Programme* ref. for global/highest producing country	76	66	73
8	Ref. pertaining to top producing country and/or global weight range	70	75	74
9	Ref. pertaining to top producing continent* and/or global weight range	99	98	99
10	Includes market size ref.	75	58	66
11	Includes table size ref.	32	32	34
12	Includes harvest size ref.	42	41	45
13	Includes grow out size ref.	14	8	15
14	Includes marketing website ref.	59	40	53
	Lower EMW value based solely on marketing website ref	27	14	17
	Upper EMW value based solely on marketing website ref	8	10	10
15	West Bengal sewage-fed culture systems	14	NA	15
16	Lower/upper EMW value based solely on ref dated < 1995	4	11	6
17	Incomplete data	1	<1	<1

* In this context the term "continent" is as used by Fishstat to summarise data and means Africa, the Americas, Asia, Europe or Oceania.

As shown in Table 10, single species category EMWs accounted for 83% of both total tonnage and total estimate numbers. Single species EMWs based on two or more rank 1 references, accounted for 71% of total tonnage. If all the references for an EMW pertain to just one country, then they will be less representative unless that country is the highest producing country. Excluding EMWs where references cover the same country other than the main producing one gives a total tonnage for single species EMWs based on two or more rank 1 references at 69% of total tonnage. Single species category EMWs based on either a global fish weight range, or a weight range for the highest producing country, provided by the FAO (in its Cultured Aquatic Species Information Programme webpages) accounted for 44% total tonnage. These FAO and multi-reference EMWs are likely to represent the most reliable single species EMWs, and together they correspond to 76% total fish tonnage and respectively 66% and 73% of the lower and upper total estimated number range i.e. 24-89 billion individuals. Single species category EMWs based on FAO and other references pertaining to the highest producing continent or globally accounted for approximately 70% of total tonnage and around 75% of the estimated numbers. Almost all single species category EMWs were based on references pertaining to the highest producing continent or globally (99% tonnage and around 99% estimated numbers).

Some fish weight data used to calculate EMWs may be less representative at the global level. If unrepresentative data is used together with other fish size data then the effect will tend to widen the EMW range and reduce, possibly unduly, the precision. It was noticeable that harvest weights for catla, mrigal carp and roho labeo reared in sewage-fed culture systems in West Bengal are smaller than other cited weights for the species and, since the relative tonnages are not available from FishStat, it is not possible to judge how representative these harvest weights are. Note that if this data related to West Bengal sewage-fed culture systems for these three species had been excluded from the EMW calculations, then the upper end of the estimated number range would have decreased by 7% to 113 billion individuals.

All data used to calculate EMWs were one of the following types: harvest size, market size, table size or grow out size, and it is assumed that these are all representative of fish size at harvest. Most fish sizes used were cited market sizes and single species EMWs based, at least in part, on market sizes comprised 75% of total tonnage. If any cited fish sizes were referring to gutted/headed weights rather than live weight then this would tend to under estimate fish weight and overestimate fish numbers. Gutted weights are sometimes given on seafood marketing websites. However, none of the cited fish sizes used in this study indicated a gutted/headed size, except for one reference document for Atlantic salmon giving HOG (head on gutted) weights and a conversion rate from live to HOG weight of 0.83, and it is an assumption of the study that all other fish sizes used are live weights, with no particular tendency to either under or over estimate average size at harvest. Single species EMWs based on data from marketing websites, rather than documents describing aquaculture, accounted for over half of total tonnage. If, as a test, these references were eliminated from all EMW calculations except where no other references were available for the species (such that less than 1% total tonnage and estimated numbers were based on marketing website references) then the total estimated numbers would have been calculated as 38-110 (midpoint 74) billion (i.e. respectively 102% and 90% of the actual lower and upper estimate). If the West Bengal sewage-fed culture system references were also eliminated, then the total estimated numbers would have been calculated as 38-96 (midpoint 67) billion individuals (i.e. 79% of the actual upper estimate).

It was noted that estimated number for common carp may possibly be an under estimate since these fish are known, from one reference, to be harvested at much smaller sizes in tropical countries but this reference was excluded from the EMW derivation because of the lower ranking for common or typical weights. If, as a test, common/typical weight references were assigned a rank of 1 instead of 2, then the total estimated numbers would have been calculated as 37-140 (midpoint 89) billion (i.e. the upper estimate would have increased by 15%).

There was one species category in this study for which the EMWs were based on incomplete data. The EMW for black carp is taken to be 2-3 kg when in fact the two references used only indicate above 2 kg or above 3 kg. This EMW may therefore be an under estimate and the 141-212 million black carp estimated could therefore be an over estimate for this species. A small number of single species EMWs, corresponding to 4% of total tonnage and respectively 11% and 6% of the lower and upper total estimated number range, were based on data that included some references dated prior to 1995. It is assumed that all cited fish sizes are indicative of fish size ranges for 2010.

This analysis of fish size data used revealed another departure from the basic rules of the method in the EMW for bighead carp. The EMW derivation included a cited marketable size of 0.75-1.5 kg for China, which was taken from an FAO reference. This reference also gave a market size for Vietnam of 2.5-3 kg, which had not been used for the EMW. The production tonnage reported by the FAO for category "Bighead carp" is nearly all from China (99%) and none of it is from Vietnam (where presumably bighead carp are reported under “cyprinids nei”). Had the EMW incorporated this market size for Vietnam, the lower end of the total estimated numbers would have been 36, instead of 37, billion.

Details of all references used to obtain estimate mean weights in this study are available on “drill down” web pages from the fishcount.org website (fishcount.org.uk, 2012a).

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