Estimating the Number of Fish Caught in Global Fishing Each Year

A Mood and P Brooke, July 2010
Corresponding author: A Mood, amood@fishcount.org.uk

Summary

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*. Previous studies suggest that fish experience pain and fear and that, for commercially-caught fish, the severity and duration are likely to be high. This study seeks to assess the numbers of such animals.

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

The estimated mean weights (EMWs) obtained in this study, and the fish numbers estimated from them will vary in their accuracy owing to the variability of fish sizes 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.

Nearly 70% of fish capture tonnage had a corresponding EMW (including single and multi-species categories), with the corresponding numbers estimated at between 0.68 and 1.97 trillion individuals. Extrapolating EMW data to estimate fish numbers for species without an EMW gave a total estimate of 0.97-2.74 trillion.

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 that this figure is indicative of the numbers caught. The most reliable estimates of fish numbers are likely to be those based on average weight data taken from more than one reference. These total 0.43-1.14 trillion and account for 29% of fish capture tonnage. In addition, the lower estimate for multi-species categories with an EMW is likely to be very conservative and totals a further 0.079 trillion for another 7% of fish capture tonnage. Combining these two figures brings the lower estimate for this 36% of capture tonnage to 0.51 trillion. It is concluded that the number of fish caught each year is of the order of a trillion.

This estimate does not include the fish caught in unrecorded fisheries capture, which may comprise up to nearly a third again of recorded fisheries capture tonnage, nor the unaccounted numbers of fish that escape from fishing gear but are fatally stressed or injured in the process.

The combination of the high severity and duration of suffering caused, and the huge number of animals affected, indicate that the treatment of fish in commercial fishing for both food and feed presents a major animal welfare problem. Potential measures for mitigating suffering in fishing, which may also benefit conservation and add commercial value, are suggested.

Introduction

A growing body of evidence points to the likelihood that fish have a pain system similar to that of other vertebrates and are capable of experiencing pain, fear and distress eg [1-3]. While some scientists continue to disagree [4] there is at the very least an argument for giving fish the benefit of the doubt. This brings an ethical responsibility to ensure the welfare of these animals "*to the greatest extent practicable*", a view adopted by the Organisation for Animal Health (OIE) in relation to fish farming [5].

The welfare of fish during commercial fish capture (still the largest area of human-fish interactions) has been described as a cause for "serious concern" in a welfare briefing published by the Fisheries Society of the British Isles [6].Wild caught fish are generally killed in ways that meet no standard of humane slaughter [7].

The FAO publishes statistics on the numbers of birds and mammals slaughtered for food each year, whereas FAO fisheries capture statistics are given only in capture tonnages. Although the number of Peruvian anchovy caught in 1971 has been estimated at 1.3 trillion (1,306 billion) [8] and the number of sandeels caught reported to be about 100 billion in "a good year" [9], literature searches by the current authors have not revealed any previous estimate of the total number of fish caught globally each year. This study seeks to assess a key aspect of the welfare impact of current practice in commercial fishing by estimating this number.

Methods

Fisheries capture statistics published by the FAO [10] were used, along with estimates of mean weights for different species, to estimate the global number of fish caught annually. These estimated average weights were based on, and extrapolated from, data for individual fish species obtained from a range of sources. The data used were as follows:

- fisheries capture tonnage by species category between 1999-2007 [10]
- 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 [11]
- an estimate of the mean weight for each fish single species or multi-species category above was obtained, or extrapolated from, fish-size data collected from a range of (mostly) internet sources.

According to the range of data available, both a lower and an upper estimated number of fish caught were calculated for each species or group of species. Data used included both marine and freshwater fish that are caught from the wild. Marine invertebrates and farmed fish are not included in this estimate.

FAO data varies in its specificity. Tonnages of fish caught are sometimes listed by single species categories (eg coho salmon), by multi-species categories (eg anchovies nei) or in generic categories without species information (eg marine or freshwater fishes nei).

Fish size measurements available from (mostly) internet sources, vary in form including “average”, “mean”, “typical”, “common” and “maximum” weights and lengths. A range of methods were used to obtain and, if necessary, calculate estimated mean weights for each FAO species category for which some size data were available. Further generic estimated mean weights were obtained by extrapolation for species for which no size data were available. Where possible, these extrapolations were based on data for fish species from the same taxonomic class.

All available data were used, whether from commercial, scientific, sporting or other sources. Methods of estimating mean weights were ranked on a scale of 1-7, where 1 is the highest ranking, according to their judged reliability (Table 1). In some cases, a ranking level was assigned to more than one method. Only data for the highest ranking method or methods available for each species were used in calculating estimated mean weights. In doing this, the lower and upper end of the estimated mean weight range were considered separately since fish size references may sometimes only apply to one end of the range.

Table 1. Reliability Ranking Scores of Methods Used to Estimate Mean Weights (EMWs) for Fish Species

Method (Type of Data)	Reliability Ranking of Length-Weight Conversion Data (if used)	Reliability Ranking
Average weight data	Not applicable	1
Common or typical weights, or normal weight ranges	Not applicable	2
Average, common or typical lengths, or normal length ranges	Good	3
	Less good	4
Any of the above where only the upper end of the EMW range was obtained	Mixed	4
Average weights based on maximum weights	Not applicable	5
Average weights based on maximum lengths	Good	5
	Less good	6
Average weights based on (rank 1-3) data for a similar species	Not applicable (not used on the species in question)	7

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 average 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 average weight (eg "average size is less than 1 pound") in which case separate references would be required for the lower and upper value and would most likely produce a range
- use of multiple fish length-weight relationship formulae to estimate weight at a given length will also produce a range.

Percentages of fish numbers estimated by methods at each ranking level are recorded in Table 2. It can be seen that almost 70% of fish capture tonnage had a mean weight estimated for it and 43-48% of estimated fish numbers are based on average weight data (a reliability ranking of 1).

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

Reliability Ranking[1] of the EMW	Average Annual Capture 1999-2007 (t)[2]	% Fish Capture	Estimated Number Lower (Millions)	Estimated Number Upper (Millions)	% of Total Number (Lower)	% of Total Number (Upper)
1	29,827,298	39	466,638	1,189,305	48	43
2	8,698,096	11	13,487	86,272	1	3
3	3,766,342	5	33,616	111,124	3	4
4	2,323,822	3	18,517	54,021	2	2
4 (upper EMW only obtained)	2,165,745	3	54,934	58,487	6	2
5	232,752	< 1	2,312	3,153	< 1	< 1
5 (based on max length)	11,485	< 1	9	12	< 1	< 1
6	363,824	< 1	2,605	3,993	< 1	< 1
7	235,387	< 1	6,192	28,978	1	1
Multi-species categories	5,400,678	7	78,876	438,735	8	16
Total capture with EMWs[3]	53,025,428	69	677,186	1,974,079	70	72
Total capture without EMWs[4]	24,362,894	31	296,785	761,500	30	28
Total fish capture	**77,388,322**	**100**	**973,971**	**2,735,579**	**100**	**100**
Total fisheries capture[5]	92,242,653					

1. See Table 1 for the methods that correspond to each reliability ranking.
2. Source of capture tonnages: FAO FishStat Plus "Capture Production 1950-2007 (Release Date: February 2009)".
3. See Table 3.
4. See Table 4.
5. Includes invertebrates eg crustaceans.

Where the upper and lower ends of an estimated mean weight (EMW) have a different reliability ranking, the reliability ranking indicated in Table 2 will be the lower ranking of the two, ie the highest number. In cases where only an upper end of an estimated mean weight range was obtained (eg a single reference giving an average weight of "less than 1 kg"), the reliability ranking indicated in Table 2 will be "4 (upper EMW only obtained)" to reflect the likelihood that it is an overestimate of the average weight.

All data were held on a MySQL database.

Multi-species categories

For multi-species categories (eg jack and horse mackerels nei, sardinellas nei), 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 [12] together with any estimated mean weight data for relevant species. Relevant species are those which, according to fishbase.org, are both:

- distributed in an ocean or inland water region from which at least 20% of global capture was recorded and
- of commercial or subsistence importance.

The ocean or inland water region(s) from which capture was taken was determined from FAO fisheries capture statistics [10]. Occasionally the estimated mean weight of a larger species was used in place of that for the smallest or largest species where respective weight data were not available.

Estimates based on length-weight relationships

Where average weight data were not available, it was possible in some cases to estimate weights from lengths using one or more length-weight relationships. Fish length-weight relationships follow the formula:

$$Weight=a*Length^b$$

where a and b are constants which vary with species, of which b is nearly always a value between 2.5 and 3.5 [13]. Fish length-weight relationships are generally given on fishbase.org [12] for a particular species over a length range and for a length type (eg "total", "standard" or "fork" length). Length-weight relationships were used, wherever possible, that corresponded to the species in question and the length and length type being converted. In these cases, the available length-weight data were classed as "good" and a length-weight reliability ranking of 1 was assigned. It should be noted that this length-weight reliability ranking is distinct from the reliability ranking for the method of estimating mean weight. A length-weight reliability ranking of 1 corresponds to a method reliability ranking of 3, except where the length being converted is a maximum length (Table 1). In some cases, the only formulae available were outside the length range, had an unspecified length range or type, or were for different but related species (same genus or family). In this case the available length-weight data were classed as "less good" and a lower length-weight reliability ranking of 2 was assigned. As shown in Table 1, a length-weight reliability ranking of 2 corresponds to a reliability ranking for the method equal to 4 except when converting maximum lengths.

Fish lengths are expressed in a number of different length types, eg total length, fork length. Unspecified lengths in the fish size references were generally assumed to be total lengths. Sometimes it was necessary to convert a fish length to a different length type in order to use the available length-weight formulae. This was done using one or more length-length relationship formulae for the species, also taken from fishbase.org.

Estimates based on maximum weights or lengths

For some species the maximum published weight or length, as reported on fishbase.org [12], was the only size data available. To estimate a mean weight from a maximum weight, data were collected for all species for which both average (ie an estimated mean weight based on "average" or "mean" weight data corresponding to a reliability ranking of 1) and maximum published weights were available. From this a mean fraction of mean to maximum weight was calculated (equating to 22-30%) and this was used to estimate a mean weight from a maximum weight. This mean fraction was calculated from 133 references relating to 108 species. These methods were assigned a reliability ranking of 5 or 6 (Table 1).

Estimates based on similar species

Where fish size data were not available for a species, estimated mean weights were sometimes based on an estimated mean weight (of reliability ranking 1-3) for a related species (same genus or family) of a similar or larger size (as judged from maximum sizes given on fishbase.org [12]). This method was assigned a reliability ranking of 7 (Table 1).

Estimates for species categories for which insufficient size data were available

Not all species categories (31% by weight, see Table 2) had a mean weight estimated for them. The capture tonnage for which no corresponding EMWs were obtained mostly comprised multi-species categories, typically encompassing a wide range of species making attempts at identification of the smallest and largest species particularly difficult, or even impossible as with the category "marine fishes nei". It also comprised a large number (several hundred) of single-species categories, each with relatively less significant capture tonnage or with no fish size data available.

The calculation of generic estimated mean weights by class, eg Actinopterygii (ray-finned fishes including teleosts), is shown in Table 3. These were obtained from the total tonnage and total estimated numbers for fish capture for single species categories with an EMW. Fish numbers for species without an EMW were estimated using these extrapolated generic ones (Table 4). For species of mixed or uncertain taxonomic class, which comprise marine fishes nei, freshwater fishes nei, finfishes nei and groundfishes nei, a generic estimated mean weight was derived from figures obtained for fish across all taxonomic classes.

Checks on references and estimates

As a general rule, references pertaining to the same reliability ranking were treated as if equally reliable. However, the following checks were performed to avoid the use of figures that are

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

FAO Category Type	Class	Average Annual Capture 1999-2007 (t)[1]	Estimated numbers lower (millions)[2]	Estimated numbers upper (millions)[2]	Generic mean weight (g)[3]
Single species	Actinopterygii	47,550,270	598,299	1,535,326	31-79
	Cephalaspidomorphi	144	2	3	48-81
	Elasmobranchii	73,809	9	14	5,108-8,275
	Holocephali	527	< 1	<1	1,155-1,575
	All classes	47,624,750	598,310	1,535,344	31-80
Multi-species	Actinopterygii	5,386,451	78,873	438,671	
	Elasmobranchii	535	<1	<1	
	Sarcopterygii	13,692	3	63	
	All classes	5,400,678	78,876	438,735	
All with EMW	**All classes**	**53,025,428**	677,186	1,974,079	

1. Obtained for each species category from FAO FishStat Plus "Capture Production 1950-2007 (Release Date: February 2009)".
2. Estimated numbers for each FAO species category were obtained by dividing capture tonnage for the category by its EMW (see text).
3. Generic mean weight (g) was obtained for single species categories, by class, by dividing Average Annual Capture 1999-2007 (t) by Estimated numbers upper (millions) and Estimated numbers lower (millions).

Table4. Estimated Numbers of Fish Caught Globally Each Year for FAO Species Categories with No Estimated Mean Weight Obtained in this Study.

Class	Average Annual Capture 1999-2007 (t)[1]	Generic mean weight (g)[2]	Estimated numbers lower (millions)[3]	Estimated numbers upper (millions)[3]
Actinopterygii	9,142,446	31-79	115,034	295,196
Cephalaspidomorphi	106	48-81	1	2
Elasmobranchii	753,499	5,108-8,275	91	148
Holocephali	7,413	1,155-1,575	5	6
Mixed class	14,457,654	31-80	181,632	466,091
Myxini	1,776	31-80	22	57
Total all classes	**24,362,894**		296,785	761,500

1. Obtained for each species category from FAO FishStat Plus "Capture Production 1950-2007 (Release Date: February 2009)".
2. See Table 3 for derivation of generic mean weights by class.
3. Estimated numbers (millions) were obtained by dividing Average Annual Capture 1999-2007 (t) by Generic mean weight (g).

doubtful. Of the 925 references obtained (688 from internet sources and 237 from 2 books), 783 (ranging in reliability ranking from 1 to 7) were treated as credible. 58 references were rejected for one of the following reasons:

- 26 data references were rejected because they could not be categorized as average, typical, common, normal or maximum weights or lengths (or weight/length ranges) for the species in question and did not give data from which a mean weight could be calculated

- 4 data references were entered on the system for "additional information only" purposes and rejected to exclude them from processing
- 16 market size references were rejected because it was not clear that they referred to ungutted sizes and for wild, rather than farmed, fish
- 12 data references giving fish lengths were rejected because insufficient length-weight data were available on fishbase.org to estimate a weight from the length.

A further 84 references were rejected, and 5 modified, in credibility checks as detailed below:

(a) If a typical weight or a fish length (or weight estimated from it) was equal to, nearly equal to or greater than the fishbase.org maximum published size for the species, then the corresponding reference was not used. Weights and lengths exceeding 90% of the maximum published size were treated as being nearly equal to it. 73 references were eliminated in this way.

(b) A minimum allowed mean weight was set and a small number of estimated mean weights (5 in total) were adjusted in accordance with it. The purpose of this was to reduce the risk of greatly overestimating fish numbers from very low estimated mean weights where less reliable data were used. This minimum allowed fish weight was set to the lowest estimated mean weight for any species obtained from data of reliability ranking equal to 1 (ie the lowest estimated mean weight based on average weight data) and equated to 3.1g. Any estimated mean weight range which was partly or wholly less than 3.1g was adjusted to this value.

(c) For estimated mean weights based on weight at maximum length, if the estimated mean weight exceeded an estimated mean weight for a larger related (same genus or family) species (based on data of reliability ranking 1, 2 or 3) then the estimate was considered to be unreliably large and the corresponding reference was not used. The estimated mean weight would instead be based on that of the related species (unless higher ranking data were also available). Comparison of estimated mean weights was based on the mid-point of each range. 4 references were eliminated in this way.

(d) A small number of references (3 in total) were eliminated because they appeared to be based on small fish, possibly not of commercial weight, being based on survey data and being very small as compared to other references for the same species.

(e) 4 data references giving maximum sizes were rejected because a greater maximum size for the species had been obtained elsewhere. For maximum sizes, the reference which gives the highest figure is used and any others are rejected.

Of the 783 references that were accepted as credible, 564 were used to estimate mean weights for 469 species categories, with the remaining 219 references not used due to relative reliability ranking checks.

Results

Table 5 shows the 12 FAO fish species categories with the highest average annual capture for 1999-2007 and the estimated numbers of fish for each. The total estimated numbers for fish species both with and without estimated mean weights are shown in Table 2 which gives the total estimated fish numbers for average annual capture in 1999-2007 as between 0.97 and 2.74 trillion fish.

The full results, including details of all estimated mean weights, are presented on a number of web pages, and 3 excel spreadsheets, available from the study home page at http://fishcount.org.uk/studydatascreens/frontpage.php).

Table 5. Top 12 Fish Species Categories by Capture Tonnage Reported by FAO

Species	Class[1]	Average Annual Capture 1999-2007 (t) [2]	Estimated mean weight (g) [3]	Generic mean weight (g) [4]	Estimated numbers (millions)[5]
Marine fishes nei	Mixed	9,684,795		31-80	120,000-310,000
Anchoveta(=Peruvian anchovy) (*Engraulis ringens*)	Act.	8,736,862	10-29		300,000-870,000
Freshwater fishes nei	Mixed	4,739,791		31-80	60,000-150,000
Alaska pollock(=Walleye poll.) (*Theragra chalcogramma*)	Act.	2,903,353	227-1,000		2,900-13,000
Atlantic herring (*Clupea harengus*)	Act.	2,165,610	100-600		3,600-22,000
Skipjack tuna (*Katsuwonus pelamis*)	Act.	2,161,174	2,000-10,000		220-1,100
Blue whiting(=Poutassou) (*Micromesistius poutassou*)	Act.	1,864,858	135-340		5,500-14,000
Chub mackerel (*Scomber japonicus*)	Act.	1,781,553	100-750		2,400-18,000
Chilean jack mackerel (*Trachurus murphyi*)	Act.	1,778,803	200-1,000		1,800-8,900
Japanese anchovy (*Engraulis japonicus*)	Act.	1,607,856	20-22		73,000-80,000
Largehead hairtail (*Trichiurus lepturus*)	Act.	1,298,327	32-713		1,800-41,000
Yellowfin tuna (*Thunnus albacares*)	Act.	1,257,110	5,000-20,000		63-250

1. Act. = Actinopterygii (ray-finned fishes).
2. FAO FishStat Plus "Capture Production 1950-2007 (Release Date: February 2009)".
3. Based on fish size data from various sources (see text).
4. See Table 3 for derivation of generic mean weights by class and all classes combined.
5. Estimated numbers are given to 2 significant figures.

Discussion

This section discusses the reliability of this estimate and, subsequently, the impact of unrecorded fish capture and animal welfare implications.

An EMW was obtained for nearly 70% of fish capture tonnage (including multi-species categories), for which the corresponding fish numbers were estimated at 0.68-1.97 trillion. Extrapolating EMW data to estimate fish numbers for species without an EMW gives the total estimate of 0.97-2.74 trillion.

Accepting that this estimate applies only to the fish caught in recorded capture published by the FAO, the potential for error in the 3 main parts of this estimate are discussed as follows:

1. estimating numbers for single species categories
2. estimating numbers for multi-species categories
3. estimating numbers for species without an estimated mean weight.

1. Estimating numbers for single species categories

The accuracy of the estimated numbers of fish caught for single species categories with an EMW will depend on the accuracy and representativeness of the EMWs obtained for them, and on the accuracy of FAO capture tonnages. It is unfortunate that the FAO does not publish data on mean weights of fish landed. Whilst these would be difficult to obtain, they would have value for conservation as well as welfare purposes.

This overall method has sought to obtain the best estimate within the limitations of the data available. Only the most reliable data was used for each EMW and, where possible, more than one such reference was used, improving its representativeness. Where estimated weights were combined (from several references or from several length-weight calculations) the full outside range was used in order to be fully inclusive of the fish size data used. As discussed in the method, a number of checks were used to eliminate the use of doubtful figures.

Assumptions

Assumptions were made relating to each estimating method, ie each type of data. It is assumed that:

- reported usual, common or typical sizes are indicative of average capture size
- length-weight calculations performed in this study give the average weight of a fish at the cited fish length
- reported average lengths are indicative of average capture size (accepting that weight at average length will be less than average weight where the capture population are not all of a similar size, owing to the approximately cubic relationship between weight and length)
- most fish caught are substantially smaller than the maximum published size and that the mean fraction of average weight to maximum weight calculated in this study for 108 species is indicative of that for other species.

Estimating weights from lengths using length-weight relationships is likely to result in a less accurate estimate of the mean weight, particularly where less reliable length-weight data (corresponding to a length-weight data reliability ranking of 2) was used.

The greatest assumptions were made for estimating methods with the lowest reliability, and these were more likely to be eliminated by the selection of references according to their reliability ranking. These assumptions apply mainly to capture for which the corresponding estimating method/s were used, though they will also have some effect on the extrapolated EMW data. Of the fish numbers estimated for single species categories with an EMW, less than 1% was based on EMWs obtained from maximum size data and 4-9% was based on EMWs obtained solely from average length data.

Specific assumptions concerning fish size data extracted from references are as follows:

- Where a weight is given separately for males and females, it was assumed that the two sexes are caught in roughly equal number and the EMW was obtained from the mean of the two weights. Similarly, where a length was given separately for males and females, the EMW was obtained from the mean of the two weight ranges obtained from converting the two lengths (using length-weight relationship formulae). Of the fish numbers estimated for single species categories with an EMW, less than 3% was based on EMWs obtained from the mean of male and female estimated mean weights.
- Fish lengths of unspecified length type were assumed to be total lengths rather than standard or fork lengths, unless the data suggested otherwise. Of the numbers estimated for single species categories, 18-22% was based on length-weight calculations where the length was assumed to be the "total length." For fish size references where this assumption is incorrect (where the length type was actually fork length or standard length), this would tend to underestimate fish size and so overestimate numbers. 7-14% of the numbers estimated for single species categories was based on length-weight calculations where the length was assumed to be the "standard length". For fish size references where this assumption is incorrect (where the length type was actually the fork length or total length) this would tend to overestimate fish size and so underestimate numbers.

Representativeness, accuracy and bias.

Fish capture sizes are likely to vary according to many different factors eg geographical region, water depth, season, type of fishing gear including mesh sizes of nets, effects of fishing on population size-structures, from year to year and according to other environmental conditions. Hence fish size data will vary in its representativeness. Data from less scientific sources is likely to be less accurate. Where average weight data were not available and other types of fish size data were used instead, the mean weights estimated are likely to be less accurate and may tend to over or underestimate actual mean weight, for example:

(a) it is suspected that reported typical or common weights may tend to be larger than the actual mean capture weight leading to an underestimate of numbers
(b) length-weight calculations inevitably introduce a degree of inaccuracy
(c) the weight at average length will tend to underestimate the mean capture weight where sizes vary significantly (since weight is approximately proportional to the cube of the length)
(d) where fish lengths are incorrectly assumed to be total lengths this will tend to underestimate fish weight (see section on assumptions above).

Biases may be associated with certain types of source document. For example:

- sport fishing websites may tend to exaggerate fish sizes
- references based on survey data may include fish below normal capture size
- seafood marketing websites may indicate above average sizes for species that are also used for reduction
- references based on less recent data may tend to over-estimate mean weight where this is in decline due to fishing pressure.

It is likely that many EMWs will underestimate mean capture weight while many others will be overestimates. The impact of biases is to some extent addressed by the wide range of document types used and by the use, where possible, of more than one reference in estimating mean weights.

The most accurate EMWs obtained for single species categories are likely to be those for which average, common or typical weights or weight ranges were available and that were based on more than one such fish size references. An estimated 0.43-1.17 trillion was calculated from such EMWs. Of this, 0.43-1.14 trillion related to EMWs solely based on average weight data, corresponding to 29% fish capture.

2. Estimating numbers for multi-species categories

Estimating the numbers of fish caught for multi-species categories with an EMW is more speculative because the precise species composition is unknown. The method used was to take the estimated mean weight for the smallest relevant species in the category, together with that for the largest relevant species, and combine them as a range. It assumes that fish not caught commercially or for subsistence, and fish that are (according to fishbase.org) only distributed in ocean or inland water regions from which less than 20% of capture is taken, do not significantly affect the mean capture weight. It seems likely that the species identified in this process as the smallest and largest relevant species will not always be the species with the smallest and largest actual mean capture weights. Determining the smallest and largest species was itself an estimate based mainly on maximum size data from fishbase.org, and therefore liable for discrepancy. However, because the method aims at the outside range it does give a wide margin for error, with the total number of fish for multi-species categories (with an EMW) estimated at between 79 and 439 billion. Although this is not a very precise figure, it seems unlikely that that the true numbers of fish represented by this multi-species capture tonnage lies outside this estimated range.

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 fish caught for these species. The method assumes that the overall average weight for species categories without an EMW, within a given taxonomic class, is similar to the extrapolated generic mean weight used to estimate their numbers. Capture for species categories with an estimated mean weight includes especially high numbers of Peruvian anchovy, equating to between 0.30 and 0.87 trillion fish, which may have skewed the extrapolated mean weight for class 'Actinopterygii' and that for all classes combined, leading to an overestimate of fish numbers. Since the method sought to avoid arbitrary rules, Peruvian anchovy were not excluded from the calculation of generic mean weights. It should be noted that had they been, the total estimated number would be from 0.86 to 2.38, instead of 0.97 to 2.74, trillion.

Fish capture not included in FAO capture statistics

This estimate of fish numbers includes only those represented by FAO recorded fish capture statistics for the period **1999-2007**. It does NOT include the following:

1. fish caught illegally
2. fish caught as bycatch and discarded (ie thrown overboard)
3. fish that die due to injuries, stress or exhaustion following escape from fishing gear
4. fish caught by lost and discarded fishing gears (”ghost fishing”)
5. fish caught for the fishers own use as bait fish but not recorded
6. fish caught for use as feed, either whole or chopped, on fish and shrimp farms but not recorded
7. all other unrecorded or unreported capture.

Global fisheries capture (finfish and shellfish) for the period 1999 to 2007 averaged 92.2 million tonnes per year, of which 77.4 million tonnes comprised fish species (Table 2). An estimated 7.3 million tonnes was discarded each year for years 1992-2001 [14]. Illegal, unreported and unregulated (IUU) fishing capture is estimated at between 11.06 and 25.91 million tonnes annually, in addition to discards [15]. Combining these figures gives a total estimated capture weight for discarded bycatch and illegal catch of 18-33 million tonnes.

According to a study published in 2001 [16] China, a target-driven economy, was actually over-reporting its fisheries capture by around 5 million tonnes per year in 1996-1999 (read from Figure 1 in the article). Allowing for this over-reporting by China, net estimated unrecorded fisheries capture (IUU and discards) therefore amounts to around 13-28 million tonnes each year, ie up to a nearly third again of reported fisheries capture.

In addition, unaccounted numbers of fish that escape from trawl nets are killed by the experience, and others are killed by lost or discarded gill nets that continue to fish. A study of survival rates for herring escaping trawl nets observed mortality rates ranging from 77-100% for escapee fish [17].

According FAO data [18], the capture of species caught for reduction to fishmeal and fish oil averages 22.2 million tonnes annually (Table 6), representing over a quarter of the 77.4 million tonnes of total fish capture (Table 2). According to an industry publication [19], the use of whole fish used to make fishmeal is “almost exclusively from small, bony species of pelagic fish”. The capture of species such as anchovies, capelin, sprat and sandeels for reduction to feed is therefore likely to constitute a large proportion of fish numbers. The 5 million tonnes of fishery production used for other non food purposes (Table 6), is likely to represent substantial additional numbers of wild caught fish, though it is not clear to what extent this includes non fish species and farmed fish. So too is the capture of fish for use as bait, since smaller vessels usually catch their own bait [20] which is presumably unreported.

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

Year	Fisheries capture for reduction (1000 t)	Fisheries production for other non food uses (1000 t)
2001	22,843	3,996
2002	24,086	4,209
2003	20,463	4,449
2004	24,594	5,374
2005	23,135	5,614
2006	20,130	6,019
2007	20,390	6,314
Average of above	22,234	5,139

Source: FAO yearbook. Fishery and Aquaculture Statistics. 2007 [18]

Conclusion

It has been estimated from FAO reported capture tonnages, together with fish size data mostly accessed from the internet, that the number of fish caught each year is 0.97-2.74 trillion. 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 that this figure is indicative of the numbers caught.

The most reliable estimates of fish numbers are likely to be those based on average weight data taken from more than one reference. These total 0.43-1.14 trillion and account for 29% of fish capture tonnage. It should also be noted that the lower estimate for multi-species categories with an EMW is very conservative since it is based on the species likely to be largest relevant one in each category. This lower estimate totals a further 0.079 trillion for another 7% of fish capture tonnage. Combining these two figures brings the lower estimate for this 36% of capture tonnage to 0.51 trillion.

It is concluded that the number of fish represented by average annual recorded capture tonnage (1999-2007) is of the order of a trillion. This figure does not include fish caught in unrecorded capture nor the unaccounted numbers of fish that escape from fishing gear but are fatally stressed or injured in the process.

Animal welfare implications

It has been proposed that the magnitude of a welfare problem can be assessed as follows [21]:

Magnitude of problem = severity * duration * numbers affected.

According to a Dutch study, most commercially-caught fish that are alive when landed die either from asphyxiation, or from a combination of asphyxiation and live gutting, with the use of potentially humane slaughter methods (percussive stunning and spiking) being the exception [7]. In this study observation of fisheries at sea revealed that, when landed on deck from a trawl, many fish were alive and conscious and that time to loss of consciousness was long. Time to lose sensibility depended on the treatment and was as follows:

Asphyxiation alone: 65-250 minutes

Asphyxiation and live gutting: 25-65 minutes.

Fish are sometimes put into ice or iced water as they asphyxiate. Live chilling has been shown to be stressful to fish and can also prolong the time taken to lose consciousness [22], thereby protracting the distress.

Fish capture usually involves some level of injury [23]. Gregory describes how fish caught by trawl nets experience a chase to exhaustion; panic as they are overrun by the net and move down it; and then compression, from which some will die, as they collect in the cod end [24]. A Canadian study of coho salmon captured by nets and hooks in commercial purse seine, troll and gill net fisheries found that all fish were severely exhausted when landed, regardless of the fishing method [25]. Fish caught in gill nets, or hooked on long lines, may remain captured for many hours or even days. One study found that, for sea bream captured by trammel net under experimental conditions, levels of stress (as measured by plasma cortisol levels) continued to rise the longer the fish remained in the net, even after 12 hours [26].

This estimate shows that the numbers of animals affected is very high. This figure, in the order of 1 trillion fish, is many times greater than the 57 billion birds and 3 billion mammals slaughtered for food each year [27]. This estimate suggests that, given the combination of the likely severity and duration of distress caused, and the number of animals involved, commercial fishing both for food and feed presents a major animal welfare problem.

Possible ways of improving the welfare of commercially-caught fish are discussed by the first author [28], including humane slaughter on landing and reducing the duration of capture. The severity and duration of suffering are likely to be particularly high for the fish impaled live on hooks as live bait, a common practice in long line fishing [24]. Alternative choices of bait, especially artificial baits or off-cuts, would reduce suffering considerably. Improving welfare could enable fishers to add value to their produce.

Mitigation of this welfare problem could also be achieved by reducing the numbers of fish caught, especially in addressing overfishing, illegal fishing and bycatch. Conservation measures which allow fish to grow larger before they are caught would also have welfare benefits.

Many of the fish caught are captured for feed, and for each such animal, the food benefit is often low. This is partly because feed fish species tend to be small and partly because it takes 2.5-5 kg of wild feed fish to produce 1 kg of farmed carnivorous fish [29]. For example, a 10g sandeel converted to fishmeal and fish oil dies a stressful death to produce 3g of salmon flesh, raising an ethical question of proportionality. Reducing levels of fishing for feed, especially where beneficial to marine food webs under threat and recovering stocks of larger fish species, could have a proportionately high impact on reducing animal suffering in fisheries.

References

1. Chandroo KP, Duncan IJH, Moccia RD (2004) Can fish suffer?: perspectives on sentience, pain, fear and stress. Applied Animal Behaviour Science 86 (2004) 225–250.

2. AHAW (2009) Scientific Opinion of the Panel on Animal Health and Welfare on a request from European Commission on General approach to fish welfare and to the concept of sentience in fish. *The EFSA Journal* (2009) 954, 1-26. Available: http://www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1211902344910.htm. Accessed 2010 Jan 6.

3. Nordgreen J, Garner JP, Janczak AM, Ranheim B, Muir WM et al. (2009) Thermonociception in fish: Effects of two different doses of morphine on thermal threshold and post-test behaviour in goldfish (Carassius auratus). Applied Animal Behaviour Science 119 (2009) 101–107.

4. Rose JD. 2002. The neurobehavioral nature of fishes and the question of awareness and pain. Reviews in Fisheries Science 10:1-38.

5. OIE (2008) Aquatic Animal Health Code. Appendix 3.4.1. Introduction to guidelines for the welfare of farmed fish. Available: http://www.oie.int/Eng/normes/fcode/en_chapitre_3.4.1.htm. Accessed 2010 Jan 6.

6. FSBI (2002) Fish welfare. Briefing paper 2, Fisheries Society of the British Isles, Granta Information Systems, Cambridge, UK. Available: http://www.fsbi.org.uk/docs/brief-welfare-refs.pdf. Accessed 2010 Jan 6.

7. Van de Vis, Kestin (1996) Killing of fishes: literature study and practice-observations (field research) report number C 037/96 1996 RIVO DLO.

8. Froese, R. 2001. Reply from Rainer Froese 17/01/2001. Fishbase.org forum correspondence webpage. Available: http://64.95.130.5/forum/reports/ForumsList_all.cfm on 6th August 2009. Accessed 2010 Apr 12.

9. Johannesson, B., Larsvik, M., Loo, L., Samuelsson, H., 2000. Aqua-scope learn more about the sea website. Available: http://www.vattenkikaren.gu.se/fakta/arter/chordata/teleoste/ammodyti/ammo1e.html. Accessed 2010 Apr 12.

10. FAO FishStat Plus (2009) Capture production 1950-2007 (Release date: February 2009). Food and Agriculture Organization of the United Nations, Rome, Italy. Available: http://www.fao.org/fishery/statistics/software/fishstat/en. Accessed 2010 Jan 7.

11. ASFIS List of Species for Fishery Statistics Purposes. February 2009 version of the ASFIS_sp.zip file accessed 2010 Feb 26 from http://www.fao.org/fishery/collection/asfis/en.

12. Froese R, Pauly D, editors (2009) FishBase.World Wide Web electronic publication. www.fishbase.org, version (10/2009).

13. Hart PJB, Reynolds JD editors (2002) Handbook of fish biology & fisheries, Volume 1. Blackwell Publishing. U.K.

14. Kelleher K (2005) Discards in the world's marine fisheries. An update. FAO fisheries technical paper 470. ISBN 92-5-105289-1. Food and Agriculture Organization of the United Nations, Rome, Italy. Available: http://www.fao.org/docrep/008/y5936e/y5936e00.htm. Accessed 2010 Jan 6.

15. Agnew DJ, Pearce J, Pramod G, Peatman T, Watson R, et al. (2009) Estimating the worldwide extent of illegal fishing. PLoS ONE 4(2): e4570. doi:10.1371/journal.pone.0004570

16. Watson R, Pauly D (2001) Systematic distortions in world fisheries catch trends. Nature 414, 534-536, 29 November 2001 doi:10.1038/35107050. Available: http://www.mindfully.org/Water/Fish-Catch-Distortions.htm. Accessed 2010 Jan 6.

17. Suuronen P, Perez-Comas JA, Lehtonen E and Tschernij V (1996) Size-related mortality of herring (*Clupea harengus* L.) escaping through a rigid sorting grid and trawl codend meshes. ICES Journal of Marine Science, 53: 691-700, 1996.

18. FAO (2009) FAO yearbook. Fishery and Aquaculture Statistics. 2007. Food and Agriculture Organization of the United Nations, Rome, 2009. Available: http://www.fao.org/fishery/statistics/programme/publications/yearbooks/en. Accessed 2010 Jan 12.

19. Green K (2009) Annual review of the feed grade fish stocks used to produce fishmeal and fish oil for the UK market. Sea Fish Industry Authority, UK. Available: http://www.seafish.org/resources/publications.asp. Accessed 2010 Feb 5.

20. Sainsbury, JC (1996) Commercial fishing methods: an introduction to vessels and gears. Fishing News Books, 3rd edition, June 1996. ISBN-13: 978-0852382172.

21. WSPA (2003) Concepts in animal welfare. An animal welfare syllabus. CD ROM format. University of Bristol, UK and the World Society for the Protection of Animals, London, UK.

22. Robb, DHF, Kestin SC (2002) Methods used to kill fish: field observations and literature reviewed. Animal Welfare 2002, 11:269-282.

23. Suuronen P (2005) Mortality of fish escaping trawl gears. FAO Fisheries technical paper 478. Food and Agriculture Organization of the United Nations, Rome, Italy. Available: http://www.fao.org/docrep/008/y6981e/y6981e00.htm. Accessed 2010 Jan 6.

24. Gregory NG (1998) Animal welfare and meat science. In: chapter 11. CAB International, November 1998. ISBN-13: 9780851992969.

25. Farrell AP, Gallaugher P, Clarke C, DeLury N, Kreiberg H et al. (2000) Physiological status of coho salmon (*Oncorhynchus kisutch*) captured in commercial nonretention fisheries. Canadian Journal of Fisheries and Aquatic Sciences 57: 1668-1678 (2000).

26. Chopin, FS, Arimoto T, Inoue Y (1996) A comparison of the stress response and mortality of sea bream *Pagrus major* captured by hook and line and trammel net. Fisheries Research 28 (1996) 277-289.

27. FAOSTAT data for 2008. Food and Agriculture Organization of the United Nations, Rome, Italy. Available: http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor. Accessed 2010 Feb 25.

28. Mood A (2010) Worse things happen at sea: the welfare of wild-caught fish. Available: http://www.fishcount.org.uk.

29. Jenkins DJA, Sievenpiper JL, Pauly D, Sumaila UR, Kendall CWC et al. (2009) Are dietary recommendations for the use of fish oils sustainable? Canadian Medical Association Journal, 2009 Mar 17;180(6):633-7. Available: http://www.cmaj.ca/cgi/content/full/180/6/633 on 6th August 2009. Accessed 2010 Jan 6.