Monterey Bay Aquarium
Seafood Watch®

Seafood Watch® DRAFT Greenhouse Gas Emissions Criteria for Fisheries and Aquaculture

Multi Stakeholder Group Draft

Contents

Introduction

The Monterey Bay Aquarium is requesting and providing an opportunity to offer feedback on the Seafood Watch Greenhouse Gas (GHG) Emissions Assessment Criteria for Fisheries and Aquaculture during our current revision process. Before beginning this review, please familiarize yourself with all the documents available on our Standard review website.

Providing feedback, comments and suggestion

This PDF document contains the second drafts of the GHG Emissions Criterion for Fisheries and the GHG Emissions Criterion for Aquaculture. A summary of the changes made to the first draft as a result of feedback during the first consultation process is provided at the end of the document, and individual changes are highlighted in the public comment guidance throughout. In their current form, these criteria are companions to the Fisheries and Aquaculture Assessment Criteria and are **unscored** due to data limitations. Seafood Watch will use these criteria to stimulate data collection and may score them in the future. "Guidance for public comment" sections have been inserted and highlighted, and various general and specific questions have been asked throughout. Seafood Watch welcomes feedback and particularly suggestions for improvement on any aspect of the Energy (GHG Emissions) Criteria. Please provide feedback, supported by references wherever possible in any sections of the criteria of relevance to your expertise. Please use the separate GHG Criteria Comment Form, which contains the excerpted "Guidance for public comment" sections from the PDF, to provide your comments.

These criteria were developed in close consultation with Dr. Peter Tyedmers of Dalhousie University, and Seafood Watch is indebted to Dr. Tyedmers for his time and dedication to this effort.

Seafood Watch DRAFT Energy Criteria for Fisheries and Aquaculture

MSG guidance - This section contains the draft guiding principle for the Energy (GHG Emissions) Criteria, which has been edited since the first public consultation to acknowledge the contribution of GHGs to the acceleration of climate change and to acknowledge that GHG emissions from food production are a significant fraction of anthropogenic GHG emissions.

Guiding Principle

The accumulation of greenhouse gases in the earth's atmosphere and water drives ocean acidification, contributes to sea level rise, affects air and sea temperatures, and accelerates climate change. GHG emissions from food production are a significant fraction of anthropogenic GHG emissions[1,2]. Sustainable fisheries and aquaculture operations will have low greenhouse gas emissions compared to land-based protein production methods.

MSG guidance - This section contains an overview of GHGs associated with seafood (and other protein) production methods, the draft rationale and summary for the Energy (GHG Emissions) Criteria for fisheries and aquaculture. This section has been edited since the first public consultation to include the overview of GHG emissions from fisheries and aquaculture. It also contains information about the GHG emissions included in our approach comparing up to the farm gate/dock emissions from seafood to land-based proteins (poultry and beef). In addition, we've clarified that we will be using the median values for comparative protein GHG intensities. Seafood Watch would like to be able to supplement or find replacement values for these comparative GHG intensities which factor soil CO_2 emissions into total GHG emissions, and welcome suggestions for comprehensive, robust values calculated with a uniform methodology for at least poultry and beef.

Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production

The range of GHGs associated with food production are diverse, and not always well described or quantified in life cycle analysis studies about these emissions (Henriksson *et al.* 2012). Here we describe the main GHGs associated with food production up to the farm gate or dock.

The primary GHG emissions associated with wild capture fisheries are from CO_2 emitted via direct fossil fuel combustion. Fossil fuels are used for propulsion, deployment and retrieval of fishing gears, powering cooling systems and other activities (Parker 2015). Other potentially significant GHG emissions from fisheries are associated with refrigerant use (Ziegler *et al.* 2011) and while not GHGs, short-lived, climate-forcing agents, namely black carbon or soot (incompletely oxidized organic carbon), are produced from fuel combustion (McKuin & Campbell In Review).

The GHGs associated with aquaculture production are more varied than those associated with wild capture fisheries and depend on the production method, species farmed and energy input regime (Pelletier et al 2011). These GHGs can include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Aquaculture CO_2 emissions are associated with farm level energy use and feed production. Feed production CO_2 emissions include both energy use emissions as well as non-energy emissions from soils. These soil CO_2 emissions are associated with land conversion and land use and are not always well described or quantified (Nijdam *et al.* 2012). N_2O emissions are associated with fertilizers used on feed crops (Pelletier & Tyedmers 2010) and from surface waters induced by microbial nitrification and denitrification (Hu *et al*. 2012). CH_4 emissions are associated with feed production and organic material degradation (Nijdam *et al*. 2012). For fed systems, feed production can represent a significant proportion of emissions (Pelletier *et al*. 2011).

[1] An overview of GHG emissions levels associated with food production (including fisheries and aquaculture) are available from the FAO (FAO 2011)

[2] An overview GHG emissions associated with household energy use in the US, including from food are available in Jones *et al.* 2011 and the associated household emission calculator is available at: http://coolclimate.berkeley.edu/calculator

The primary GHG emissions associated with land-based food production systems (including crop and livestock) include CO_2 from energy consumptive activities, CO_2 resulting from land use and land conversion, N_2O from fertilization of arable land and manure management and CH_4 emissions from ruminant livestock (Nijdam *et al.* 2012).

Rationale for and Summary of the Greenhouse Gas Criteria for Fisheries and Aquaculture

Seafood Watch is proposing to incorporate GHG emission intensity into our science-based methodology for assessing the sustainability of both wild caught and farmed seafood products. GHG accumulation in the Earth's atmosphere and water drives ocean acidification, contributes to sea level rise, affects air and sea temperatures and accelerates climate change. The proposed criterion will evaluate greenhouse gas emissions per edible unit of protein from fisheries and aquaculture operations up to the dock or farm gate (i.e. the point of landing), consistent with the scope Seafood Watch assessments.[3,4] Although a reliable index to define sustainable (or unsustainable) emissions of GHGs does not yet exist, as a baseline, we expect sustainable fisheries and aquaculture operations to have relatively low GHG emissions compared to the demonstrably high emission of some land-based protein production methods. Therefore, in order to classify the GHG emission intensity of seafood products, Seafood Watch initially proposes to relate them to those of intensive poultry and beef production up to the farm gate; with products falling below the median value for poultry production considered as low emission sources, those between the median values for poultry and beef as moderate emission sources, and those above the median value for beef as high emission sources. The advantage of this method is that it provides consumers with information concerning relative impacts of food choices, beyond just seafood, enabling them to compare GHG intensity across edible protein sources Currently, Seafood Watch does not have a scalar metric (as we do for the scored criteria) to score the fisheries energy criterion. GHG emission intensity per edible unit of protein for both fishery and aquaculture products will be calculated using species-specific edible protein estimates based on a literature review compiled by Peter Tyedmers (Dalhousie University, Nova Scotia, Canada). The edible protein estimate is based on the percent edible content and the percent protein content of muscle tissue for each species. Seafood Watch has discussed alternative standardization methods, such as excluding the percent protein content of muscle tissue (because invertebrates often have higher values), using wet weights or standardizing by product form, however, we are retaining the edible unit of protein standardization.

We are basing the farm gate median values for poultry (13 kg CO_2/Kg protein) and beef (134 kg CO_2/Kg protein) production on the supplementary information available from Nijdam *et al.* (2012), incorporating, if possible, a quantitative measure of uncertainty associated with these values, such as suggested in Henriksson et al (2015). The values from Nijdam *et al*. (2012) take into account both energy and non-energy GHG emissions, and include N_2O emissions from fertilization of arable land and manure, CH_4 emissions from ruminant production and manure, and CO_2 from fossil fuel energy. While this source acknowledges the importance of CO_2 emissions from soil cultivation, these emissions are not factored in. This likely will underestimate total GHG emissions. Currently, Seafood

---

[3] Seafood Watch assesses the ecological impacts on marine and freshwater ecosystems of fisheries and aquaculture operations up to the dock or farm gate. Seafood Watch assessments do not consider all ecological impacts (e.g. land use, air pollution), post-harvest impacts such as processing or transportation, or non-ecological impacts such as social issues, human health or animal welfare.

[4] Seafood Watch will direct users of our recommendations to available post-harvest greenhouse gas emissions calculators. Post-harvest emission assessment is outside the scope of the current standards review.

Watch is investigating comparative measures that incorporate soil CO_2 emissions from land use and land conversion to supplement the values from Nijdam *et al.* (2012).

For the wild-capture fisheries criterion, Seafood Watch proposes using Fuel Use Intensity (FUI) to derive GHG emissions intensity for the target fishery plus an FUI derived GHG intensity factor for bait usage when available. For the aquaculture criterion, we propose a measure of direct farm-level GHG emissions use plus an indirect measure of the GHG emissions associated with feed production.. Emissions associated with feed will be evaluated using a tiered approach, using specific ingredient information where available, and will be based on the dominant feed-ingredient categories (aquatic, crop and land animal) when less information is available. An additional grouping for aquatic ingredients may be possible. Values will be sourced from existing data.

Commercial fisheries and fish farms can achieve both environmental and financial benefits from reducing their energy use and non-energy related GHG emissions. We recognize, however, that data collection related to energy use and non- energy GHG emissions are currently limited, so our aim with these criteria are to incentivize the collection and provision of energy use data and non-energy GHG emission data from both fisheries and aquaculture operations to both track and improve the sustainability of seafood products.

In this first iteration, the Seafood Watch Greenhouse Gas Criteria will be unscored additions to the Seafood Watch criteria, and will be used as companion criteria to our sustainable fisheries and aquaculture assessments.

Wild Capture Fisheries Greenhouse Gas Criterion

MSG guidance - This section contains the introduction to the Fisheries Energy (GHG Emissions) Criterion. This section is substantively unchanged from the first consultation draft. Feedback on the methodology is requested in the Methods section.

Introduction

Fuel consumption is the primary driver of GHG emissions up to the point of landing for most wild capture fisheries, and is often the main source of emissions through the entire supply chain (Parker 2014, Parker & Tyedmers 2014). As such, measures of fuel consumption in fisheries provide an effective proxy for assessing the GHG emissions, or carbon footprint, of fishery-derived seafood products. As mentioned earlier, Seafood Watch acknowledges that for some fisheries other GHG emissions and other climate forcing agent emissions may be significant, and will consider these additional emissions as information becomes available.

Fuel consumption varies significantly between fisheries targeting different species, employing different gears, and operating in different locales. Fuel use also varies within fisheries over time: consumption increased in many fisheries throughout the 1990s and early 2000s, but has reversed in recent years as fisheries in Europe and Australia have both demonstrated consistent improvement in fuel consumption coinciding with increased fuel costs since 2004. As a result of this variation in fuel use, while it is difficult to estimate fuel consumption of individual fisheries without measuring it directly, generalizations can be made by analyzing previously reported rates in fisheries with similar characteristics. To this end, Robert Parker (PhD Candidate, Institute for Marine and Antarctic

Studies, University of Tasmania, Australia) and Dr. Peter Tyedmers (Dalhousie University, Nova Scotia, Canada) manage a database of primary and secondary analyses of fuel use in fisheries (FEUD – Fisheries and Energy Use Database). Using this database, the draft Seafood Watch wild capture energy criterion is based on "Fuel Use Intensity "(FUI, as liters of fuel consumed per metric ton of round weight landings, L/MT) converted to Green-House Gas Emission Intensity per edible unit of protein (KgCO_2 equivalent/Kg edible protein).

MSG guidance - This section contains the methodology for the Fisheries GHG Emissions Criterion and is substantively unchanged from the first consultation draft, except for the inclusion of example results in Figure 1 and the addition of a section on data collection.

Methods

The sections below describe how GHG emission intensity will be calculated for wild capture fisheries and how data quality will be described.

Part 1: Determining Greenhouse Gas Emission Intensity from Fuel Use Intensity

Fisheries were categorized by species, ISSCAAP (International Standard Statistical Classification of Aquatic Animals and Plants) species class, gear type and FAO area. These codes were used to match each fishery to a subset of records in the FEUD database[5] and each subset was analyzed using R to provide descriptive statistics and a weighted FUI estimate.

The subset of database records used to estimate FUI of each fishery was selected using a ranked set of matching criteria. The best possible match in each case was used. The following ranking of matches were used to choose the subset most appropriate for each fishery's estimate:

1) Records with matching individual species, gear type and FAO area
2) Records with matching individual species and gear type
3) Records with matching species class (ISSCAAP code), gear type and FAO area
4) Records with matching species class (ISSCAAP code) and gear type
5) Records with matching generalized species class (set of ISSCAAP codes), gear type and FAO area
6) Records with matching generalized species class (set of ISSCAAP codes) and gear type

For each fishery, after selecting the most appropriate subset of records, the following information was calculated:

- weighted mean (see below)
- unweighted mean
- standard deviation
- standard error
- median

[5] FEUD currently includes 1,622 data points, covering a wide range of species, gears and regions. The best represented fisheries are those in Europe, those targeting cods and other coastal finfish, and those using bottom trawl gear. Coverage of fisheries from developing countries is limited but increasing. The database focuses on marine fisheries, and includes very few records related to freshwater fishes (except diadromous and catadromous species which are fished primarily in marine environments), marine mammals, or plants.

- minimum value
- maximum value
- number of data points
- number of vessels or observations embedded in data points
- temporal range of data

The weighted mean, intended as the best possible estimate of FUI for each fishery, was calculated and weighted by both number of vessels in each data point and age of the data. To avoid biasing the analyses by large numbers of vessels reported in any one fishery, we used the log of the number of vessels in each data point. For example, the weights of two data points representing 1000 and 10 vessels, respectively, have a ratio of 3:1, rather than 100:1. In addition, data from more recent years were given greater weight (10% difference in weight between subsequent years).

$$w_i = \log10(v_i + 1) \cdot 0.9^{2014-y_i}$$

$$FUI = \sum_{i=1}^{n} \frac{w_i}{\sum_{i=1}^{n} w_i}$$

w_i = the weight given to data point *i*
v_i = the number of vessels reporting in data point *i*
y_i = the fishing year of data point *i*
n = sample size (number of data points included)

The weighted FUI means (L/t) were converted to GHG emission intensity (KgCO_2 equivalent/Kg edible protein) using a conversion factor of 3.12 kg CO_2 emitted per liter of fuel combusted and species specific percent yield and protein content of fish and invertebrate species. The GHG emission factor is based on an assumed fuel mix of bunker C, intermediate fuel oil, and marine diesel oil, and includes emissions from both burning the fuel and all upstream activities (mining, processing and transporting). This conversion factor was calculated using IPCC 2007 GHG intensity factors and EcoInvent 2.0 life cycle inventory database (Parker *et al*. 2014). The species specific percent yield and protein content of muscle data used to convert landed tonnage to edible protein were derived from Peter Tyedmers unpublished database of published and grey literature values.

Part 2: Quality indicators

The amount of data available pertaining to different species and gears varies dramatically, with some classes of fisheries being researched far more than others. As a result, the "quality" of FUI predictions varies. For example, Atlantic cod (*Gadus morhua*) fisheries have been researched extensively, and so FUI estimates for Atlantic cod are relatively reliable. Meanwhile, some fisheries have not been assessed, and so these estimates are based on other similar fisheries instead. Each FUI estimate generated here was given three quality ratings:

- a ***match quality*** indicator, reflecting the degree to which records in the database matched the species, gear and region criteria for each fishery. The species match is particularly reflected here, as all estimates match the gear type. *Low* = records match the generalized species class (e.g. crustaceans, molluscs); *medium* = records match the species class (e.g. lobsters); *high* = records match the individual species (e.g. Atlantic cod); *very high* = records match the individual species, gear type and region (*e.g.* Atlantic cod caught using longlines in FAO area 27). Table 2 shows a breakdown of assessed fisheries on the basis of the match quality.

Table 2. Criteria used to match Seafood Watch fisheries with FEUD records.

Matching factors	Number of FUI estimates
Individual species, gear type and FAO area	21
Individual species and gear type	15
Species class (ISSCAAP code), gear type and FAO area	64
Species class (ISSCAAP code) and gear type	54
Generalized species class (set of ISSCAAP codes), gear type and FAO area	45
Generalized species class (set of ISSCAAP codes) and gear type	38

- a ***temporal quality*** indicator, reflecting the proportion of data points from years since 2000. *Very low* = all records are from before 2000; *low* = <25% of records are from 2000 on; *medium* = 25-49% of records are from 2000 on; *high* = 50-74% of records are from 2000 on; *very high* = 75% or more of records are from 2000 on.

- a ***subjective quality*** indicator reflects the confidence of the author in each estimate, based on the match criteria, temporal range, variability in the data, sample size, types of sources, and general understanding of typical patterns in FUI.

The subjective quality indicator is a good indication of the relative reliability of each estimate. It takes into account the range of data used, the method of weighting, and the degree to which the estimate reflects previous assessments of FUI in fisheries around the world. There are instances where the subjective quality indicator does not agree with the other quality rankings. For example, some estimates include a large number of older data points, and are therefore given a low temporal quality rating, but because the weighting method used gives more influence to more recent data points, the estimate closely reflects recent findings and is therefore given a high rating.

Data Collection

As part of the assessment process, the analyst will search for and request additional information on Fuel Use for the fishery under assessment to supplement and add to data in the Fuel Use Intensity Database. The analyst will also research the potential for other GHG emissions and non-GHG emissions of substances, like black carbon, which have high global warming potentials.

Communicating GHG intensity values for wild capture fisheries

As stated in the Rationale section, the proposed Seafood Watch GHG Criteria will be unscored additions to our sustainable seafood assessments. GHG intensity values for seafood will be compared to median GHG intensity values for land based protein production: poultry (considered a medium emission protein) and beef (considered a high emission protein). See the Rationale section for more information. Any method of communicating a GHG Intensity value for fisheries based on the FUI estimates generated here should take into account three things:

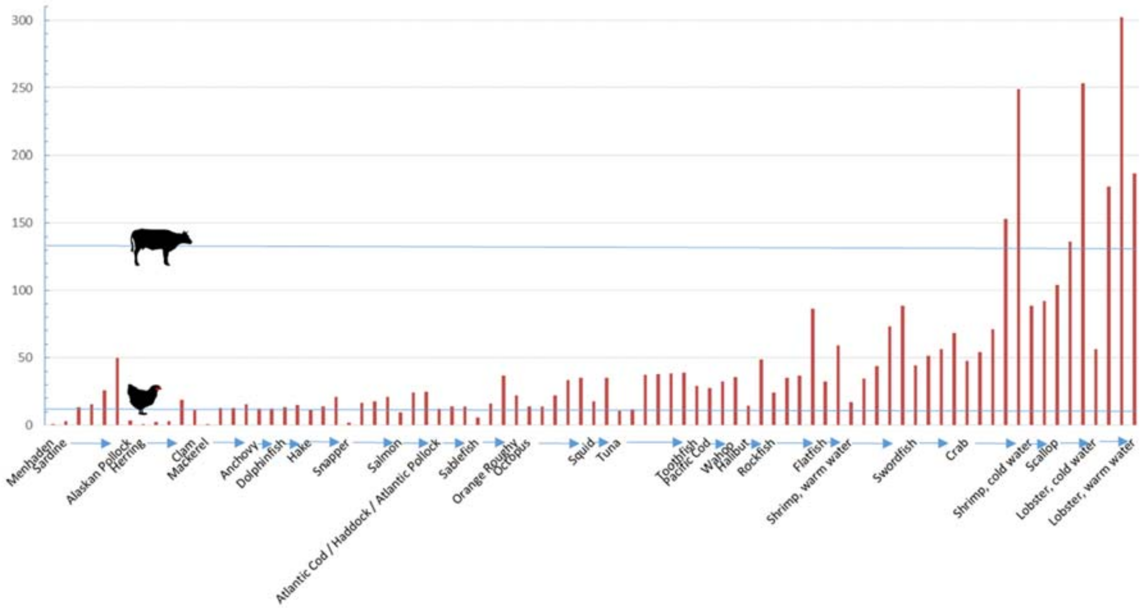
a) the estimates are based on fuel inputs to fisheries only, and, while fuel often accounts for the majority of life cycle carbon emissions, they need to be viewed in the context of the total supply chain. Most importantly, products that are associated with a high amount of product waste and loss during processing, or that are transported via air freight, are likely to have high sources of emissions beyond fuel consumption.

b) the quality of estimates varies, as is reflected in the quality indicators provided. Scoring fisheries with better quality estimates is easier than scoring predicted FUI of fisheries based on similar fisheries. For that reason, it may be justifiable to score only fisheries with a 'high' quality estimate, or to indicate that some scores are based on expected FUI rather than actual reported values.

c) the value should be expressed relative to some base value, reflecting relative performance of similar fisheries and/or alternative fishery products and/or alternative protein sources.

An example of how a subset of fisheries would fall relative to poultry and beef is shown in Figure 1 below.

Figure 1: GHG Intensity Values for a subset of Seafood Watch recommendations, based on work performed by Robert Parker using the FEUD database. Fisheries represented by multiple gear types are shown by multiple red bars. Numerical value of median emission intensity for poultry production and beef production are shown as horizontal lines. Beef and poultry values were derived from Nijdam et al (2012).



Aquaculture Greenhouse Gas Emission Criterion

MSG guidance - This section contains the introduction to the Aquaculture GHG emission Criterion.

Introduction

Feed production and on-site farm energy use are the two major drivers of GHG emissions from aquaculture operations up to the farm gate (Pelletier *et al.* 2011). For fed systems (fed systems comprise 69% of global aquaculture production (FAO 2014)), feed production is often the greater of these two drivers, particularly for net-pen systems where important processes such as water exchange, aeration and temperature regulation are provided naturally by the ecosystem (Pelletier *et al.* 2011). In pond production systems, large variations in the rate of water exchange (i.e. the volume of pumping) and aeration practices mean that farm-level energy use varies greatly between species and regions. Farm-level energy use is often the primary driver of GHG emissions for tank-based recirculating systems which require energy to run all life support and control systems (Parker 2012b) (Samuel-Fitwi *et al.* 2013). In stark contrast, farmed bivalves and aquatic plants (which represent less than 31% of global aquaculture production (FAO 2014)), require few external inputs and have low energy demand (Pelletier *et al.* 2011).

Farm location may also be a significant factor influencing total GHG emissions from aquaculture operations due to differences in the regional mix of energy sources used to generate electricity. Farms that are run primarily on fossil fuel based electricity (such as coal or oil) will have much higher total GHG emissions than those run on renewable energy sources (such as hydropower, wind, geothermal or solar) or on nuclear energy (Parker 2012b).

Additional GHG emissions may result from sources other than farm level energy use and feed production, such as from energy use associated with grow out infrastructure and smolt production and from non-energy emissions of CH_4 and N_2O from ponds (as discussed in the above section "Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production").

Seafood Watch recognizes that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations. It is noteworthy that improving practices for some of the Aquaculture Assessment Criteria may lead to more energy intensive production systems (e.g. where our recommendations are better for energy-intensive closed recirculation systems than for open systems). Seafood Watch also recognizes (as mentioned in the above section "Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production"), that non-energy emissions associated with aquaculture production may be significant but are not always well described or quantified.

MSG guidance - This section contains the methodology for the Aquaculture GHG Emissions Criterion. This criterion is less well developed than the fisheries criterion, primarily due the greater complexity of assessing the GHG emissions of aquaculture operations and the very limited data available. Changes made to this section since the first public consultation include 1) a tiered approach to evaluating GHG emissions associated with feed based on data availability 2) data from a literature review of farm level energy use and feed energy 3) factoring in non-energy GHG emissions from both feed and farm level activities where this data is available 4) Separation out of sections on data collection and communicating GHG intensity values. Given the paucity of data, Seafood Watch will continue to collect and actively solicit information on GHG emissions associated with feed production and farm level activities. In particular, Seafood Watch will seek out information on the GHG emissions associated with specific feed ingredients.

Methods

Seafood Watch is currently developing the methodology for assessing GHG emissions from aquaculture operations up to the farm gate. This methodology will include an assessment of the cumulative GHG emissions from feed use (primarily feed ingredient production, processing and potentially transport) as well as farm-level emissions from energy use.

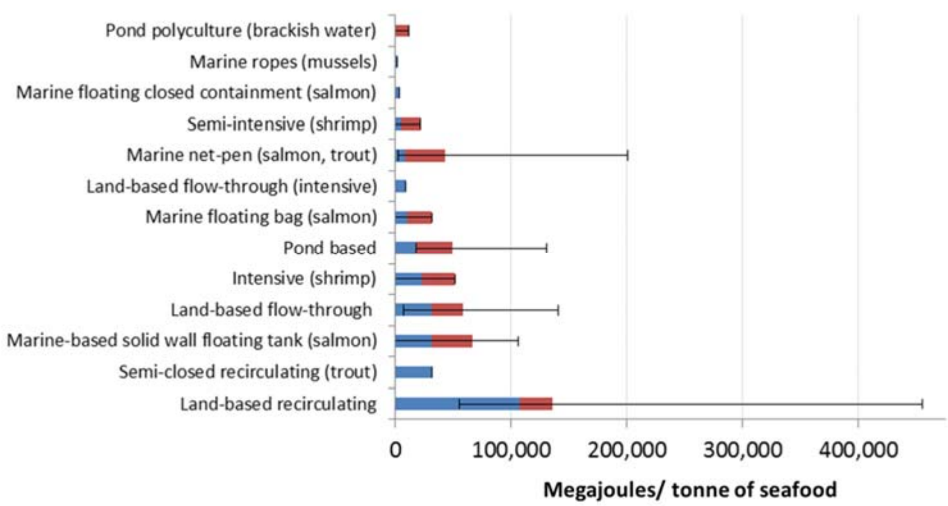
We propose using a tiered approach to evaluating the feed contribution to GHG emissions. Where the specific origins of feed ingredients can be identified, it may be possible to determine the GHG emissions with high accuracy. When the specific ingredients are unknown, we propose basing the feed component on GHG emission estimates of dominant feed ingredient groups; i.e. aquatic (fishmeal and oil), crop and land animal (from Pelletier *et al*. 2009 and from additional sources) along with corresponding estimates of feed types and quantities fed by operations under assessment. We recognize that there may be significant differences in GHG emission values between the feeds in each of these groups, notably within the aquatic feed group (such as between a feed based primarily on fishmeal sourced from bycatch from a regional fishery on the low end of the spectrum and a feed sourced primarily from a distant reduction fishery), and we will break out the feeds in these groups where possible.

For the farm-level component, Seafood Watch proposes quantifying GHG emissions associated with pumping, aeration and other energy consumptive activities. Seafood Watch will draw data from existing studies and data gathered directly from aquaculture operations. As an initial step, Seafood Watch has compiled information from Life Cycle Analysis (LCA) studies and other sources on farm level energy use and energy use associated with feeds (carried out by Keegan McGrath). The results are summarized in Figure 2. When data are not available to finely estimate GHG emissions for each component (feed and farm-level energy), Seafood Watch proposes defaulting to GHG estimates based on the most closely related species type, production type and the energy mix most commonly used in the region under assessment.

As with the Fisheries criterion, all emissions estimates will be standardized to GHG Intensity per edible unit of protein (KgCO_2 equivalent/Kg edible protein).

The total GHG emissions will be obtained by summing the GHG emissions from feed ingredients (Part 1 below) and farm-level energy use (Part 2 below).

Figure 2: Energy use associated with aquaculture feeds (red bars) and farm level activities (blue bars) for a variety of species and production methods in units of megajoules/tonne of seafood, drawn from LCA studies and other information sources. Literature review carried out by Keegan McGrath. These data will be transformed into GHG Intensity per unit of edible protein (KgCO2 equivalent/Kg edible protein) when applied to this criterion.



Part 1: GHG Emissions associated with feed ingredients/ Energy Return on Investments

As mentioned above, Seafood Watch proposes using a tiered approach to quantify the GHG Intensity (KgCO_2 equivalent/Kg edible protein) of feed ingredients. The tiers are based on the level of information available for the species and production system in the region or country under assessment. The first tier will be used when Seafood Watch can determine the specific feed ingredient mix and can determine associated GHG emission intensity values associated with the primary components (ideally taking into account the energy and non-energy emissions associated with the feed). Data on the specific feed ingredient mix will be requested at the start of the assessment process with the goal of using this first tier. Seafood Watch will employ the second tier when we are unable to determine the specific feed ingredient mix, but can determine the percentage of the three dominant ingredient types (aquatic, crop and land animal). When significant differences in GHG emissions can be clarified between feeds used from the dominant ingredient types, we will use a hybrid of the first and second tiers.

Factored into the GHG Intensity calculation for both tiers (and the hybrid tier) is the Economic Feed Conversion Ratio (eFCR), the total amount of feed used to produce a given output of harvested fish biomass, taking into account loss of feed via escapes, death, predation, disease, environmental disasters and other losses. In addition to the GHG Intensity value, Seafood Watch will provide an estimate of confidence in the value (whether this will be a numerical value or a scalar value is being discussed)

GHG Emissions for Feed Ingredient Inputs:

Tier 1
Cumulative GHG emission from feed = Total of ingredient specific GHG emission values* x eFCR

* Depending on the data collected by the analyst, this will be the total of ingredient specific GHG emission values or a total value for a feed formulation. Seafood Watch is currently investigating the derivation method for calculating feed specific or formulation specific GHG values, and input for how best to accomplish this is requested during this second public consultation process.

Tier 2
a) Aquatic ingredient inclusion rate = _____ %
b) Crop ingredient inclusion rate = _____ %
c) Land animal ingredient inclusion rate = _____ %
d) Economic Feed Conversion Ratio (eFCR) = _____

Cumulative GHG emissions from feed (kg CO_2-eq/t) = [(a x 2158) + (b x 1007) + (c x 4138)] x (d)[6]

For all tiers: Total feed cumulative GHG emissions (expressing edible return on investment) = ________ Kg CO_2 equivalents/Kg of edible protein

Kgs of edible protein (above) will be derived from metric tons of harvested fish using two factors:
- the species specific edible percentage and
- the species specific protein percentage of muscle tissue.

These percentages will be drawn from Peter Tyedmers' unpublished database.

Part 2: Farm-Level Energy Use

For this component Seafood Watch proposes to quantify the GHG emissions associated with direct farm-level energy use. The primary energy consumptive farm activities are water pumping and aeration but also might include activities such as temperature regulation, filtration, feed and chemical dispersal and harvesting. We acknowledge that additional energy consumptive activities are associated with aquaculture production, such as from grow out infrastructure and smolt production, but are not included in our assessment. We propose the following assessment methods, depending on data availability. For each of the options, Seafood Watch intends to provide an

[6] Mean values for the feed ingredient groups were derived from Pelletier *et al.* 2009, using the methodology described in Pelletier *et al.* 2010.

estimate of confidence in the value (whether this will be a numerical value or a scalar value is under consideration)

Farm-level data
As the most accurate measure, Seafood Watch aims to obtain farm-level information on total energy use as well as the energy mix (e.g. diesel versus electricity, but also the regional mix of fuels used for electricity generation) specific to the aquaculture operations under assessment in order to estimate farm-level GHG emissions. In addition to farm level energy, Seafood Watch aims to obtain information on non-energy GHG emissions produced at the farm level. Such non-energy emissions include N_20 and CH_4 from ponds (see the discussion in the section above: "Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production"). As with the feed component, GHG emissions will be standardized to the Kgs of edible protein.

Energy use values from scientific and grey Literature
Where farm-level information is not available, Seafood Watch proposes to model GHG emissions based on production method, species and farm-level energy use data and non-energy GHG emissions published in peer reviewed journals and available from grey literature. To estimate GHG emissions, this farm-level energy use data will be synthesized with data on the most common mix of fuels used for electricity generation in the region of assessment. As with the feed component, GHG emissions will be standardized to the Kgs of edible protein.

Relative energy use from water pumping and aeration
When farm-level or literature data are unavailable, Seafood Watch has developed the following tables to classify energy use from water pumping and aeration on a relative scale, which can be translated to relative GHG emission intensity. This method does not factor in non-energy GHG emissions:

Water Pumping
A crude estimated measure of the energy used in pumping water

Use pumping data or descriptions to select score value from the table below.

	Water pumping characteristics[7]	**Score**
Zero	No significant water pumping, e.g. cages, passive fill ponds, gravity fed tanks/ponds/raceways.	5
Low	Static ponds	4
Low-Moderate	Harvest discharge or occasional exchange	3
Moderate	Low daily exchange rate >0 to 3%	2
Moderate-High	Significant daily water exchanges 3-10%	1
High	Large daily water exchanges, recirculation systems >10%	0

Note - low energy use is given a high score

Energy use (pumping) score = ______ (range 0-5)

Record water pumping data here if available:
Pumped volume per metric ton of product _______ m^3 MT^{-1}]
Average pumping head height _______ m
Average pump power _______ KW or HP

[7] As a guide, Low = <1000 m^3/MT, Low-Moderate = 1000 – 5,000 m^3/MT, Moderate = 5,000 – 20,000 m^3/MT, Moderate-High = 20,000-150,000 m^3/MT, High = >150,000 m^3/MT

Aeration

A crude estimated measure of the energy used for aeration

	Aeration characteristics[8] or average duration	Score
Zero	Zero	5
Low	Minimal aeration	4
Low-Moderate	Low power and/or short duration <6h/day	3
Moderate	Moderate power and/or 6-12h/day	2
Moderate-High	Moderate-high power and/or 12-18h/day	1
High	High power and/or >18 hours per day	0

Note low energy use is given a high score

Energy use (aeration) score = _____ (range 1-5)

Record aeration data here if available:
Aeration energy use = ______ kW·h per MT
Average aeration duration per day ______
Aerator power ______ kWh or HP

Overall Farm-level Calculations

Farm Energy Use (FEU) = Pumping + aeration
Farm Energy Use Score (FEU) = ______ (range 0-10)

If the above method is used, Seafood Watch will determine a conversion to GHG emissions in order to combine this measure with the feed GHG measure.

Data Collection

As mentioned in the above methods sections, the analyst will search for and request additional information on 1) farm level GHG emissions (both energy and non-energy GHG emissions), 2) the country/regional energy mix or if off the grid – the energy sources generally used for that production system and 3) information on feed composition and GHG values associated with the ingredients used.

Communicating GHG intensity values for aquaculture operations

As stated in the Rationale section, the proposed Seafood Watch GHG Criteria will be unscored additions to our sustainable seafood assessments. GHG intensity values for seafood will be compared to median GHG intensity values for land based protein production: poultry (considered a medium emission protein) and beef (considered a high emission protein). See the Rationale section for more information. Any method of communicating a GHG Intensity value for aquaculture will need to be transparent about the GHGs included in the derived GHG value as well as those emissions which are likely significant but which are not included in the assessment due to lack of data.

[8] As a guide, low = <500 kW·h per MT, Low-Moderate = 500 – 1,500 kW·h per MT, Moderate = 1,500-3,000 kW·h per MT, Moderate-High = 3,000 – 4,500 kW·h per MT, High = >4,500 kW·h per MT (values are for example only (based on Boyd et al, 2007) and need refining)

Summary of Changes Made Since the First and Second Public Consultation

Several changes were made to the Criteria for Fisheries and Aquaculture as a result of the first consultation process feedback from the Seafood Watch Technical Advisory Committees, feedback solicited during an expert webinar and from collaborative work with Peter Tyedmers, who is both on the Seafood Watch Technical Advisory Committee for Aquaculture and was involved in the expert webinar. No substantive changes were made as a result of the second consultation process. Seafood Watch would like to thank and acknowledge everyone who provided feedback. These revisions are briefly described in bulleted format here:

- Revised the Guiding Principle to acknowledge the contribution of GHGs to the acceleration of climate change and to acknowledge that GHG emissions from food production are a significant fraction of anthropogenic GHG emissions.
- Included an overview of the range of GHG emissions associated with fisheries and aquaculture in the introductory information. The purpose of this is to acknowledge the range of potential GHGs associated with seafood production and provide for the assessment of the full range of emissions as information becomes available.
- Provided additional information about the GHG emissions included in our approach comparing up to the farm gate/dock emissions from seafood to land-based proteins. In addition we've clarified that we will be using the median values for comparative protein GHG intensities.
- Included example results for the Fisheries Criterion
- Created a tiered approach to evaluate GHG emissions associated with feed, based on data availability
- Included data obtained from a literature review of farm level energy use and feed energy
- Factored in non-energy GHG emissions from both feed and farm level activities when these data are available.
- Added separate sections on data collection both the fisheries and aquaculture criteria
- Added separate section on communicating GHG intensity values for aquaculture.

References

BSI. (2012). PAS 2050-2: Assessment of Life Cycle Greenhouse Gas Emissions – Supplementary Requirements for the Application of PAS 2050:2011 to Seafood and Other Aquatic Food Products. British Standards Institution.

FAO (2011). "Energy-smart" Food for People and Climate. Rome: FAO.

FAO. (2014). The State of World Fisheries and Aquaculture: Opportunities and Challenges. Rome: FAO.

Henriksson, P.J.G, Guinee, J.B., Kleijn, R & G.R. de Snoo. (2012) Life cycle assessment of aquaculture systems – a review of methodologies. *International Journal of Life Cycle Assessment* 17:304-313.

Henriksson, PJ.G., Heijungs R., Dao H.M., Phan L.T., de Snoo GR & J.B. Guinée. (2015). Product carbon footprints and their uncertainties in comparative decision contexts. *PLoS ONE* 10(3): e0121221. doi:10.1371/journal.pone.0121221

Hu, Z., Lee, J.W., Chandran K, Kim S & S.K. Khanal. (2012). Nitrous oxide (N2O) emission from aquaculture: a review. *Environmental Science and Technology* 46 (12): 6470-80.

Jones, C.M., & D.M. Kammen. (2011). Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities. *Environmental Science and Technology* 45 (9): 4088–4095.

McKuin, B. & J.E. Campbell. In Review. Emissions and climate forcing from global and Arctic fishing vessels. Journal of Geophysical Research: Atmospheres.

Nijdam, D., Rood, T. & H. Westhoek. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 37, 760-770.

Parker, R. (2012). Energy use and wild-caught commercial fisheries: Reasoning, feasibility and options for including energy use as an indicator in fisheries assessments by Seafood Watch. Report for Seafood Watch, Monterey, California.

Parker, R. (2012b). Review of life cycle assessment research on products derived from fisheries and aquaculture. Report for the Sea Fish Industry Authority, Edinburgh, UK.

Parker, R. (2014). Estimating the fuel consumption of fisheries assessed by Seafood Watch. Report for Seafood Watch, Monterey, California.

Parker, R., Hartmann, K., Green, B., Gardner, C. & R.A. Watson. (2015). Environmental and economic dimensions of fuel use in Australian fisheries. *Journal of Cleaner Production* 87: 78-86.
Parker, R., & P. Tyedmers. (2014). Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*.

Parker, R, Vázquez-Rowe, I. & P. Tyedmers. (2015). Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production* 103:517-524.

Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., Flysjo, A., Kruse, A. Cancino, B. & H. Silverman. (2009). Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems. *Environmental Science and Technology* 43: 8730–8736.

Pelletier N., & P. Tyedmers. (2010). Life cycle assessment of frozen tilapia fillets from Indonesian lake-based and pond-based intensive aquaculture systems. *Journal of Industrial Ecology* 14: 467–481.

Pelletier, N., Audsley, E., Brodt, S., Garnett, T., Henriksson, P., Kendall, A. & M. Troell, 2011. Energy intensity of agriculture and food systems. *Annual Review of Environment and Resources*. 36:223-246.

Samuel-Fitwia,B., Nagela F., Meyera S., Schroedera,J.P. & C. Schulz. 2013. Comparative life cycle assessment (LCA) of raising rainbow trout(Oncorhynchus mykiss) in different production systems. *Aquacultural Engineering* 54: 84-92.

Tyedmers, P., Watson, R., & Pauly, D. (2005). Fueling global fishing fleets. *Ambio, 34*(8), 635-638.

Ziegler, F., Emanuelsson, A., Eichelsheim, J.L.,Flysjo, A., Ndiaye, V., & M. Thrane (2011). Extended life cycle assessment of southern pink shrimp products originating in Senegalese artisanal and industrial fisheries for export to Europe. Journal of Industrial Ecology 15(4): 527-538.