FAO Fisheries and Aquaculture Report No. 1011 FIRO/R1011 (En)

ISSN 2070-6987

Report of the

EXPERT WORKSHOP ON GREENHOUSE GAS EMISSIONS STRATEGIES AND METHODS IN SEAFOOD

Rome, 23–25 January 2012

Copies of FAO publications can be requested from:

Sales and Marketing Group
Publishing Policy and Support Branch
Office of Knowledge Exchange, Research and Extension
FAO, Viale delle Terme di Caracalla
00153 Rome, Italy
E-mail: publications-sales@fao.org
Fax: +39 06 57053360
Web site: www.fao.org/icatalog/inter-e.htm

FAO Fisheries and Aquaculture Report No. 1011 FIRO/R1011 (En)

Report of the

EXPERT WORKSHOP ON GREENHOUSE GAS EMISSIONS STRATEGIES AND METHODS IN SEAFOOD

Rome, 23–25 January 2012

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2012

ISBN 978-92-5-107351-3

PREPARATION OF THIS DOCUMENT

This is the report of the Expert Workshop on Greenhouse Gas Emissions Strategies and Methods in Seafood, held in Rome from 23 to 25 January 2012.

The papers contained in this work have been reproduced as submitted by the participants, without editorial intervention by FAO.

FAO. 2012.
Report of the Expert Workshop on Greenhouse Gas Emissions Strategies and Methods in Seafood. Rome, 23–25 January 2012.
FAO Fisheries and Aquaculture Report No. 1011. Rome. 117 pp.

ABSTRACT

This document contains the report of the Expert Workshop on Greenhouse Gas Emissions Strategies and Methods in Seafood held in Rome, Italy, from 23 to 25 January 2012. The Workshop was convened by the Director-General of the Food and Agriculture Organization of the United Nations, following a recommendation by the Twenty-ninth Session of the Committee on Fisheries that FAO should provide Members with information on possible fishing industry contributions to climate change, and on ways to reduce the sector's reliance on, and consumption of, fossil fuels, respecting the principles embodied within the United Nations Framework Convention on Climate Change. Financial and in-kind support for the Expert Workshop was provided by the Government of Norway, the FAO Regular Programme, Seafish, Dalhousie University and other contributing participants.

CONTENTS

OPENING OF THE MEETING AND ARRANGEMENTS FOR THE SESSION

1. The Twenty-ninth Session of the Committee on Fisheries (COFI) recommended that FAO should provide Members with information on possible fishing industry contributions to climate change, and on ways to reduce the sector's reliance on, and consumption of, fossil fuels, respecting the principles embodied within the United Nations Framework Convention on Climate Change (UNFCCC). Following this recommendation, and the deliberations of industry practitioners and policy agents expressed at the International Symposium on Energy Use in Fisheries (Seattle, 2010) and the Seafood Summit (Vancouver, 2011), the Director-General of the Food and Agriculture Organization of the United Nations convened an Expert Workshop on Greenhouse Gas Emissions Strategies and Methods in Seafood. The Expert Workshop was held at FAO headquarters, Rome, Italy, 23–25 January 2012, with funding and in-kind support from the Government of Norway, the FAO Regular Programme, Seafish, Dalhousie University and other participants.

2. FAO staff members, researchers and academics, industry representatives, standards experts, civil society, and fisheries consultants attended the Workshop. The attendance list is provided in Appendix 2. Background papers circulated to the participants prior to the Workshop are provided in Appendix 3.

3. The Secretary of the Workshop, Mr Francis Chopin, called the meeting to order.

4. Mr Árni M. Mathiesen, Assistant Director-General, FAO Fisheries and Aquaculture Department, referred in his opening statement on behalf of the Director-General to the high dependence of the food system on fossil fuels, and to the fact that, for the fisheries and aquaculture sector, the use of fossil fuels has significantly helped feed the world over the last few decades, mainly through their contribution to increased mechanization of fishing vessels, processing and transport to markets. He highlighted that ensuring that the agrifood sector becomes "energy smart" at both the small family and large corporate scales will require strong and long-term supporting policies and innovative multistakeholder institutional arrangements. He noted that at the Twenty-ninth Session of COFI, FAO reported that net greenhouse gas (GHG) contributions of fisheries, aquaculture and related supply chain features are poorly studied and the paucity of data on GHG emissions across fisheries and aquaculture supply chains is a key factor constraining the development of strategies to address energy use. He observed that FAO also reported that the transition to energy-efficient and low-footprint aquatic food production systems would be facilitated through the development of: standardized methodologies for energy and emissions calculations throughout the food chain; collection of data within this framework; and the development of policy and technologies associated with energy use and GHG emission reductions. He thanked the experts at the Workshop for taking the time to consider these important issues. His statement is attached as Appendix 4.

ELECTION OF THE CHAIRPERSON

5. Mr Graeme Macfadyen (the United Kingdom of Great Britain and Northern Ireland) was elected Chairperson of the Workshop. In assuming the Chair, he expressed his thanks to the Workshop for its confidence in electing him to the position. The workshop participants agreed with the Chairperson's proposal that discussions would be held both in plenary and in informal breakout working groups, as required, in addressing specific issues.

ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE TECHNICAL CONSULTATION

6. The consultation adopted the agenda as given in Appendix 1. The Chairperson then outlined the timetable of work for the consultation, noting that a degree of flexibility would be required to make best use of the resources available to the meeting.

NOMINATION OF THE WORKSHOP FACILITATORS AND RAPPORTEURS

7. Mr Rod Cappell (the United Kingdom of Great Britain and Northern Ireland) was nominated as a workshop facilitator, with Mr Cappell and Mr Macfadyen nominated as rapporteurs to prepare this workshop report.

DAY 1 – BACKGROUND PRESENTATIONS

8. The Workshop was informed that a number of organizations with a mandate or history of engagement on seafood sustainability issues, including *inter alia* (FAO, Seafish, Dalhousie University, industry), are working within a framework for collective action as a means of addressing and potentially resolving some of the issues around methodologies for GHG emissions and mitigating strategies. This framework for action, within which the Workshop fits, aims to work towards common positions on GHG emissions methodologies, common standards where possible, shared understanding of key seafood production systems, and platforms for sharing emissions-related data.

9. Presentations during the first day of the Workshop focused on an overview of findings to date with respect to GHG emissions, a review of key methodological choices in GHG emission methodologies, and some potential performance metrics. Some key points highlighted were:

10. Mr Francis Chopin of FAO highlighted the growing pressure on global food production, in which fisheries, particularly aquaculture, would play an important future role. However, future production needs to be "energy smart" as many production methods were developed when fossil fuels were much cheaper and their impact on climate change was not widely understood. To develop effective policies, it is necessary to be certain that the appropriate data for measurement are available; it is not a case of favouring large-scale producers in industrialized countries, or of placing unnecessary burdens on small-scale producers.

11. Mr Angus Garrett of Seafish described their work analysing seafood systems, which identified GHG emissions as an issue throughout the supply chains. He explained how Seafish sought to contribute to changes in industry practice and described the objectives and scope of the collective action between Seafish, FAO and Dalhousie University. There are four areas of action: common methods of assessment (the focus of this Workshop); development of standards; understanding seafood systems; and sharing data.

12. Mr Peter Tyedmers of Dalhousie University explained the range of threats posed by GHG emissions, the significant contribution by food production (particularly livestock) to global emissions and the growing interest in measuring these and attempting mitigation. There is an opportunity for seafood to make a major contribution to future food demand with GHG emissions that are lower than other animal protein choices, and these GHG emissions can be reduced further. The key emissions stage in fishing is the fishing stage itself, but fuel use varies hugely by type of fishing gear. For aquaculture, the main emissions come from the feed production stage and, therefore, differing feed formulations, levels of intensification and food conversion ratios can make a big difference. For some production systems and supply chains, there are other stages where emissions may be significant (e.g. if product is air freighted). To date, the focus of life cycle assessment (LCA)/GHG assessment has been on whitefish fisheries in the Northern Hemisphere with less on pelagics and shellfish. For aquaculture, the focus has been on salmonids, but in recent years other finfish and shrimp studies have emerged.

13. Mr Rod Cappell of Poseidon described GHG assessment methods. Two broad approaches are noted: a top-down "approach" using economic input–output tables; and a bottom-up "process LCA" approach summing the emissions from the various stages identified within a lifecycle. He noted that most seafood assessments to date have considered large-scale systems with very few small-scale and developing country examples. The presentation highlighted some of the methodological challenges in their application to the fisheries and aquaculture sector, defining common product typologies and system boundaries, allocation issues and the lack of available resources for key emissions factors (e.g. from fuel use by gear type and from various aquaculture feed formulations).

14. Mr James Muir of the University of Stirling presented a number of GHG emissions sources and issues at each stage in the fisheries and aquaculture production chains. A number of performance metrics were identified specific to each production stage, e.g. energy use in fisheries (tonnes fuel/tonnes catch), aquaculture food conversion (tonnes food/tonnes product), processing energy use (kWh/tonne produced). He noted the importance of recognizing the trade-off between specific accuracy and wider, simpler applicability.

Mr Brian Such of the British Standards Institute presented the range of standards used in carbon management and the potential process for developing seafood standards. All GHG standards take a whole lifecycle approach and cover all the Kyoto gases. The differences in standards are mainly in the approach to reporting and communication. Most standards work at a product (goods and services) level rather than on a wider organizational level. The main reason organizations undertook carbon accounting was to identify hotspots so that improvements could be made. A secondary driver was customer pressure to report GHG emissions. An assessment helped organizations to understand better their processes and to target GHG reduction measures. He also highlighted the standards development work specific to the seafood sector, and outlined how this work would be expected to proceed.

15. All presentations are provided in Appendix 5.

DAY 2 – BREAKOUT WORKING GROUPS ON METHODS FRAMEWORKS

16. Two working groups were established, broadly divided into: governance-related stakeholders, with a primary background in considering national/global assessments; and industry-related stakeholders primarily involved in addressing company-level and group-level assessments. Working across these levels, each group considered both the challenges and options associated with different methodological choices related to: setting the overall goal and objectives of assessments; the subject of assessment; the system boundaries; allocation methods; emissions factors; the approach in terms of using existing data or generating new data; and reporting. The deliberations of the working groups were then presented in plenary.

17. A summary of the working group discussions is provided in Appendix 6. Both groups reported that the overall goal was to enable the identification and reduction of GHG emissions, but the main driver for companies was internal improvement, while a global-level assessment is to enable comparison between sectors, production methods, nations and over time. A primary aim of identifying GHG emissions is to refine estimates in an effective manner. At the global level, this may involve using default data (tier 1 approach), with more specific data collected at the hotspot stages of fuel use for fisheries and feed production for aquaculture. This is less likely to be sufficient for a company, where production-specific data (a tier 2 approach) would be needed and in many instances the collection of primary data (tier 3 approach) may be expected.

18. It was noted that global assessments are likely to be species-based and further defined in terms of production method (gear métier for fisheries, and level of intensity for aquaculture). For a company, a product-level assessment is likely to be at the product level. As products are defined by species, company data could subsequently be aggregated to enable national species-level reporting. It was agreed that assessments should include all Kyoto GHG gases, particularly as contributions by vessel refrigerants (fisheries) and agricultural production (aquaculture feed) are significant.

19. The working group reported that boundaries should be clearly defined. For companies, an important emphasis could be on those practices the company itself can influence, e.g. "cradle to gate". For national or global assessments, the whole lifecycle is of interest, but the focus is expected to be on the productive sector, i.e. "gate to gate", which for primary producers such as fisheries could also be described as "cradle to gate". The allocation of emissions to a single species or product can be difficult for fisheries where other species may be landed. Allocation on the basis of value (economic allocation) is the norm for the existing GHG assessment standard PAS 2050, but allocation by weight (mass allocation) or an alternative could be chosen if this can be properly justified.

20. The working group noted that standardized reporting would be important at every level. For companies, the reporting is likely to be in the context of LCA and reporting standards already exist, but high-level reporting could be more variable.

21. Mr Michael Macleod of FAO's Livestock Information, Sector Analysis and Policy Branch gave a presentation on FAO's ongoing LCA work in relation to livestock commodities. Work streams include developing a model to estimate livestock emissions and a database of supporting information such as emissions factors for animal feed. The process of developing a partnership between FAO, industry and academia provided an example of how work in the seafood sector could be progressed and also identified that information sharing on feed components would be mutually beneficial;

especially with respect to livestock consuming fish-based feed constituents and aquaculture using land-based components.

22. Mr Marc Taconet of the FAO Fisheries and Aquaculture Department gave a presentation on the Fishery Resource Monitoring System (FIRMS), which provides information on the status of global fisheries resources via submissions from members of an information partnership. The partnership includes regional fishery management organizations (RFMOs) and other regional partners. Information-sharing rules and guidelines have been developed to address data ownership, dissemination rules and quality assurance mechanisms. Resource inventories and fact sheets enable analysis of state and trend statistics on a global and regional basis. The seven-year process to establish FIRMS provides some lessons if LCA resources for seafood are to be established.

DAY 3 – DISCUSSION ON COMMONALITIES BETWEEN METHODS FRAMEWORKS

23. The morning of day three was used to discuss the commonalities between the preferred methodological choices suggested by the two working groups as reported on day 2. Despite some differences in the preferred methodological choices, largely resulting from the primary goal/objective of conducting emissions assessments, a number of commonalities were identified. A summary of the discussion during the morning of day three is provided in Appendix 6.

24. A group discussion on existing approaches and work areas followed. It was recognized that product-level assessments are favoured in a commercial context and these are being addressed through GHG assessment standards. One work package of the collective action is tasked with defining amendments to existing standards specific to the seafood sector. International intervention could usefully be made in the form of operational guidelines (describing how to undertake assessments, particularly in LDC settings) and information provision (databases and emission factor inventories).

25. For the fisheries and aquaculture sectors, the impact hotspots are identified as the fishing stage and feed production stage, respectively. Information exists in relation to fuel use per gear and feed formulations, but there is no platform for information sharing.

26. It was noted that the input–output method provides a useful approach for national and international-level assessments. For example, the Environmental Impact of Products (EIPRO) project of the European Union (Member Organization) using environmentally extended input–output tables is continuing to enable coverage beyond its 27 member States.

CONCLUSIONS AND FUTURE WORK

27. The Workshop progressed the debate on GHG emissions assessment by reviewing approaches and exploring the implications of key methodological choices. However, it was recognized that more work is needed to assess the consequences of such methodologies.

28. Participants agreed that, while an overall reduction in emissions was a common goal across all levels of application, the aim for a common approach for GHG assessments in fisheries and aquaculture was not likely to be appropriate as the drivers, objectives and levels of detail needed at the company level may differ from those at an industry group, a national or global level. However, there are important areas of interchange between these levels, and communication between them would be essential.

29. The working group noted that, at the company level in particular, GHG assessments are likely to focus on identifying internal improvements in performance and there is often a wish to communicate these efforts. For credibility, these are likely to be assessments according to recognized standards often conducted by independent third parties. General GHG assessment standards exist and part of this collective action is to address what specific amendments are necessary for application of those standards to the seafood sector.

30. Higher-level assessments at an industry group, a national or global scale are likely to be informed and validated by company or product-level assessments, but would focus on more generic approaches. Strategies for aggregating data need to be well conceived, and an important practical aim would be to keep the data collection and reporting burden to a minimum. A simplified approach based

on existing data systems might be to allocate national/global production data (e.g. FAO FishStat) to production methods (for example, defined by fishing gears not available and feed-use regimes), and from this to generate sector-wide GHG estimates. This could then be used to identify potential “hotspots” such as fuel use in fisheries and feed ingredients in aquaculture, and where necessary and appropriate to develop more detailed sectoral data together with industry participants. A simplified approach might be to use existing data systems to enhance the assessment of GHG emissions contributions from recognized “hotspot” activities in seafood, e.g. fuel use in fisheries and feed ingredients in aquaculture. Where necessary and appropriate, more detailed sectoral data could be developed together with industry participants.

31. The majority of assessments and available data are from large-scale fisheries (gadoid and salmonid fisheries) in developed countries. There is a role for FAO, partner agencies and industry in ensuring that small-scale producers and less-developed countries are not disadvantaged by the growing demand for GHG assessment information. Assistance could include filling data gaps by encouraging GHG assessment examples from lesser-studied regions such as Asia and Africa and fishery types. It would also be helpful to both company-level and high-level assessments to establish a database of emissions factors for the fisheries and aquaculture sector.

32. Following the Workshop, the organizers and a small number of participants held a discussion/follow-up session to explore possible future options, work areas and shared activities. These are outlined in Appendix 7. These work areas are to be further defined and prioritized by the collective action partners

33. Building on the findings from this Expert Workshop, a second workshop is planned in order to identify mitigation measures to reduce GHG emissions in fisheries and aquaculture.

CLOSING OF THE WORKSHOP

34. The Chairperson thanked the workshop experts for their contribution to the workshop discussions, and invited the Secretary, Mr Francis Chopin to close the Workshop. Mr Chopin expressed his gratitude to the experts for their active participation in the Workshop, and formally declared the Workshop closed.

APPENDIX 1

AGENDA

Time	Session title	Speaker	Theme
Day 1 – Setting the scene **Key themes:** **Objectives of Workshop** **Benefits and drivers (commercial/policy) of GHG emissions assessment** **Examples of assessment** **Methods used**			
08:30 – 09:00	Building/security, registration, etc		
09:00 – 09:20	Welcome	FAO Opening address Árni Mathiesen ADG Department of Fisheries and Aquaculture FAO	1
09:20 –09:45	Introduction to workshop and objectives Nomination of Workshop chair	Frank Chopin, FAO Angus Garrett, Seafish	1/2
09:45 – 10:30	Tour de table; workshop expectations and comments, housekeeping	Chaired discussion	1/2
10:30 – 11:00	Coffee		
11:00 – 11:30	Overview of findings to date/ Review approaches used to assess GHG emissions in the seafood sector, plus discussions	Peter Tyedmers, Dalhousie University	2/3
11:30 – 12:00	Performance metrics – existing approaches & information sources	James Muir, Consultant	4
12:00 – 12:30	Review implications of key methodological choices on GHG emission assessment outcomes and challenges	Rod Cappell, Poseidon	4
12:30 – 13:30	Lunch		
13:30 – 15:00	Preliminary discussions and feedback	Chaired discussion	4
15:00 – 15:15	Presentation of development in standards	BSI	4
15:15 – 15:45	Break		
15:45 – 16:45	Industry and governance perspectives on methods and tradeoffs Industry (economic drivers) & governance (policy drivers)	Chaired discussion	4
16:45 – 17:00	Establish working groups to consider each of three major methods issues of interest: • setting of system boundaries of analysis • addressing coproduct allocation and related issues • tradeoffs between detailed, accurate but resource intensive assessment methods versus accessible, timely and resource "lite" approaches Remit to deliver high-level principles and detailed guidance		4
17:00 – 17:15	Review and schedule for Day 2	Chair	
18:15 – 20:00	FAO reception (Aventino Room)		
Outcome: Participants are clear on objectives of workshop and have a good understanding of the need for GHG emissions assessment, the "state of the art" (how this is currently done), where choices/techniques affect results i.e. why methods matter, and are prepared to engage on a substantive issue at the start of Day 2.			

Day 2 – Reviewing GHG emissions methods **Key themes:** **Identify key methods and preferences** **Define potential standard/common methods and areas of diversity** **Develop methods framework**			
Time	**Session title**	**Speaker**	**Theme**
08: 30 – 09:00	Day 2 introduction – update, aims and methods	Chair/facilitation	
09:00 – 10:30	Stakeholder methods*	Breakout groups (Group 1 = industry, Group 2 = governance)**	1
10:30 – 11:00	Coffee		
11:00 – 12:00	Stakeholder methods (continued)	Breakout groups (as above)	1
12:00 – 12:30	Plenary / feedback session	Rapporteurs present Group conclusions	1
12:30 – 13:30	Lunch		
13:30 – 15:00	Opportunities for common methods; identifying individual grounds and discussing areas of common ground (areas of agreement and dissonance)	Breakout groups (possibly mix Group 1/Group 2 members) = governance)	2
15:00 – 15:30	Plenary / feedback session	Rapporteurs present Group conclusions	2
15: 30 –16:00	Break		
16:00 – 16:15	Methods framework	Facilitators overview on potential framework	3
16:15 – 17:15	Group discussion on framework for organizing group methods, recognizing individual and common ground, shared positions and choice points	Facilitated discussion process across key points and issues	3
17:15 – 17:30	Establish working groups to consider each of three major methods issues of interest: • setting of system boundaries of analysis • addressing co-product allocation and related issues • trade-offs between detailed, accurate but resource intensive assessment methods versus accessible, timely and resource “lite” approaches Remit to deliver high-level principles and detailed guidance		4
17:00 – 17:15	Round-up and conclusions to carry forward	Chair	
Outcome: The critical issues associated with GHG emissions methods in seafood (including data issues) are identified and broad agreement on appropriate methods framework.			

* Two breakout groups, each containing LCA technical experts, based on:

- industry stakeholders
- governance stakeholders

** Key questions for stakeholders (provided in a template, and used as basis for rapporteur feedback to plenary):

- What purposes do you assess GHG emissions for?
- What are the preferred units of analysis?
- What are the preferred system boundaries?
- What is the preferred allocation to coproducts?
- What is the preferred level of granularity?
- What practical challenges (including data and information challenges) does this produce?

In each case, provide a “position” where there is agreement, or provide a “choice point” where there is dissonance, plus justification

Day 3 – Developing methods **Key themes:** **Agreeing framework approaches** **Identifying pilot systems** **Strategic issues – collating and disseminating data, developing a support tool for those wishing to conduct fisheries GHG assessments (with assessment tools, database of emission factors, etc., use and reporting issues)**			
Time	**Session title**	**Speaker**	**Theme**
08:30 – 09:00	Day 3 introduction – update, aims and methods	Chair	
09:00 – 09:15	Discussion/issue setting for proposed framework approaches		1
09:15 – 10:15	Practical applications of operating the proposed framework; agreeing an approach - stakeholder methods*	Breakout groups (mix across Group 1 = industry, Group 2 = governance)	1
10:15 – 10:30	Plenary / feedback session	Rapporteurs present Group conclusions	
10:30 – 11:00	Coffee		
11:00 – 12:00	Stakeholder methods (continued)	Breakout groups (as above)	1
12:00 – 12:30	Plenary / feedback session	Rapporteurs present Group conclusions	1
12:30 – 13:30	Lunch		
13:30 – 14:00	Strategic implications – introduction to issues/topics (possible inputs from FAO statistics service and NRC)	Facilitation	3
14:00 – 15:00	Strategic implications – stakeholder methods to discuss priorities, potential problems, ways of addressing these	Breakout groups (Group 1 = industry, Group 2 = governance)	3
15:00 – 15:30	Plenary / feedback session	Rapporteurs present Group conclusions	3
15:30 – 16:00	Break		
16:00 – 17:00	Overview of decisions, agreements, choice points, issues to resolve	Facilitated agreement of the workshop report	
17:00	Workshop round-up and conclusions	Chairperson and FAO	
Outcome: An agreed approach is established and a number of pilots covering a range of situations are identified. Strategic implications identified and discussed with recommendations as appropriate for further action.			

Day 4 – The next steps Key themes: Detailing a work plan – preparation of the workshop report Establishing what issues need more investigation/discussion The next steps			
09:00	Work plan: how this will be taken forward, information needs timing, who is involved, etc.		1
Lunch			
14:00	Future work areas / actions		2 / 3
Outcome: A work plan is produced establishing which pilots and approaches are to be taken forward, who is involved (structure of pilots and steering group) with each and agreement on info/data use. Identification of any unresolved issues needing more work. Agreement on how participants are to be kept informed of collective action.			

APPENDIX 2

LIST OF PARTICIPANTS

Mr Adolfo Alvial
Natural Resources and Environmental Management
Santa Elena Parcela 13
Puerto Varas, Chile
Tel. + 56 65 231692
Fax + 56 65 231692
E-mail: adolfoalvial@gmail.com

Mr Agnar Erlingsson
NAVIS ehf
Flatahraun 5a, 220 Hafnarfjörður
Iceland
Tel.: +354 544 2450
Mobile: +354 8932920
E-mail: agnare@simnet.is; ae@navis.it

Associate Professor
Giles Thomas
Head, Maritime Engineering
Deputy Director
AMC – NCMEH
University of Tasmania
Locked Bag 1395
Launceston Tasmania, 7250
Australia
Tel.: +03 6324 9883
Mobile: +0447876901
E-mail: giles@amc.edu.au

Mr Jeroen Guinée
Universiteit Leiden - Faculty of Science
Institute of Environmental Sciences (CML)
Department of Industrial Ecology
PO Box 9518, 2300 RA Leiden,
The Netherlands
Tel.: +31 71 5277432
Fax: +31 71 5277434
E-mail: guinee@cml.leidenuniv.nl

Mr Papa Gora Ndiaye
Executive Secretary
REPAO
Villa N° 5000, Sicap Liberté IV
Dakar, Senegal BP: 47076 Dakar,
Senegal
Tel.: +221 33 8252787
Mobile: +221 776443473
Fax: +221 33 8252799
E-mail: gndiaye@gmail.com

Ms Rattanawan "Tam" Mungkung, PhD
Centre of Excellence on Environmental
Strategy for GREEN business (VGREEN)
Department of Environmental Science
Faculty of Science, Kasetsart University
50 Ngamwongwan Road, Ladyao, Chatuchak,
Bangkok 10900, Thailand
Tel.: +66 2562 4555, ext. 1508
Fax: + 66 2942 8715
E-mail: fscirwm@ku.ac.th

Mr Sebastian Mathew
International Collective in Support of Fishworkers (ICSF)
27 College Road
Chennai 600 006, India
Tel.: +91 512 2598433; +91 944 4065433
E-mail: sebastian1957@gmail.com

Ms Friederike Ziegler
SIK-The Swedish Institute for Food and
Biotechnology
Sustainable Food Production
PO Box 5401
SE- 402 29 Göteborg, Sweden
Tel.: +46 10 5166654
Mobile: +46 10 5166600 (switchboard)
Fax: +46 31 833782
E-mail: fz@sik.se; Friederike.Ziegler@sik.se

Mr Alex Elmerdahl Olsen
Head of Sustainable Production
Espersen A/S
Fiskerivej 1
DK-3700 Roenne, Denmark
Tel.: +45 56 906000
Mobile: +45 20154259
E-mail: alex.olsen@espersen.dk

Dr. Ing. Ms Annik Magerholm Fet
Professor Department of Industrial
Economics and Technology Management
Norwegian University of Science and Technology, NTNU
N-7491 Trondheim, Norway
Tel.: +47 73593509
Mobil: +47 92296890
E-mail: annik.fet@iot.ntnu.no

Mr Brian Such
MCMI Project Manager
Carbon Management Specification
and Guidance
British Standards Solutions
BSI Group
Chiswick Tower, 389, Chiswick High Road,
London, W4 4AL
United Kingdom
Tel.: +44 (0)2 089967196
Tel. (Personal Office): +44 (0)1 206830178
Mobile:+44 (0)7 850668064
E-mail: brian.such@bsigroup.com

Mr Daniel Lee
BAP Standards Coordinator
Global Aquaculture Alliance
2 Tyn y Caeau, Menai Bridge, LL59 5LA
United Kingdom
Tel.: +44 1248 712906
Mobile: +44 7981517510
E-mail: dangaelle@aol.com

Mr Erik Skontorp Hognes
SINTEF Fisheries and Aquaculture AS,
Life Cycle Assessment
BP 4762 Sluppen, 7465
Trondheim, Norway
SINTEF Sealab, Brattørkaia 17C
Tel.: +47 40 225577
E-mail: erik.hognes@sintef.no

Mr Paul Macintyre
Aquaculture Services Director
Food Certification International
Findhorn Business Centre
Dochgarroch Inverness
IV3 8GY, United Kingdom
Mobile: +44 (0)7834206936
E-mail: paul.macintyre@foodcertint.com

Mr Rod Cappell
Associate Director
Poseidon
96 Lower Granton Road
Edinburgh, Scotland
EH5 1ER, United Kingdom
Tel/Fax: +44 0131 5514960
Mobile: +44 07974351325
E-mail: rod@consult-poseidon.com

Mr Graeme Macfadyen
Director Geneva Office
Poseidon
308 Rue d'Arbere
Divonne Les Bains 01220
France
Mobile: +33 06 89362374
E-mail: graeme@consult-poseidon.com

Mr Angus Garrett
Senior Economist Seafish
Tel.: +0131 5248967
Mobile: +07876 035724
E-mail: a_garrett@seafish.co.uk

Mr Peter Tyedmers
Associate Professor
School for Resource and Environmental
Studies Dalhousie University
Suite 5010 - 6100 University Ave
Halifax B3P 1X6, Canada
Tel.: +902 4946517
E-mail: peter.tyedmers@dal.ca

FAO Staff

Mr Francis Chopin
Senior Fishery Industry Officer
Fishing Operations and Technology Service
Fisheries and Aquaculture Resources Use
and Conservation Division
Fisheries and Aquaculture Department
Viale delle Terme di Caracalla
00153 Rome, Italy
Tel.: +39 06 57055257
E-mail: francis.chopin@fao.org

Mr Ari Gudmundsson
Fishery Industry Officer
Fishing Operations and Technology Service
Fisheries and Aquaculture Resources Use
and Conservation Division
Fisheries and Aquaculture Department
Viale delle Terme di Caracalla
00153 Rome, Italy
Tel.: +39 06 57054561
E-mail: ari.gudmundsson@fao.org

Ms Doris Soto
Senior Aquaculture Officer
Aquaculture Service
Fisheries and Aquaculture Department
Viale delle Terme di Caracalla
00153 Rome, Italy
Tel.: +39 06 57056149
E-mail: doris.soto@fao.org

Ms Cassandra De Young
Fishery Planning Analyst
Policy Economics and Institutions Service
Fisheries and Aquaculture Policy
and Economics Division
Viale delle Terme di Caracalla
Rome, Italy
Tel.: +39 06 57054335
E-mail: Cassandra.DeYoung@fao.org

APPENDIX 3

BACKGROUND PAPERS

Life cycle analysis and green house gas emissions methods in seafood production systems

Poseidon Aquatic Resource Management Ltd

Acronyms

ADP	Abiotic depletion Potential
AP	Acidification Potential (AP)
CE	Carbon equivalent
CFC	Chlorofluorocarbon
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COFI	Committee on Fisheries
EF	Emission Factor
EP	Eutrophication Potential
FAO	Food and Agriculture Organisation (of the United Nations)
FCR	Feed Conversion Ratio
FETP	Freshwater Aquatic Ecotoxicity Potential
GHG	Green House Gas
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon (gas used in refrigerants, e.g. R-22)
HTP	Human Toxicity Potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment / Life Cycle Analysis
LDC	Less Developed Countries
METP	Marine Aquatic Ecotoxicity Potential
N2O	Nitrous Oxide
NMVOC	Non-methane Volatile Organic Compounds
NOX	mono-Nitrogen Oxides
ODP	Ozone-layer Depletion Potential
PFC	Perfluorocarbon
POFP	Photochemical oxidant formation potential
SF_6	Sulphur hexafluoride
SIP	Seafloor Impact Potential
SO_2	Sulphur Dioxide
TEP	Terrestrial Ecotoxicity Potential
UNFCCC	United Nations Framework Convention on Climate Change

Introduction

Background to research

Sustainable seafood production is important for meeting the growing dietary needs of the world's population, which recently exceeded 7 billion people. The consumption of seafood is increasing, along with consumer interest in where our food comes from and how it is produced. Seafood is the most globally traded primary commodity with around 40% of all fisheries and aquaculture production traded internationally. Decisions made by operators in this global trade, from producers through to consumers, have significant impacts on natural resources, on greenhouse gas (GHG) emissions, and on developed and developing country economies.

The world stands to lose up to fifty percent of current gross revenues of about $80 billion per year from the world's fisheries in the face of severe climate change and continued overfishing in global fisheries [if current trends and management practices continue], resulting in serious economic and social consequences (Sumaila & Chung, 2010).

Industry practitioners and policy makers have increasing concerns about fuel prices, long-term energy availability and climate change – as articulated at the International Symposium on Energy Use in Fisheries (Seattle, 2010) and the Seafood Summit (Vancouver, 2011). The 29th session of the Committee on Fisheries (COFI) recommended that FAO should provide Members with information on possible fishing industry contributions to climate change and on ways to reduce the sector's reliance on, and consumption of, fossil fuels, respecting the principles embodied within the United Nations Framework Convention on Climate Change (UNFCCC).

At a conference addressing climate change in December 2011 (the 'Durban Platform'), world governments committed themselves to write a comprehensive global agreement to reduce greenhouse gas emissions (Durban Platform, 2011). This legally-binding agreement will come into force in 2020 and covers developed and developing countries; making it all the more important to understand and measure GHG emissions using globally-consistent methods.

A key requirement is to develop practical and reliable ways to measure the impacts and the effects of activities throughout the seafood sector. In the food and agriculture sectors, the International Organization for Standardization (ISO), the Intergovernmental Panel on Climate Change (IPCC), and others have developed methodology standards, but their extension to the seafood sector is so far limited. Some Life Cycle Assessments (LCA) of seafood products have been completed, and while variable in approach and scope, have identified a number of significant drivers of energy use and related GHG emissions, with clear economic, social and environmental consequences.

Seafood systems share many features in common with other food systems (e.g. dependence on certain key inputs, highly variable product forms, modes of transport, etc.), but they also exhibit a number of distinguishing features that make their characterization challenging. These include high heterogeneity, and very dynamic local and international production and trading systems.

Identifying areas for improvement in efficiency and resource use can be beneficial for all scales of operators, but when developing approaches and standards, consideration should be given to stakeholders in data and resource-limited situations to ensure they are not disadvantaged. FAO's Fisheries and Aquaculture Department, Seafish (in the UK), and Dalhousie University (in Canada), with additional support from the Government of Norway, are progressing a collective action as a means of addressing and potentially resolving some of these issues[1]. This collective action will result in agreed positions on GHG emissions' methodologies, common standards (where possible), improved understanding of key seafood production systems, and platforms for sharing emissions-related data. The project partners propose to investigate methods for understanding and enabling mitigation of GHG emissions in fisheries and aquaculture production systems and supply chains. This paper addresses the first of these elements, exploring current methods for GHG emissions assessment and their use within the seafood sector.

Life cycle assessment

Life Cycle Assessment (LCA) is an approach that evaluates all stages of a product's life. LCA quantifies resource use and environmental impacts of products and services related to raw material extraction, conversion and value-added processes, distribution, consumption and finally waste and disposal. The methodology therefore considers the flow of resources and the outputs and environmental impacts of these.

Carrying out an LCA is an iterative process, in which subsequent reiterations may imply increasing levels of detail, from a screening LCA to a full LCA, or even, the necessity for changes in the first phase prompted by the results of the previous phases (UNEP-DTIE, 2003).

[1] http://www.seafish.org/media/516150/ghg%20emissions%20in%20seafood%20proposal%20final.pdf

LCA processes have been standardized (e.g., ISO 14044) and follow the main steps of: goal definition and scoping to define the process and boundaries; inventory analysis to identify material and energy flows and environmental releases; impact assessment to assess the environmental effects of the inventory analysis; and interpretation to draw conclusions from the assessment (SAIC, 2006). Nevertheless differences in the scope of assessments and the presentation of results remain due to the different goals of assessment and target audiences. Kim and Neff (2009) outline some of the differing approaches to LCA:

- Process life cycle assessment (PLCA) is a ‘bottom-up’ approach that sums the impacts of each activity directly or indirectly involved in the production, transport, storage, retail, consumption and disposal of a particular food from “farm to fork” or “farm to waste”. For example, for industrially-produced beef, these activities might include the production and application of agricultural chemicals for feed crops, transportation of feed to feedlot, ruminant emissions from cattle, energy use in feedlot and slaughter, packaging, transportation, refrigeration and retail, and
- Economic input–output life cycle assessment (EIOLCA) is a ‘top-down’ approach that models the life cycle impacts of a food based on economic and environmental data on the industries involved. EIOLCA is used to estimate the emissions associated with a given amount of spending on an industry at the national level. Weber and Matthews' assessment of the U.S. food system (Weber and Matthews, 2008) is one illustrative example.

Comparing EIOLCA and PLCA, EIOLCA results are limited to broad industry-level estimates such as grain, cattle or poultry production, while PLCA results are specific to food type, geographic context and exact mode of production. EIOLCA industry data is generally comprehensive and readily available, whereas PLCA models often depend on incomplete data sources. Additional strengths, limitations and details of LCA methods are described in the literature (e.g. ISO, 2006). A number of software packages a commercially available that provide a framework for LCA and links to extensive data inventories. The most widely-used LCA software is SimaPro by PRé consultants.

Other approaches combine a variety of sources and methods. For example, Eshel and Martin’s (2006) analysis (widely cited in popular literature and carbon calculators) assigned GHG emissions to dietary lifestyles (e.g. vegan, vegetarian, U.S. average) based on a combination of the estimated energy inputs required for producing various foods as calculated by Pimentel (1996), combined with the estimated methane and nitrous oxide emissions from enteric fermentation and manure resulting from meat production. A listing of many LCA tools that have been developed can be found at: http://lca.jrc.ec.europa.eu/lcainfohub/toolList.vm

Methodologies incorporating social accounting and other dimensions attempt to address questions of possible trade-offs between the environmental, economic and social impacts of various production choices. Common to all assessment methods, however, is the need for sound approaches to: identifying the functional unit (i.e. what is being quantified); the system boundaries; impact categories; and allocation methods.

The impact categories that are considered within an LCA varies, but the following impact categories are common to many seafood LCAs (Pelletier et al, 2007):

- Abiotic depletion potential (ADP) (non-renewable resources);
- Global warming potential (GWP) (greenhouse effect).
- Acidification potential (AP);
- Eutrophication potential (EP);
- Ozone layer depletion potential (ODP);
- Photochemical oxidant formation potential (POFP);
- Freshwater Aquatic Ecotoxicity Potential (FETP);

- Marine Aquatic Ecotoxicity Potential (METP);
- Terrestrial Ecotoxicity Potential; and
- Human Toxicity Potential (HTP).

Some have added fisheries-specific impact categories. For example Vazquez-Rowe et al (2011) added seafloor impact potential (SIP) and discard reporting.

The focus of this paper is on the assessment of GHG emissions, which relates to one impact category (Global Warming Potential). However, many of the methodological choices to be made are common to both LCA and GHG assessment; this paper and the examples presented here therefore include LCAs as well as assessments only focusing on GHG emissions.

Greenhouse gas emissions

GHG emissions assessment is a simplified form of LCA that addresses a single impact, global warming. It provides a single numerical index of environmental performance which is easily understandable; however, this concept may be criticized as being one-dimensional, as it focuses on climate change effects while completely excluding all other environmental aspects of a product (Weidema et al, 2008).

Man-made climate change, or global warming, is caused by the release of certain types of gas into the atmosphere. These are termed greenhouse gases as their presence in the atmosphere contributes to the ‘greenhouse effect’. The dominant man-made greenhouse gas is carbon dioxide (CO_2), which is emitted whenever we burn fossil fuels in homes, factories or power stations. But other greenhouse gases are also important. Methane (CH_4), for example, which is emitted mainly by agriculture and landfill sites, is 25 times more potent per kilogram than CO_2. Nitrous oxide (N_2O) is emitted in smaller quantities, but is about 300 times more potent than carbon dioxide and released mainly from industrial processes and farming. Finally a number of other gases, mainly used as refrigerants such as Chlorofluorocarbons (CFC-12) and Hydrochlorofluorocarbons (HCFC-22), are typically several thousand times more potent than the same quantity of CO_2.

CO2 accounts for the largest share of total emissions. In 1990 and 2009, it contributed 79.4 per cent and 81.1 per cent, respectively, to total emissions. CH4 was the second highest contributor to total emissions (of about 12 per cent) in both 1990 and 2009, followed by N2O. The emissions of HFCs, PFCs and SF_6 taken together contributed approximately 1.5 per cent in both years (UNFCC, 2011).

Due to the differing Global Warming Potential (GWP) of these greenhouse gases and the variable significance in different processes, for simplicity they are often presented using functional units that relate to the ‘carbon equivalent’. GHG emissions assessment has therefore also been termed ‘carbon accounting’ and ‘carbon footprinting’. These now common terms are not, however, supported by common approaches to assessment.

Wiedmann & Minx (2008) identify a number of questions relating to defining a ‘carbon footprint’: Should the carbon footprint include just carbon dioxide (CO2) emissions or other greenhouse gas emissions as well, e.g. methane? Should it be restricted to carbon-based gases or can it include substances that don’t have carbon in their molecule, e.g. N_2O? One could even go as far as asking whether the carbon footprint should be restricted to substances with a greenhouse warming potential at all. After all, there are gaseous emissions such as carbon monoxide (CO) that are based on carbon and relevant to the environment and health. What's more, CO can be converted into CO_2 through chemical processes in the atmosphere. Also, should the measure include all sources of emissions, including those that do not stem from fossil fuels, e.g. CO_2 emissions from soils? This is a critical issue for agri-food assessments where significant impacts can relate to land use change and the consequences for carbon embedded in the soil.

Brenton et al (2010) provides an extensive summary of company, national and international carbon accounting initiatives and policies. This illustrates the growing interest in and demand for GHG emissions assessment, but also highlights the difficulties in agreeing consistent methods. The ISO has a standard under development for assessing GHG emissions and removals (ISO 14067), but there remains no internationally accepted approach to assessment to date, and many question whether a single approach could be acceptable for all interested parties. There is also the danger that market or national requirements for GHG assessment could put developing countries at a disadvantage. This is one of a number of challenges for those seeking to agree methods for the assessment of GHG emissions in seafood production systems.

Objectives

This paper presents a review of LCA / GHG emission methods in fisheries and aquaculture food production systems and:

- Sets out a preliminary scoping approach of key production systems (including industrial and small-scale fisheries and aquaculture production and related supply chains), quantitative GHG features, data resources and significant knowledge gaps;
- Provides examples of how GHG emissions from fisheries, aquaculture and supply chain processes can vary with systems and methods (e.g. gear type, vessel size, distance to fishing grounds, feed inputs, land /coastal area use);
- Compares aquatic sector LCA/GHG approaches to those used in wider food and agricultural production and supply systems to define options for further application in the aquatic sector, based on a reasoned argument around the following:
    - Data availability;
    - Costs of data collection and complexity / errors associated with up-scaling;
    - Complete supply chain assessments versus focus on specific elements (e.g. production, processing);
    - Pragmatic / realistic boundaries of emissions data collection;
    - Modelling of changes in production technology and practices;
    - Level of detail at the species / product /sub sector level; and
    - Global assessment methods for GHG emissions in fisheries and aquaculture;
- Identifies the potential constraints to and options for development and use of GHG assessment methods and related approaches more widely and routinely across the seafood sector.

Common assessment requirements

Some common aspects for consideration in LCA and GHG assessment are:

1. **The goals/objectives for assessment** – why is it being done and who is it seeking to inform;
2. **The subject of assessment** – is it a product, a process, a company or a country;
3. **Establishing system boundaries** – set the scope of the assessment by specifying what is included and what is excluded;
4. **The allocation method** – how will the emissions be allocated to the product in question?
5. **Deciding on the approach** – will the assessment use generic data, existing specific information or require primary data collection?
6. **The emission factors and units** – establish the units and emission factors to be used in measurement; and
7. **The style and structure of reporting**– determine the presentation of results based on who the target audience is.

These elements are explored in the following sections.

Goals and objectives for assessment

There are now numerous market and policy drivers towards the assessment of GHG emissions for particular products and company activities. Wider private and public sector procurement policies are driving demand for GHG assessments. For example, the London Organising Committee for the Olympic Games (LOCOG) requires suppliers to provide information on the embedded energy of products that would be determined via a GHG emissions assessment.

Companies frequently cite the following reasons for undertaking a GHG assessment (WRI & WBCSD, 2004):

- Managing GHG risks and identifying reduction opportunities;
- Public reporting and participation in voluntary GHG programmes;
- Participating in mandatory reporting programmes;
- Participating in GHG markets; and
- Recognition for early voluntary action.

For most stakeholders there are multiple reasons for, and expected benefits resulting from, GHG assessments. These reasons and benefits dictate the elements to be included in an assessment; for example, seeking reductions through efficiency gains will require the use of specific company or product information, while the use of generic data and simplified assessment approaches may be sufficient for compliance with customer procurement policies.

Subject of assessment

GHG emissions are assessed in terms of product-related impacts, or on a wider basis in terms of the companies or countries producing and consuming those products, so assessment may examine:

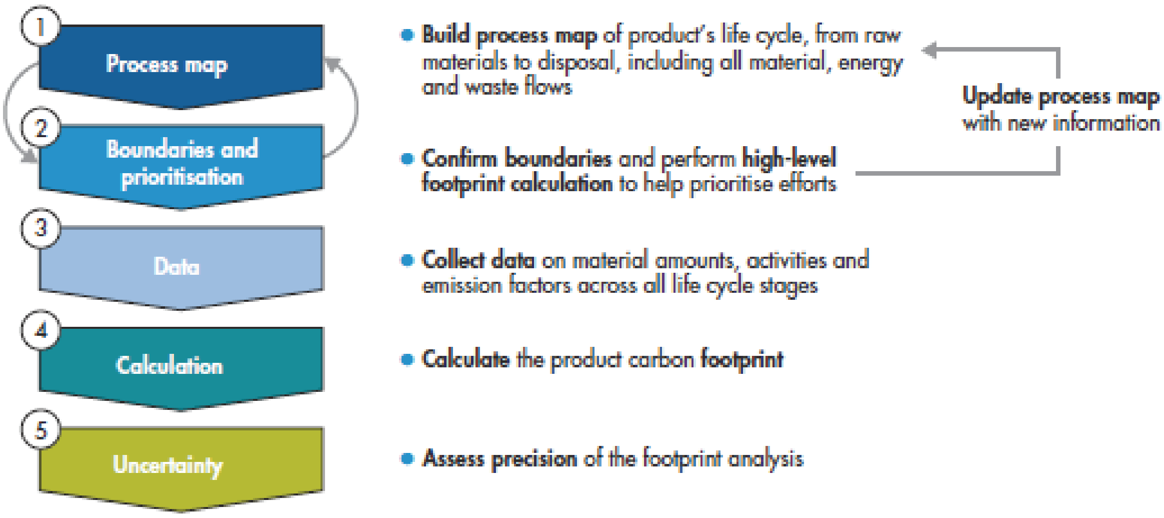
- Specific products;
- Product groups;
- Individual production units;
- Corporations; and/or
- Countries.

These different subjects of assessment are discussed below. The subject of assessment is generally informed by the goal of assessment. For example, a corporation should consider the products and services it supplies across all its operations if undertaking GHG assessment to identify efficiencies or for corporate social responsibility (CSR) reporting. If the procurement policy of a government or customer requires GHG assessment it may be focused on a specific product.

Products

In 2008 the British Standards Institute (BSI) published the Publicly Available Standard (PAS) 2050: Specification for the assessment of the life cycle Greenhouse Gas emissions of goods and services (BSI, 2008). PAS 2050 sets out a simple five-step process for carbon footprint assessment of a product (Figure 1).

Figure 1 Steps in carbon footprint assessment in PAS 2050



Source: BSI, 2008

The assessment of a product may be business-to-business (to the point where a product is sold on to another business also termed 'cradle to gate') or business-to-consumer (sometimes termed 'cradle to grave'), which generally includes the additional steps of 'consumer use' and 'disposal/ recycling'. The LCA of fresh and canned mussel production and consumption in Galicia, Spain (Box 1) is an example of an assessment of individual products. It illustrates the importance of defining scope and system boundaries, which must be consistent if results are to be comparable. The results also show how the assessment of GHG emissions can produce initially surprising results that risk putting small-scale producers at a disadvantage.

Box 1 LCA of Galician Fresh and Canned Mussels (Iribarren, Moreira and Feijoo, 2010)

An LCA was conducted to assess the environmental impacts of fresh and canned mussel products, which identified common phases (S1) and distinct phases (S2-5) in the product life cycles (Figure 2). System boundaries were then determined to establish what activities should and should not be included in the impact inventory for each phase. Figure 3 shows the system boundaries for the inventory of fresh mussels: purification in dispatch centres (S2) and consumption (S4). Mussel organic waste valorisation (processing waste meat into fishmeal or pâté) was excluded from the scope [for simplicity].

Figure 2 Systems involved in the LCA of fresh and canned mussels

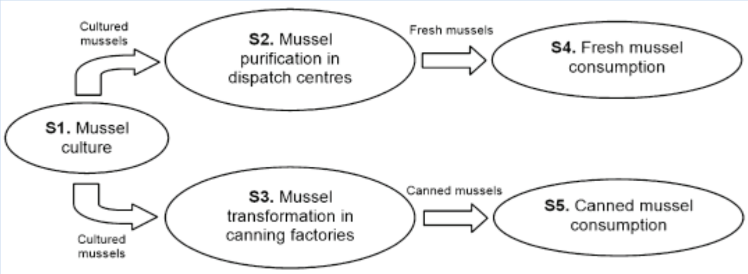
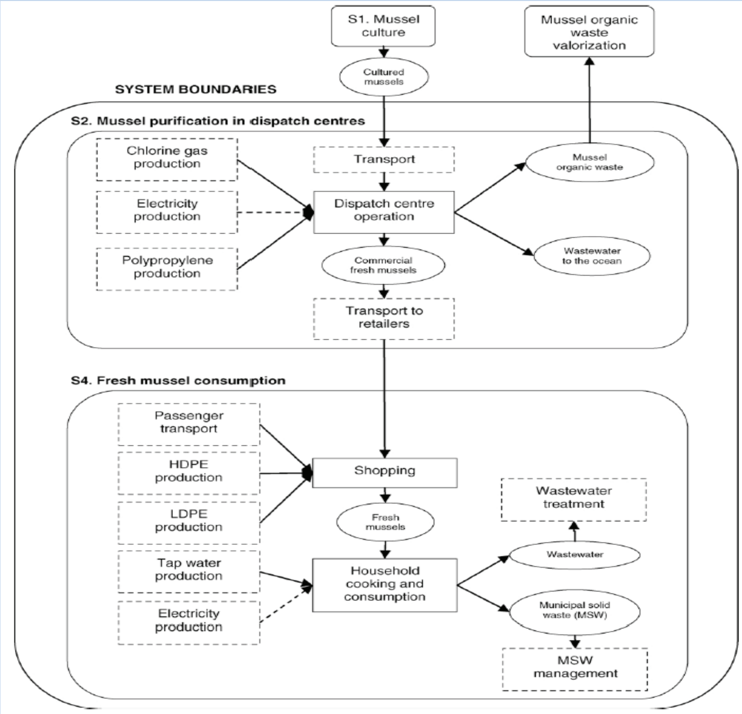


Figure 3 Process flow diagram for the LCA of fresh mussels*



*Solid box lines = foreground system using specific data, dashed box lines = background system using LCA database data. Solid arrows = mass flows, dashed arrows = energy flows.

For fresh mussels, the mussel purification stage dominated in all of the ten impact categories considered. The main source of impact was from the production of electricity, which accounted for 90% of Global Warming Potential (GWP). The other significant GWP contribution was from transport to retailers. For canned mussels, the main source of GWP was fuel oil production associated with ancillary operations (31.6%); followed by electricity production at various stages contributing to 22% GWP; 15% of GWP for canned mussels came from emissions to the environment and 9% from tin can production. The consumption phase only contributed 0.5% from tin plate waste treatment.

The impact of including mussel culture (S1) gave significant changes to results; the processing stage still dominated for fresh mussels, but for canned mussels the culture stage became the most significant. This initially surprising result is explained by the efficiencies in the large scale canning operations compared to the inefficient use of electricity seen in the small-scale dispatch centres associated with fresh mussels.

Product groups

For product-related assessments there are varying levels of aggregation depending on the goals of the assessment. These levels can be described as, from high to low (IPTS, 2006):

1) **Functional areas of consumption:** up to a dozen elements, e.g. 'transport', 'clothing', 'healthcare' and 'recreation'

2) **Consumption domains:** up to several dozens of elements, e.g. 'transport' contributing to 'healthcare' and 'recreation'

3) **Product groupings:** up to several hundreds of elements, e.g. sub-division of 'Consumption domain' (2) into 'car transport', 'rail transport', 'air transport', etc.

4) **Homogeneous product groups,** e.g. medium range diesel cars

5) **Individual** products, e.g. a specific diesel car.

The European Commission's Environmental Impact of Products (EIPRO) project, aiming to determine the impact of consumption by the Member States of the European Union, opted to work to the third level of detail, product groupings. A number of national government studies have also determined that product groups are sufficient for their purposes, namely identifying priority areas for targeting reduction measures. Examples of GHG assessments for seafood product groups are presented in section 0.

Corporations

Corporate level assessments should attempt to assess all activities by that corporation. To date these have generally focused on corporations involved in manufacturing products, but voluntary CSR reporting and recent government requirements such as the US Mandatory Reporting of Greenhouse Gases Rule (EPA, 2009) have led to assessments of large companies that may only provide services.

The US-based World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) developed the GHG protocol in 2001. Since then it has been revised and has developed into two streams; a Corporate Standard and a product assessment standard. The Corporate Standard has been used as the basis for a number of national GHG programmes and global corporate groups such as the Business Leaders Initiative on Climate Change (BLICC) (see http://www.ghgprotocol.org/about-ghgp/users for a listing of users).

The GHG Protocol Corporate Accounting & Reporting Standard (WRI/WBCSD, 2004) provides requirements and guidance for companies and other organizations to prepare and publicly report a GHG emissions inventory that includes direct and indirect emissions (termed scope 1 and scope 2 emissions), while a new standard (WRI/WBCSD, 2011) also requires the reporting of emissions resulting from a corporations value chain activities (scope 3 emissions). Issues associated with applying these different system boundaries are discussed in section 0.

Some corporations are not only undertaking GHG assessments of their own value-chain, but are taking a more proactive approach to supplier reporting. In 2007 Wal-Mart and the Carbon Disclosure Project worked with Wal-Mart suppliers to first make an assessment of GHG emissions and to then take action to reduce emissions associated with products supplied to Wal-Mart (Wal-Mart, 2009).

Countries

Most country GHG emissions inventories are compiled based on the methodological guidelines developed by the Intergovernmental Panel on Climate Change (IPCC), initially the IPCC National Greenhouse Gas Inventories methodology (Houghton et al, 1997 updated 2006).

In accordance with Articles 4 and 12 of the United Nations Framework Convention on Climate Change (UNFCCC), countries that are Parties to the Convention submit national greenhouse gas

(GHG) inventories to the Climate Change secretariat[2]. The inventory data are provided in the annual GHG inventory submissions by Annex I Parties and in the national communications under the Convention by non-Annex I Parties.

The GHG data reported by countries contain estimates for direct greenhouse gases, such as - Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Perfluorocarbons (PFCs);– Hydrofluorocarbons (HFCs); Sulphur hexafluoride (SF_6); as well as for the indirect greenhouse gases such as Sulphur Dioxide (SO_2), mono-nitrogen oxides (NOx), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC).

The inventories require 'key categories' to be identified, which are then assessed and aggregated to give the national inventory. The key categories to be assessed are determined quantitatively by level (when summed together in descending order of magnitude, add up to 95 percent of the sum of all emissions and removals in the most recent assessment year) and by trend (those that are most different from the trend seen in total emissions). Key categories are also identified qualitatively e.g. if a country identifies that certain mitigation techniques and technology are noteworthy or if growth is expected in certain sectors.

Agricultural production and in particular land use change (which can be associated with agricultural production) are often key categories within national inventories, but fishing or seafood production are not often identified within those key categories as requiring assessment. Even for two of the largest fishing nations, Spain and Japan, fishing remains grouped with 'agriculture/forestry/fishing sources'.

System boundaries

ISO defines a system boundary as 'a set of criteria specifying which unit processes are part of a product system'.

A common classification is used to group and report on emissions per unit based on where the energy is used and where the emissions occur. On this basis, GHG emissions can be classified into three main types:

- **Direct emissions**: GHG emissions from greenhouse gas sources owned or controlled by the organisation;
- **Energy indirect emissions**: GHG emissions from the generation of imported electricity, heat or steam consumed by the organisation; and
- **Other GHG emissions**, which are a consequence of an organisation's activities, but arise from greenhouse gas sources that are owned or controlled by other organisations (e.g. suppliers).

These are confusingly also sometimes referred to in the literature as Scope or Tier 1, 2 and 3, but will here remain as 'direct', 'indirect' and 'other'. Most involved in GHG assessment would include direct and the indirect emissions, but the inclusion or extent of other GHG emissions are less consistent.

Taking tuna as an example; direct emissions would relate to the fuel and refrigerants used by vessels; indirect emissions would include the energy used in processing and transport to a given point in the supply chain; other emissions could include emissions from the production of steel for fishing vessels and plastics for gear or packaging.

To fully understand production systems, assessments should be as comprehensive as possible. From a commercial perspective, there may be an incentive to limit system boundaries, but there is also benefit in transparency and the validation of assessments by third parties. There is also a limit to the extent to which final consumers and even intermediate businesses can affect emissions occurring far up the supply chain. Therefore most simply seek system boundaries that are

[2] The UNFCCC provides an inventory of data is provided at http://unfccc.int/ghg_data/items/3800.php

consistent with similar products or companies Thus, a balance must be made, and consistent, comprehensive rules must be developed to decide the proper extent of inclusion for supply chain GHG emissions (Matthews, 2008).

The setting of system boundaries has clear implications for the final scale of GHG emissions and the complexity of any assessment. A fundamental decision is therefore what system boundaries should be set for seafood and whether these should differ when assessing specific products rather than product groups, or corporations compared to countries.

Allocation method

When the system boundaries are set, the 'allocation' of emissions to the subject of the assessment (generally a product or product group) takes place. ISO 14044 defines allocation as: "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO, 2006). Products from capture fisheries have often gone through a long value chain before being consumed. Some of the steps in the value chain are multiple output processes. In these steps, the environmental burden must be distributed among the outputs via allocation.

The simplest way of avoiding the need for allocation is to include all products in the same functional unit, a so-called global functional unit (GFU) (see section 0). For seafood LCAs this may be possible for the processing and fishing stages if the objective is to assess the overall impact of these operations, but not if an individual product is the subject of assessment as fishing often results in the capture of more than one species and processing of more than one product. Therefore emissions are allocated to the subject of assessment. This can be done in different ways based on mass, economics or gross energy content. For example the emissions from a fishing vessel are divided based on the volume, value or energy associated with each species landed. Winther et al, 2009 present a comprehensive discussion of the advantages and disadvantages of each method.

Svanes et al (2011) found that different allocation methods might be appropriate for different purposes in seafood LCAs. For external communication to the market, mass allocation might be the preferred method in most cases. For internal improvement work, both economic and mass allocation could be used, but economic allocation might be the best alternative (Svanes et al, 2011). The majority of seafood studies reviewed for this paper resort to mass allocation, citing reasons of price variation and data availability, with only a handful using economic allocation (e.g. Ziegler and Valentinsson, 2008).

Approach

Emissions are estimated at different levels of complexity. Within the IPCC and EPA/EAA Guidelines, these methods of estimation are expressed in three tiers of increasing complexity (Goodwin, 2009):

Tier 1 method: a 'simple' method using default emission factors from readily available statistical sources. The guidelines advise against using Tier 1 for key categories.

Tier 2 method: the default emission factors should be replaced by country-specific or technology-specific emission factors. This might also require a further split of the activity data over a range of different technologies, implicitly aggregated in the Tier 1 method. Tier 2 methods are more complex, reduce the level of uncertainty, and are considered adequate for estimating emissions for key categories.

Tier 3 method: a method that uses the latest scientific knowledge in more sophisticated approaches and models. At one end of the range there are methodologies similar to Tier 2 (i.e. activity data x emission factor) but with a greater disaggregation of activity data and emission factors. At the other end of the range are complex, dynamic models in which the processes leading to emissions are described in great detail.

EIPRO used a model based on inventory/emission data for the EU-15, assuming that the differences in technologies in the new Member States were less relevant (IPTS, 2006). This approach compromises the accuracy of results to some extent, but has the benefit that less developed countries are not disadvantaged due to their use of less efficient technology and the need for specific data from these countries is reduced.

As fisheries and aquaculture activities are not often disaggregated within key categories, seafood LCAs have used a tier 2 or 3 approach using primary data associated with the specific fishery or company rather than default emission factors to determine emission levels. The development of databases of emissions factors that are relevant to fisheries and aquaculture would enable the wider application of such assessments as the complexity of assessments is reduced, with a reduction in cost and resources.

Functional units and emission factors

The functional unit used can differ between assessments, and again is a consequence of the goal of the assessment. PAS 2050 advises that the appropriate functional unit is driven by how the product is typically consumed (e.g. one can of tuna); however, it may be easier to collect data and calculate the footprint using a larger unit (e.g. one tonne of tuna).

Examples of seafood functional units from a cod fishery are presented in Table 1. The results are presented as kg of CO_2-equivalent/functional unit.

Table 1 Functional units used for cod autoline fishery case study

Functional unit	Source	Sales unit	State	System border ends at:
Wetpack, 1 kg	Belly and tail pieces	400 g packages	Frozen	Retail in Sweden
IQF, 1 kg	Belly and tail pieces	400 g packages	Frozen	Retail in Sweden
Fish burger, 1 kg	Mince, block and plant-derived ingredients	5 kg package	Frozen	Institutional buyer in Sweden
Loins product, 1 kg	Back piece (loin)	2 kg package	Chilled	Regional distribution centre in the UK
Processing residue, 1 kg	Skin, bones and other residue from processing	Large blocks	Frozen	Buyer in Oslo, Norway

Source: Svanes, 2011

If reporting to third parties, a carbon equivalent (CE) is generally presented, but this aggregates the composition of GHG emissions, which can be important in determining mitigation measures. In some systems other greenhouse gases are very significant, for example methane (CH_4) from enteric fermentation from cattle constitutes 32% of total greenhouse gas emissions from agriculture (Bellarby et al., 2008).

For the national inventories that are required by the UNFCCC, data are provided for separate gases. Data are also provided for total aggregate GHG emissions (the weighted sum of CO_2), both including and excluding net GHG emissions/removals from land use, land-use change and forestry (LULUCF) (UNFCCC, 2011).

More information on functional units and metrics relating to seafood GHG emissions is presented in Muir (2011) a further background paper for the GHG emissions workshop.

A number of emissions inventories have been developed to enable LCA research. These are databases of emissions factors associated with particular activities and inevitably focus on the areas of most relevance to those developing the resource. A few examples are:

- American Petroleum Institute Compendium of methods, calculations and emissions factors for each type of emission identified in the oil & gas industry;
- Ecoinvent contains more than 4,000 LCA data sets with a focus on industrial processes (www.ecoinvent.ch);
- The EMEP/EEA air pollutant emission inventory guidebook (formerly called Corinair) is a freely available resource produced for the European Environment Agency that is designed to facilitate reporting of emission inventories by countries to the UNECE Convention on Long-range Transboundary Air Pollution and the EU National Emission Ceilings Directive;

- The IPCC established the Emission Factors Database (EFDB) containing the IPCC default data and also holds the EMEP/EAA data (www.ipcc-nggip.iges.or.jp/EFDB/main.php); and
- The open access database LCAFood (www.LCAFood.dk) is a comprehensive LCA database covering most food products produced under Danish/North European countries.

The last example, LCAFood contains data from Thrane (2003) on fishery groups such as cod, flatfish, lobster, mussels and farmed trout. A compendium of more recent research with a far wider geographic scope would be a useful resource for those seeking to undertake seafood LCAs and GHG assessments.

Reporting

The presentation of assessment data may take a number of forms depending on the target audience. Reports can be very technical using LCA terminology to present the specific functional units, .e.g.: “Globally, agricultural CH_4 and N_2O emissions increased by 17% from 1990 to 2005, an average annual emission increase of 58 $MtCO_2$-eq/yr. Both gases had about the same share of this increase. Three sources together explained 88% of the increase: biomass burning (N_2O and CH_4), enteric fermentation (CH_4) and soil N_2O emissions (US-EPA, 2006a).”

It is possible and often necessary to adjust the presentation of results for a wider readership that is unfamiliar with LCA terminology, such as: “The greenhouse gas emission per kg pork, carcass weight is 3.6 kg CO2 eq. This equals the amount of greenhouse gas emitted from a 10 km drive in passenger car (LCA Food, 2008).”

As the above examples illustrate, a range of styles is very evident in the reporting of assessments within the agri-food sector. Agriculture is a key category in most national inventories and also highly relevant to the public as consumers. ‘Livestock’s Long Shadow’ is an LCA assessment of cattle conducted for the FAO (Box 2). The assessment was global in scope and the researchers were required to make the same methodological decisions described in the preceding sections. The report is presented in a number of forms with non-technical summaries and detailed technical annexes explaining the methodologies employed.

The use of generic reporting templates is an important developmental step in relation to standards and mandatory reporting requirements. In developing seafood GHG assessment consideration should be given to the need for defined reporting structures.

Box 2 Livestock's Long Shadow - methodological choices

From Steinfeld et al, 2006

Livestock's Long Shadow is an assessment of the world's livestock sector environmental impact. It takes into account direct impacts and feed crop agriculture and finds that livestock production contributes 18% of GHG emissions in carbon equivalent terms. This is mainly from land use changes, but methane emissions from enteric fermentation also represent a major contributor. Therefore assessing methane emissions from enteric fermentation as accurately as possible is critical.

Levels of methane emission are determined by the production system and regional characteristics as well as several other animal and feed characteristics (feed type, weight and age of animal, even the amount of exercise.). This detailed data is generally not available in most countries and so standard emission factors are used. These are less accurate, but a standard factor does provide consistency that is not found with a mix-and-match approach, i.e. adopting more detailed methodology where data permit.

The report's methodology varies by livestock type and GHG emission source depending on the data available. For cattle, researchers adopted a Tier 2 methodology using the FAO database of agricultural production combined with IPCC default data and the EPA livestock analysis model. For all other livestock types, a Tier 1 methodology was adopted and default emissions factors from the IPCC manual were used.

Using Tier 2 methodology caused (a) an increase in the weighted average for dairy cattle in most developing regions and (b) a decrease for other cattle in OECD and transition regions. The association of low feed digestibility (from poorer quality feed) and a comparatively higher default methane conversion factor resulted in higher emission levels for developing country regions. The researchers also note that using default values in a Tier 1 methodology for rapidly industrialising developing regions such as Asia (particularly China) and Latin America result in the largest differences compared to a Tier 2 approach.

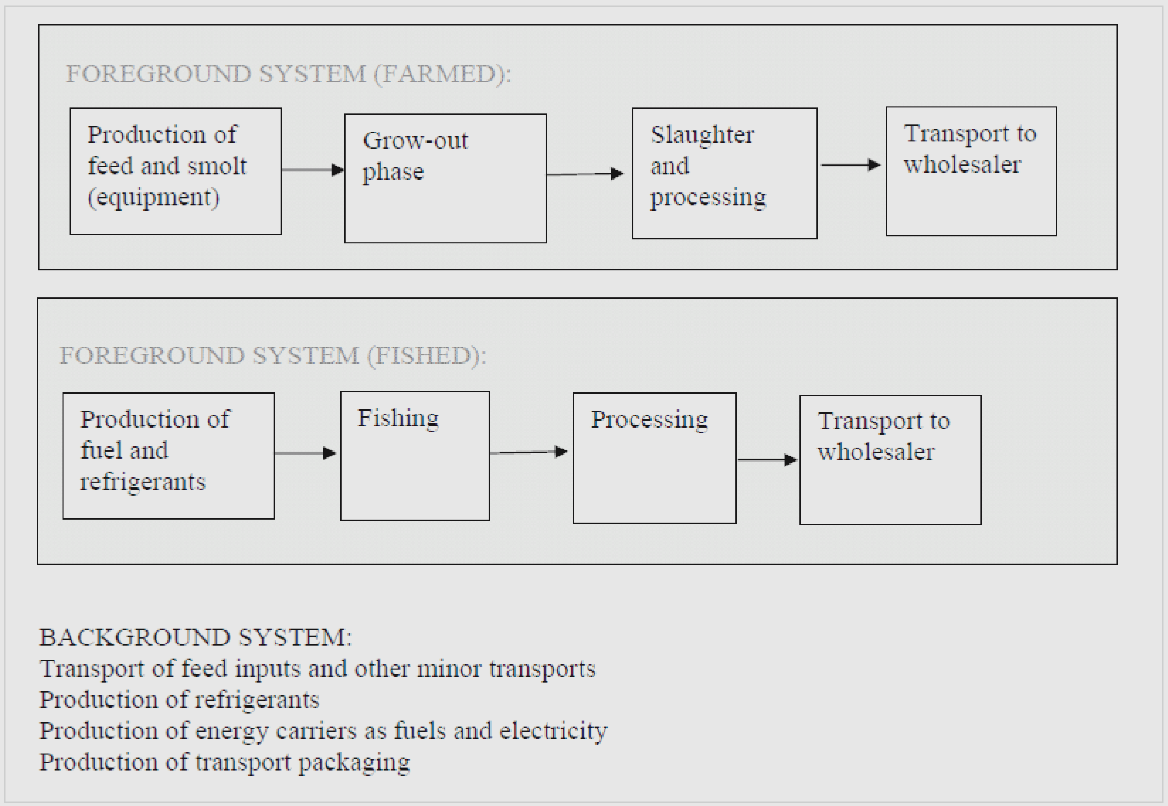
GHG emissions assessment in seafood production systems

Occurrence of GHG emissions

GHG emissions occur at every stage in the seafood value chain. These emissions differ most significantly between the production stages of capture fisheries and aquaculture systems, but there is significant variation in production systems within both sectors as well as differences in terms of inputs and post-harvest handling and processing.

Figure 4 presents a generalised process flow diagram for Norwegian seafood products identifying common stages of farmed fish and capture fish production. Foreground systems are those where direct impacts are established via specific data and the background system is reliant on data from LCA databases to account for indirect impacts to be included in the assessment. This pragmatic approach ensures potentially significant indirect impacts are included, while the assessment remains manageable as resources are concentrated on sector-specific elements in the process. Additional methodological detail on the Winther et al study (2009) and its results are provided in Box 3. GHG emission for wild caught cod and farmed salmon are found to be very similar and close to the emissions associated with the production of chicken. For fishing, diesel and refrigerant use were the two most important elements. Diesel use was far less for pelagic species (mackerel and herring), which are targeted with relatively resource-efficient gear catching very large volumes within well-managed fisheries, compared to the whitefish fisheries. For farmed salmon it is the production of feed which is the most significant stage.

Figure 4 Process flow diagram of farmed and capture seafood systems



Source: Winther et al, 2009

Box 3 Assessment of GHG emissions and energy use in Norwegian Seafood products

From Winther et al 2009
At the request of the Norwegian Seafood Federation, SINTEF conducted an assessment of GHG emissions and energy use in Norwegian Seafood. 22 products were defined from 7 production systems (5 capture systems for cod, haddock, saithe, herring and mackerel; 2 farmed systems for salmon and mussels.
The study looked at two impacts:

(a) GHG emissions using a modified[1] version of the IPCC 2007 indicators with a 100-year perspective, measured in kilograms of CO_2 equivalents.

(b) Cumulative Energy Demand (CED) directly in the production chain and to produce supply materials, measured in MJ equivalents.

Production of supply materials for the fishing and farming stage represent the starting points for the assessment. The finishing point for the assessment was transport to the wholesaler. The functional unit chosen was 1kg of edible product therefore only mussel meat; requiring various conversion factors were applied to the product quantities transported to the wholesalers to reach per kg of edible product.
Fuel consumption was calculated by combining data from Norwegian profitability survey and landing statistics to establish fuel use per species. This raises the problem of how to allocate the resource use to several fish species being landed simultaneously. Allocation also arises with feed production and fish processing where several products are produced. Economic allocation was rejected due to the high variability in fish and feed prices over time. Gross-energy content was rejected as it was felt the higher energy found in whitefish by-products (e.g. cod liver oil) would create misleading results. Therefore mass allocation was selected, as it is stable over time, relatively simple and directly related to the functional unit. Despite these advantages an external reviewer suggested that economic allocation should have been chosen as value best reflects the drivers behind seafood production. Recognising that choice of allocation does impact on results sensitivity analysis was undertaken using economic allocation for two product chains.
Results from the study are presented in Table 2 below.
Table 2 Carbon footprint an energy usage for meat and seafood products at landing/slaughter site

Species	Carbon footprint (kg CO_2e/kg edible part at slaughter/landing)	Energy use (MJe/kg edible part at slaughter/landing)	Reference
Beef, Swedish	30	79	Cederberg et al. 2009
Pork, Swedish	5.9	41	Cederberg et al. 2009
Chicken, Swedish	2.7	29	Cederberg et al. 2009
Salmon	2.9	40	Current study
Cod	2.9	27	Current study
Haddock	3.3	34	Current study
Mackerel	0.54	7.1	Current study
Herring	0.52	6.8	Current study

Source: Winther et al, 2009
(1) The modification involved removing a plant assimilation factor as the authors felt these did not result in any net contribution to CO_2 in the atmosphere.

The following sections are categorised in three broad processes; capture fisheries; aquaculture; and post-harvest, to explore how seafood GHG assessments have been conducted to date.

Capture fisheries

Inputs (capital goods)

An analysis of the energy inputs to fisheries would ideally encompass (Tyedmers, 2000):

- direct fuel energy inputs;
- direct and indirect inputs to build and maintain fishing vessels;
- direct and indirect inputs to provide fishing gear ‘consumed’ in the process of fishing; and
- the energy required to sustain the fishing labor inputs.

In GHG assessment terms, the inclusion of energy for material construction could be viewed as the third category of indirect inputs, ‘other emissions’ (scope 3 in GHG protocol terms) relating to energy use in the upstream supply chain.

Researchers of large-scale fisheries have found that direct fuel energy inputs typically account for between 75 and 90% of the energy inputs, regardless of the fishing gear used or the species targeted (e.g. Rawitscher, 1978), Watanabe and Uchida, 1984, Tyedmers, 2000). Depending on the character of the fishery and the scope of the analysis conducted, the remaining 10 to 25% is generally composed of energy inputs associated with vessel construction and maintenance, and the provision of labor, fishing gear, bait, and ice if used (Tyedmers, 2004).

Calculating the embedded energy from capital goods adds complexity, resource demands and further uncertainty to an assessment. PAS 2050 excludes capital goods from assessment due to (a) the lack of carbon footprint data currently available to identify sectors where capital goods emissions are material and (b) cost/complexity of analysis. Draft versions of PAS 2050 included emissions related to capital goods and their inclusion will be considered in future revisions of the specification (BSI, 2008). For these reasons and the comparatively small contribution in most fisheries systems studied to date, the embedded energy from constructing the materials used in fishing tends not be included in GHG assessments.

A greater number of LCAs include capital goods due to the added impact of resource use in addition to embedded energy. Vazquez-Rowe et al (2010) included vessel, net, diesel and ice production due to the availability of data from Galician shipyards and gear manufacturers. Estimated amounts were divided by the average lifespan of each to derive annual consumption estimates.

The treatment of capital goods is a critical decision as it will influence GHG assessment results and could differ significantly between regions. If the objective of a GHG assessment is to compare two industrialised processes or products derived from these, researchers would be more inclined to exclude embedded energy from assessments. The use of metals such as aluminium and steel in vessel and gear construction results in far greater embedded energy than for wood or fiberglass. The inclusion of embedded energy is therefore one area where artisanal operations are likely to be at an advantage.

Production

Production operations in fisheries relates to the fishing stage, generally spanning the entirety of a trip from and to the point of landing. The key source of GHG emissions in this stage is the direct burning of fossil fuels, generally diesel oil by the vessel.

Although such traditional, low-input fisheries persist in many parts of the world, high-input, industrialized fisheries now account for the majority of global landings. Among these fisheries, particularly those targeting high value species, it is now common for direct fossil fuel energy inputs alone to exceed the nutritional energy embodied in the catch by at least an order of magnitude (Tyedmers, 2004).

There are three main energy flows on board most fishing vessels (Thomas et al, 2010): a diesel engine for propulsion; a diesel generator for electrical demand; and a net winch, auto-line or pot/trap hauler. On most fishing vessels, direct fuel inputs are used primarily for vessel propulsion. In some fisheries secondary energy-consuming activities, including onboard processing, refrigeration, and freezing, can account for a nontrivial portion of the fuel burned. Squid jigging vessels employ high intensity lamps, automated jigging machines and freezers, which are estimated to account for over 40% of fuel burned (Ishikawa et al, 2004).

Several factors are known to influence the fuel intensity of commercial fisheries. Driscoll & Tyedmers (2010), suggest that these include:

- the abundance and characteristics of the target species;
- vessel and engine size;
- fleet size and the degree of its (over)capitalization;
- trip length;
- distance travelled to fishing grounds; and
- the gear used.

Due to this complexity, and as national statistics on economic performance of fishing fleets are often absent or lacking the necessary detail, data to inform fuel consumption is often derived from questionnaires (e.g. Hua and Wu, 2011 and Winther et al, 2009).

Figure 5 Equation for establishing fuel consumption per gear

$$FS_j = \frac{\sum_i^n FD_{ij}}{\sum_i^n f_{ij}} = \frac{\sum_i^n \frac{f_{ij} D_i}{F_i}}{\sum_i^n f_{ij}}$$

- FS_j: Fuel factor for equipment j [l/kg]
- FD_{ij}: Fuel allocated to equipment j on boat i [l]
- f_{ij}: Landings by equipment j on boat i [kg]
- D_i: Total fuel consumed by boat i [l]
- F_i: Sum of all landings by boat i [kg]
- n: number of boats in profitability survey after data corrections

Source: Winther et al, 2009

A recent estimation of emissions from the Taiwanese fishing fleet (**Error! Reference source not found.**) illustrates the level of complexity that can be applied to this single critical stage in a GHG emissions assessment if adopting a Tier 3 approach, particularly when the subject of assessment is the fleet itself rather than particular products.

Box 4 Estimation of GHG emissions in the Taiwanese fishing fleet

From Hua and Wu, 2011

The study used the engine output (kiloWatt, kW) method to estimate emissions for diesel engines associated with fishing vessels. A survey collected information concerning propulsion and auxiliary engines powering the vessels. Auxiliary engines generally supply power for equipment, such as capstan systems for trawling, lighting systems for fish attraction, and freezer units for harvests.

Based on the survey, individual engine profiles were developed by combining specific information regarding engines. That information included engine use, engine type, make and model, horsepower, annual hours of operation, typical engine load, ‘‘wet’’ or ‘‘dry’’ engine exhaust, and a number of engine-specific specifications used for emission factor elements.

The numbers of propulsion and auxiliary engines associated with each fleet in each district were estimated by multiplying the numbers of vessels in specific categories by the average numbers of engines per vessel category. Average numbers of engines by engine type and vessel category were estimated using the results from the survey. For emission estimation purposes, two of the key inputs included the annual hours of operation (manoeuvring and at sea) and the typical engine load.

The survey collected engine-specific annual use values to estimate cumulative engine use. Engine use was further estimated by multiplying the annual use by the age of the engine. Engine load under normal operating conditions was the second activity input. Information concerning operating loads for fishing craft engines was limited. The primary source of marine engine load factors was the U.S. EPA’s Non-road Model (US EPA, 2003). Using this model, a load value of 43% was assigned to each fishing vessel and engine type. Load on the main engines during navigation and manoeuvring in the harbour was assumed to be between 20% and 45%, depending on the size and type of fishing craft. For modelling purposes, an average size was determined and assumed equal for all types of fishing vessels within a particular size category.

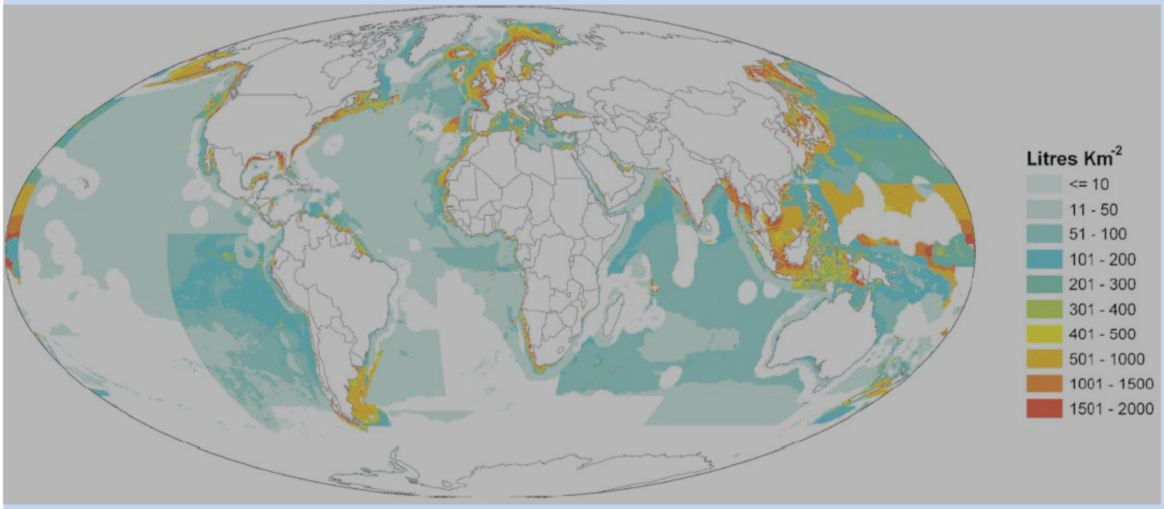
The approach used to develop fishing vessel emissions inventory estimates entailed the determination of average daily emissions per engine. This was accomplished using the ARB’s HARBOR model (ARB, 2004) to estimate annual, or daily, emissions for each engine. This data was used to estimate average emissions for each category of vessel. At cruising speed, the propulsion engine speed is 82.5% in average. At higher loads, fuel consumption and engine maintenance cost go up dramatically (Schau et al., 2009). The auxiliary engine load factor represents the actual engine load used divided by the total installed auxiliary engine power.

Most studies have explored fuel use on a product, product group, or fleet basis. Tyedmers, Watson & Pauly (2005) did however estimate fuel use by fisheries on a global scale (Box 5). They found that in terms of energy efficiency, fisheries globally dissipated 12.5 times the amount of fuel energy as they provided in the form of edible-protein energy. This 8% return on energy invested seems low, but is a better return than many other intensive food production systems; beef was estimated at between 2.5% and 5% depending on the production system, pork 7.1% and lamb 1.8% (Pimentel, 2004).

Box 5 Estimating fuel use in global fisheries

From Tyedmers, Watson & Pauley, 2005
The researchers assembled detailed fuel consumption, catch, and vessel/gear characteristic data from a wide range of published and unpublished sources. In total, data representing more than 250 distinct fisheries or fleet subsets, based in 20 countries, were assembled. From these were calculated species-specific, globally- and where possible, regionally-representative average fuel use values. These values then were integrated with species-specific, spatially resolved catch data for the year 2000 to provide estimates of global total and average fuel use intensity, and the basis upon which fuel consumption could be mapped.
To proceed from individual fuel use case studies to estimates for each reported commercial taxa from each of 18 statistical areas used by the FAO required a process of progressive refinement, where average values were replaced at each step by more specific (with regard to taxa and location) estimates where possible. To provide all combinations of fished commercial taxa and statistical reporting areas with an initial estimate, the researchers started with values based on the average of all case studies within the same broad taxonomic group (for example, ‘‘shrimp’’ or ‘‘tuna’’), ignoring geographic area. Recognizing that in many cases, fisheries land more than one species, a provision was also made to weight averages based on the relative contribution that a given species made to the total landings recorded in a case study [mass allocation].
The edible-protein energy efficiency of global fisheries was calculated by dividing the maximum edible-protein energy that could be derived from global catches in 2000 by the energy content of the fuel burned. In 2000 there was a reported 80 million tonnes of global fisheries landings from marine waters, which was caught by burning approximately 50 billion litres of fuel. This amounts to 1.2% of global oil consumption. Approximately 1.9 t of fish was landed for each tonne of fuel consumed directly in their capture, which resulted in 1.7t of CO_2 emissions per tonne of fish landed.

Figure 6 Distribution and intensity of fuel consumption by marine fisheries in 2000



Most fuel is expended in nearshore fishing grounds of the Northern Hemisphere. This in part reflects the variable productivity of the world’s oceans, but also illustrates the focus of industrialised fishing effort in these areas. Fishing grounds in which heavy fuel use was particularly widespread in 2000 included the western Pacific and adjacent seas, the Bering Sea, and coastal waters of the northeastern and southwestern Atlantic and northern Indian Ocean.

The inclusion of refrigerants results in GHG emissions totals that are not exactly proportional to energy use. The extensive use of cooling and freezing operations within seafood supply chains, including on board fishing vessels, means that GHG emissions totals would exceed estimates derived solely from energy use. However the second most significant contributor to GHG emissions after fuel oil combustion in many systems is refrigerant use and some assessment of refrigerants is generally included.

GHG emissions from refrigerants result from leakage and during repair and maintenance. As these are occasional events with varying levels of refrigerant loss, this element has generally been determined via survey and consultation with providers of refrigeration equipment. A key refrigerant that is still in use is R22, a hydro-chlorofluorocarbon (HCFC) with high ozone depletion and global warming potentials 1,810 times greater than CO2.

New EC rules require the use of agents that are less harmful to the ozone layer (European Commission, 2010). The European industry is slowly shifting to other types of refrigerants, such as R507, R404A and natural refrigerants, ammonia (NH3) and CO_2 itself, but a number of LCA researchers have found that the majority of fishing vessels still use R22 (e.g. Iribarren, 2011). This continuing use of R22 led Winther et al (2009) to conclude that replacing R22 is the single most important potential improvement in the fishing phase.

As with vessel material and engine use, the lack of onboard refrigeration in artisanal operations would mean refrigerants would make a minimal contribution to GHG emissions if refrigerants are included in an assessment.

Aquaculture

Ziegler (2003) notes that, when looking at aquaculture, it resembles animal production more closely than fishing. As a result, the greatest [LCA] impacts are typically seen in feed production (Ziegler, 2003). This is especially likely to be the case for carnivorous finfish production where fish-based feed is added, but recirculation systems are relatively energy-intensive and may surpass GHG emissions from the feed stage. Aquaculture also includes finfish culture using plant-based feed (e.g. carps) and more extensive shellfish production with no feed added (e.g. mussels).

Assessment of GHG emissions in aquaculture has focused on product groups (farmed salmon, sea bass, turbot, shrimp, etc.) and production methods (described as intensive through to extensive).

Inputs (capital goods)

Investment in infrastructure is significant particularly for intensive culture systems with containment, feed barges, well boats and supporting landside infrastructure. There may also be significant investment in capital goods for some semi-intensive culture operations such as pond excavation, cage construction, and even for extensive systems, e.g. mussel dredgers used in bottom-grown mussels.

As with fisheries LCA and GHG assessment, capital goods are generally excluded. The analyses of production and maintenance of associated infrastructure in aquaculture systems, indicate that these typically make trivial contributions to final results (Ayer and Tyedmers 2009). In some instances they are deemed to be significant and so warrant inclusion even if still excluded from other systems under assessment (e.g. for mussel culture in Winther et al, 2009).

Production

GHG emissions at the production stage occur predominantly from feed use (production, transport and application). The amount of feed used, the feed conversion ratio (FCR), and the type of feed used are critical elements of any aquaculture assessment.

FCR can differ from one production site to the next as it depends on local conditions and the overall management of the farm, but a major difference in FCR is often seen between varying intensities of production system. Cao et al (2011) found that the amount of feed required to produce 1 t of shrimp varied from 1600 kg in intensive farming to 907 kg in semi-intensive farming. Clearly this is a major contributor to the different GHG emissions calculated for the two systems (see Box 6).

Aubin et al (2009) assessed three different intensive finfish production systems and found that feed production (including agricultural and fishery stages) requires a relatively large amount of energy and represents a major proportion of energy use in raceways and cage production systems (40% and 72%, respectively). The next largest contribution was from energy use on the farm itself (15% for raceways and only 5% for cage systems). The only system where this differed was recirculation where on-farm energy use accounted for 61% of total energy, reducing feed production down to 32% (Aubin et al, 2009).

Pelletier and Tyedmers (2010) also found feed production was dominant for Indonesian tilapia accounting for 92% of energy n lake production systems and 66% in pond-based systems, where on-farm energy use was larger and resulted in around 28% more energy per tonne of tilapia fillets than lake production systems.

Feed contains both fish-based products, requiring consideration of fishing operations as per the preceding fisheries section, and agriculture-based products, requiring consideration of a complex system of agricultural production and the need to consider methane and other GHG, as described in section 0.

Fishmeal and oil is mainly derived from a number of industrial fisheries for small pelagics (e.g. anchovy in the southern Atlantic or sandeel in the North Atlantic). These are targeted by purse seining which is one of the most energy-efficient fishing methods using 50 litres of fuel per tonne of fish caught compared to an estimated global average of 620 litres (see Box 5). The composition of the feed is important as different component products and their origin will have different impacts.

The extent to which feed formulation is detailed differs between studies. Some researchers have identified FCR as the major contributing factor and therefore use a single average feed composition (Aubin et al, 2009; Papatryphon, 2004). Winther et al (2009), however, noted more than 12 different species plus waste from trimmings was used to produce the feed used in Norwegian salmon farming. A feed producer provided data on meal and oil yield per species on a confidential basis. Feed composition varied year on year (due to supply and price variation) and therefore modeling was based on compositions from more than one year.

Pelletier and Tyedmers (2010) detail the GWP for all components of tilapia feed milled in Indonesia and found wide variation. The transport associated with some feed ingredients (sourced from the US and China) makes a significant contribution to their GWP. The GWP of fish meal is more than twice that of soy meal, but is very similar to corn gluten meal. While the biotic resource use is highest for fish-based ingredients, fish oil’s GWP was 40% less than for palm oil where its production has major land use change impacts.

Some fishmeal and oil is derived from fish waste, supplementing supplies from industrial fisheries. The processing of this waste at fishmeal plants requires energy to produce and transport, which should be included. It is more debatable whether the fishing stages associated with fish waste should be included in the same way as reduction fisheries. Carbon equivalents could be allocated in the same way as target fisheries, but it is a by-product of fishing and processing activity rather than being the targeted activity.

Salmon feed is typically composed of 60% of marine products and 40% agriculture products (e.g. soy meal, rapeseed oil, wheat). While the land-based component does create additional complexity, there are a number of resources providing data on the farming and processing of crop ingredients (e.g. Ecoinvent or the SIK Feed database). These data can be made more specific to local conditions. For example, as electricity is required (e.g. in crop drying) Pelletier & Tyedmers (2010) modeled country-specific electricity mixes on the basis of International Energy Association data (IEA 2008), including transmission losses. Fertilizer, seed, and pesticide application rates specific to crop and region were employed.

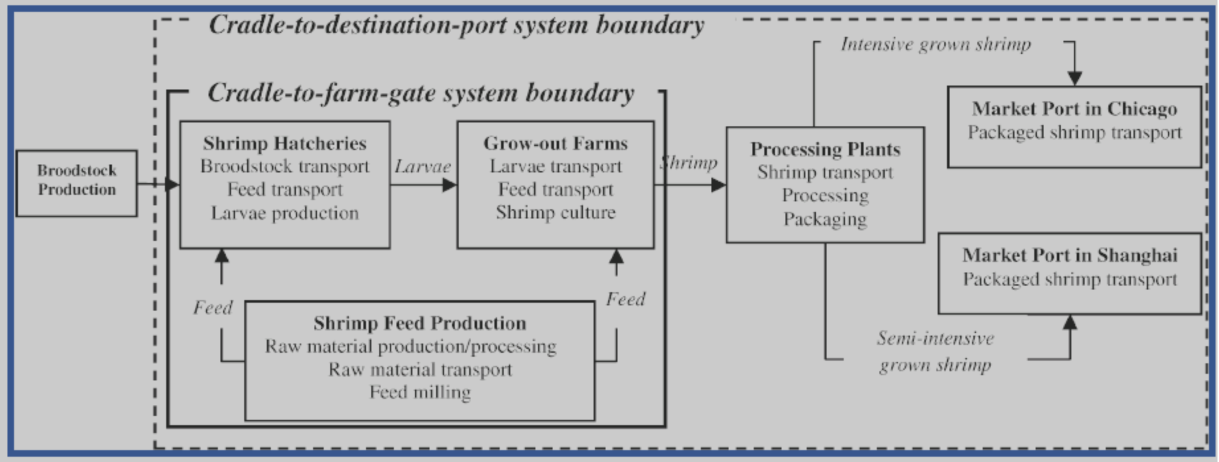
In most assessments seed/hatchery/smolt production is considered as the first part of this production stage, but the level of detail varies depending on the focus of the assessment. A producer may buy-in seed from a third party and therefore exclude more elements of seed production than if it were within the same company. Some studies, such as Aubin et al (2009) excluded the hatchery stage partly due to the hatchery stage being separate to production operations and partly due to a lack of data.

Box 6 LCA of intensive and semi-intensive shrimp farming in China

From Cao et al, 2011

The boom of Chinese shrimp farming has been triggered by growing demand, mainly from international markets in the United States, the European Union, and Japan. Increase of export-oriented shrimp production is achieved with intensification of farming systems by large commercial companies, which have greater farm size, material inputs, energy demands, and effluent discharge. However, the majority of shrimp production in China is still based on traditional techniques from small farms, directed to feed the local population and not for export. These two supply chains were considered as per the process diagram in Figure 7.

Figure 7 LCA process diagram for Chinese shrimp products for domestic market and export



Methods

Results from CML2 Baseline 2000 method were verified by adopting two different LCIA methodologies available in Simapro software to test the consistency and reliability of results. One end-point method (Eco-indicator 95) and one midpoint and end-point combination method (IMPACT 2002+) three common impact categories (Acd, Eut, and GW) that were considered important for aquaculture were selected as comparison criteria. Despite differences in characterization methods and parameters between CML2, IMPACT 2002+, and Eco-indicator 95, all three methods gave similar results for acidification and global warming. IMPACT 2002+ predicted much lower eutrophication for both systems compared to the other two methods.

Sensitivity analysis was conducted to estimate how global warming would change if the Chinese electricity mix was shifted from coal-dominated to less CO2 -intensive energy. Results showed a 25 to 50% drop in GW when coal was replaced by hydro or nuclear but only a 12 to 25% drop when coal was replaced by natural gas.

Results

Overall, intensive farming had consistently higher on-farm energy and feed use. Higher stocking density and water exchange rates also required more electricity use for aeration and pumping in intensive farming. Relative to semi-intensive systems, on-farm energy use per metric ton of shrimp was 470% higher for intensive systems. For cradle-to-destination-port life cycle impacts of shrimp production, grow-out accounted for 69.4 to 96.8% in intensive and 67.4 to 99.3% in semi-intensive systems for each impact category and thus it is the key life cycle stage. Although frozen packaged shrimp was transported a long way to destined ports, transportation contributed only 2 - 11.8% in intensive systems and 0.6 - 3.7% in semi-intensive systems in each impact category.

Given the importance of shrimp feed, comparative life cycle impacts of shrimp feed production were evaluated. Fishmeal accounted for 44% of acidification, 47% of global warming, 47% of cumulative energy use, and 91% of biotic resource use.

Post-harvest

Few [LCA studies] have considered supply chain impacts beyond the farm gate (Mungkung et al. 2006). In light of the multiple potential product forms, distance, and transport modes by which products may travel to markets, this represents a significant gap in the literature (Pelletier & Tyedmers, 2010). Recent studies have attempted to address this by comparing products from similar production systems with different supply chains (see Box 1 and Box 7).

The consideration of post-harvest activities is an important element, particularly when comparing different products or supply chains. Fisheries and aquaculture studies to date have identified the dominance of the production stage in terms of GHG emissions compared to post-harvest activities. However, for some highly processed products impacts will be significant and detailing these is essential if the goal of the assessment may relate to identifying efficiencies in the post-harvest supply chain.

Post-harvest stages generally start from point of landing and can involve a number of stages: handling, storage, distribution as well as processing. This should therefore be distinguished from 'processing' where the system boundary may be 'at the factory gate' with material entering and leaving the factory. Box 7 also shows that in some fisheries, significant processing occurs on-board and therefore energy use at this production stage can also include elements that may be within post-harvest stages in other systems.

A number of post-harvest elements (transport, packaging, storage, retail, etc.) can be considered in the same way as other agri-food systems and lend themselves to the use of default EF data. Processing impacts can however be very specific to the process and species involved.

The inclusion of post-harvest stages in seafood production is important for certain assessment goals, but they can be misleading in isolation (i.e. without also considering retail, consumption and post-consumer waste stages). As noted by Rawitscher and Mayer (1977), there is a large increase in energy in-put as a result of processing, regardless of the method, but to have a valid comparison of foods it is also necessary to know the total energy input through home use, which depends to a degree on the previous processing method. For example a frozen fillet has a number of advantages

Box 7 Environmental Assessment of frozen octopus from the Mauritanian EEZ

From Vazquez-Rowe et al, 2012

Mauritania is one of the countries most dependent on fish trading in Africa; 18% of Mauritanian exports were linked to the fishing industry in 2007. However, an important amount of total production is made by industrial fishing fleets from other countries that operate in the Exclusive Economic Zone (EEZ) of Mauritania under fishing agreements with other countries.

The selected seafood production system studies comprised the capture and landing of common octopus in the port of Nouadhibou (Northern Mauritania) by the Spanish cephalopod trawling fleet, the freezing processing and packaging activities performed on board and the export route of this frozen product to the three main importing countries: Japan, Spain and Italy. The unit selected for this study was a 24 kg carton of frozen common octopus up to the point of import in the year 2009.

The researchers used primary data collected via questionnaires with skippers, combined with default EF data on diesel production, trans-ocean transport and packaging from Ecoinvent and frozen storage from the LCA food database. Mass allocation was felt to be the most appropriate allocation method for the study.

The inventory data was divided into two main sub-systems: on-board activities and post-landing activities. Post-landing activities on land embrace landing operations, port logistics, transportation to and from storage, and marine freight up to unloading in the receiving port. On-board activities represented more than 95% of the total burdens with seafood extraction [fishing] amounting to 83% of total GWP and on-board processing 15%. The contribution of the refrigerant R22 to this category was noted. The contribution of marine freight to GWP was minimal with the greater distances to Japanese markets having little consequence on results.

in GHG emission terms, e.g. a longer shelf-life enabling transport by sea container, but will result in GHG emissions with home freezer storage and longer cooking times compared to fresh fillets.

Thrane (2004) identified that for non-perishables (such as canned goods) certain stages are irrelevant as products can be stored at ambient temperatures almost indefinitely. When Hospido et al (2006) undertook an LCA of canned tuna from gate-to-grave, i.e. only the post-harvest elements of the lifecycle; they therefore excluded assessment of wholesale and retail. The system starts at the harbour with the landing of frozen tuna carcases and ends with the management of post-consumer waste. National recycling averages for packaging were used with the remained assumed to go to landfill.

The inclusion of later post-harvest stages in LCA research is also prone to variation in what aspects are included and excluded. Elements include shopping travel, plastic bag production, cooking and waste treatment. Each of these leads to additional assumptions, e.g. cooking method that should be stated. The objective of assessments could lead some researchers to choose to exclude certain post-harvest stages. If various food product groups are being compared, they may be expected to result in the same retail and similar consumption stage impacts. The iterative process advocated by LCA methods will therefore lead to a focus on the stages that may result in significant differences in results.

Summary of seafood assessment

Table 3 presents a summary of some recent seafood assessments described within this paper. It illustrates the varied approaches and scopes of LCA and GHG assessment of the seafood sector to date. With a lack of default data appropriate to seafood production systems, all studies have required a relatively resource-intensive tier 2 with most adopting tier 3 methodology. Researchers have used primary data collection in the form of questionnaires and commercial data. The majority of studies focus on intensive production systems, rather than extensive or small-scale production. There is limited research comparing scale and intensity, but examples are Ziegler & Valentinsson (2008) comparing creel and trawl fisheries, and Hua & Wu (2011) comparing intensive and semi-intensive shrimp culture. It is also evident that assessments to date have predominantly been associated with large-scale European, particularly Scandinavian, and North American fisheries. This is partly a consequence of the location of LCA research capacity and examples in other regions are emerging as LCA capacity grows. Two notable exceptions are the studies conducting global-level assessments of energy use in fisheries (Box 5) and an LCA of aquaculture production (Box 8)

Table 3 Data resources and information gaps in seafood production systems

Production system	**Species group**	**Reference**	**Method**	**Data sources**	**Tier**	**Scope of assessment (type of emissions included)**			
						direct	**indirect**	**other**	**exclusions**
Fisheries									
Demersal	Whitefish (cod, haddock, saithe)	Winther, 2009	GHG process	Questionnaire, national statistics	3			x	Wholesale, retail, consumer stages.
Pelagics	Tuna	Tan, 2009	GHG Input output & process	Default EF + commercial data	2			x	CO_2 only – no other GHG
Shellfish	Nephrops	Ziegler & Valentinsson, 2008	LCA process	Questionnaire + national statistics + default EF data	3				Some impact categories. Allocation in storage and transport stages.
All	Not specified (focus on Taiwanese fleet)	Hua & Wu, 2011	GHG process	Questionnaire + national statistics + model	3		x	x	GHG emissions resulting from refrigerants (fuel use only)

Aquaculture									
Finfish	Trout, seabass, turbot	Aubin et al, 2009	LCA Process	Commercial data + modelling	2			x	Infrastructure, Hatchery stage, slaughtering, processing & sales
	Tilapia	Pelletier & Tyedmers, 2010	LCA process		3				Infrastructure, chemotheraputants
shellfish	shrimp	Cao et al, 2011	LCA Process	National statistics, questionnaire, commercial data + modelling	3			x	Infrastructure, wholesale, retail, consumption, and disposal of waste
All	All – 13 species groups	Hall et al, 2011	LCA process	National statistics, commercial data, expert opinion	2				building infrastructure, seed production, transport of feed or produce, post-harvest
Post harvest									
Cradle to gate (culture to wholesaler)	mussels	Iribarren et al, 2010	LCA process	Default EF + commercial data	2				Organic waste use (meat to pate, shell to fertilizer)
Cradle to gate (fishing to wholesaler[‘)	octopus	Vazquez-Rowe, 2011	LCA process	Questionnaire + Default EF	3			x	
Gate to grave (landings onwards)	tuna	Hospido et al, 2006	LCA process	Default EF + commercial data	3				Wholesale, retail

The challenges of seafood GHG Assessment

The following section explores the specific challenges of seafood GHG assessment in relation to the various elements of assessment that have been identified.

Goals of assessment

To date the majority of GHG assessment of seafood production systems can be said to be driven more by academic curiosity rather than by commercial demand, but the benefit of this research in steering policy has been recognised by government interests and strong industry engagement in the work shows the commercial benefits of identifying efficiency improvements.

Some supermarket chains, as the main customers of seafood suppliers, are already the drivers for increased information on and assessment of sustainable sourcing of products. The growing call for voluntary and mandatory company reporting is now resulting in many seafood companies seeking to assess GHG emissions across their operations. The goal of assessment is therefore predominantly to define the environmental performance of products, product groups and in some instances the whole company supplying those products.

In a few instances, seafood companies have already commissioned carbon footprinting to help identify efficiencies, but also to support the environmental credentials of their products. For example, the shrimp company, UNIMA, with the support of the Association of Shrimp Farmers and Fishers in Madagascar (GAPCM) and the French Fund of the Environment has undertaken an assessment of its GHG emissions from each of its business lines. This will be used to define a carbon policy to reduce GHG emissions and will address energy consumption across UNIMA operations, for example, to reduce the pumping needs in shrimp farming operations and consequently the fuel cost and gas emissions.

The IPCC methodology for country-level emissions focuses on key categories, which in the majority of national economies would not require the explicit consideration of fisheries and aquaculture production. These may however be considered as part of the agri-food sector where they make a significant contribution.

As illustrated by the COFI call for information and the collective action this paper supports, there is growing interest in identifying fishing and aquaculture’s contribution to climate change and ways to reduce the sectors’ reliance on fossil fuels. This is particularly important for a sector that is critical to economic development and food security in developing economies and points to a broader goal of future assessments; informing development policy. Some such as the Worldfish report, Blue Frontiers (2011) attempt a global assessment. The assessment of GHG emissions from national production systems would enable international benchmarking.

As with other efforts to improve resource sustainability, the first challenge for the GHG assessment of seafood is to define goals for broader national or fleet level assessments that balance environmental, economic and social objectives and issues. Reducing GHG emissions may have economic and social costs as well as benefits.

A further challenge is to develop common assessments methods without putting small-scale producers and developing economies at a disadvantage in terms of the resources required to carry out the assessments, the method of calculation chosen and the reporting of results.

Box 8 Assessing the environmental costs of global aquaculture

From 'Blue Frontiers' Hall et al, 2011

The objective of the study was to compare and contrast the global and regional demands of aquaculture for a range of biophysical resources across the entire suite of species and production systems. Researchers identified 71 species that accounted for 90% of total world production. Extracting records for these species revealed that 29 countries contributed to this total. Using this data set, each of the individual species was then allocated to one of twelve separate species groups. Production was further categorized into one of four separate coastal and inland production systems (Table 4). For these production systems the researchers also considered the intensity of production (extensive, semi-intensive and intensive). For each country, allocations per production method and intensity were determined using a combination of country production data and expert judgement. Five primary feed categories were also defined and allocated to each species group, country, production system, habitat and intensity combination. Researchers then examined the literature and combined this with expert opinion to estimate the dominant feed type for each data record.

Table 4 Generic species-group production system used to assess environmental impact

Species Group	Bottom Culture	Off-Bottom Culture	Cages & Pens	Ponds
Bivalves	✓c	✓c		✓ci
Carps				✓i
Catfish				✓i
Crabs and Lobsters			✓c	✓c
Eels				✓i
Gastropods		✓ci		
Other Finfish			✓ci	✓ci
Other Invertebrates				✓ci
Other Vertebrates				✓i
Salmonids			✓c	
Shrimps and Prawns				✓ci
Tilapias				✓ci

With the data reduction described above, the fundamental units of analysis were the elements of a sparse six dimensional matrix comprising: 13 species groups x 18 countries x 3 production intensities x 4 production systems x 2 habitats x 5 feed types. This resulted in 75 positive matrix elements, accounting for 82% of total world production in 2008.

Results indicated that aquaculture contributes about 0.96% to total CO2 emissions and between 6.3 and 7.5% of agriculture emissions based on IPCC global estimates. China dominates aquaculture climate change impacts due to the large number of production systems (carp and increasingly shrimp), however Figure 8 below shows that per tonne of fish the impact is distributed across a number of producer countries with the more efficient salmonid producing countries showing less impact. Results per country show large efficiency gaps in environmental performance, indicating great potential for improvement.

Figure 8 Relative climate change impacts from aquaculture per country

Subject of assessment

The subject of assessment can be a specific product, product groups, companies or countries. This determines the 'what', but for seafood an even more varied aspect of defining the subject of assessment is the 'how'; the type of production system under consideration. The production stage is therefore defined by the species (group) and the production system. The particular challenges posed by seafood in this regard are discussed below.

Species groups

The great majority of the world's seafood production and trade would be included within the key categories presented in Table 5. For aquaculture, where feed use is the main impact, key categories could be defined by the carnivorous or herbivorous nature of species being cultured.

Table 5 Potential first order categories for fisheries and aquaculture production

Product Group	Production system	
	Fisheries	**Aquaculture**
Whitefish (cod, pollack, etc.)	Trawling, lining, netting	Intensive cage culture
Small pelagics (anchovy, sardine, mackerel)	Seining, trawling	Not cultured
Tuna (various sp.)	Seining, longlining, handlining and pole and lining	Intensive cage culture
Salmon (Pacific, Atlantic and trout)	Netting	Intensive cage culture
Freshwater fish (Carp, tilapia, etc.)	Netting, traps, handlines, – mainly but not exclusively small-scale	Intensive to extensive Pond or freshwater cage culture
Bivalves (mussels, clams, scallops)	Dredges	Extensive bottom culture, rope culture
Shrimp (*penaeus* & *pandalus* sp.	Trawling, creel	Intensive to extensive pond culture

The product group categories proposed above could be viewed as a first order level. If combined with the production system (i.e. gear or culture method) these may suffice for broad company or country-level assessments.

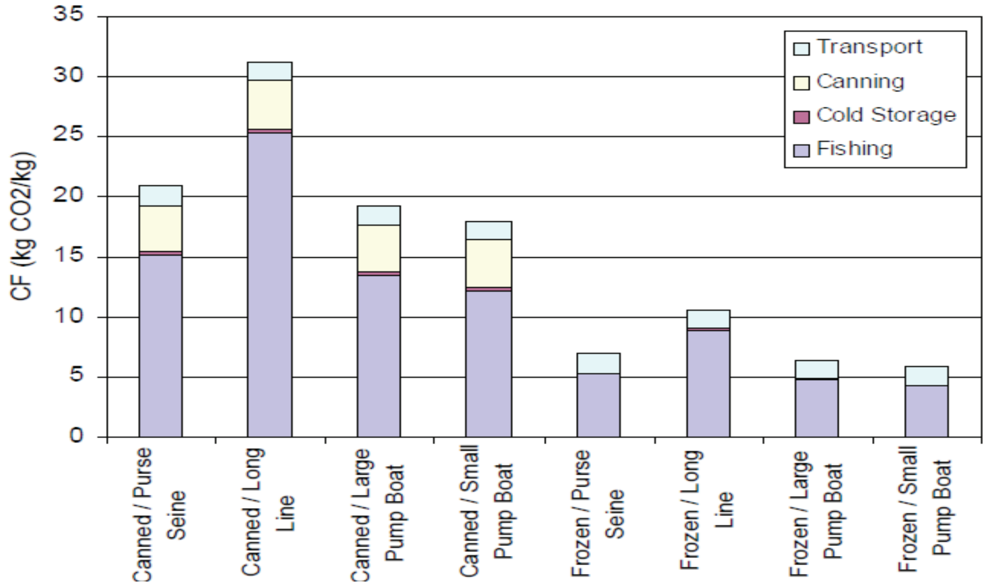
Supporting data on species in terms of global production is reasonably detailed and readily accessible, i.e. from FAO Fishstat J. For many assessments therefore further refinement perhaps even down to species level is possible.

The appropriate level of detail in terms of species will be defined by the goal of assessment. It should be determined whether common methods of assessment necessitate the definition and use of a common typology or whether common methods could be applied to various subjects of assessment at any level of detail.

Fisheries production method

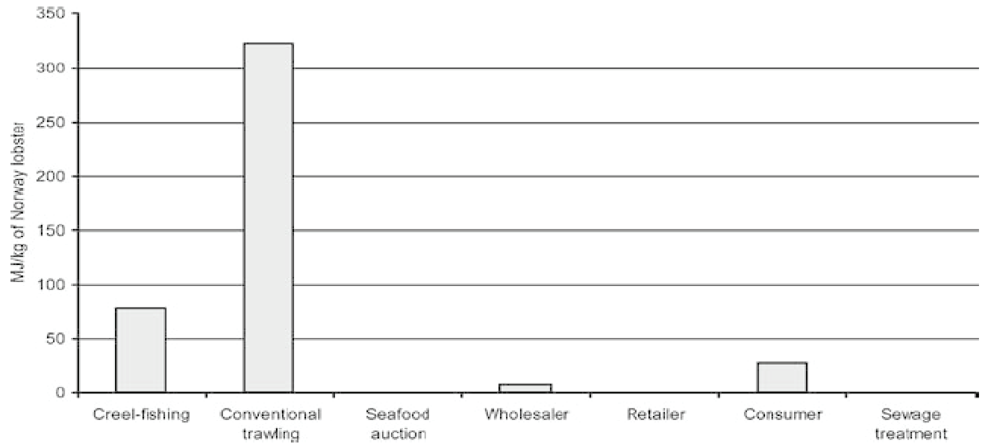
As Figure 9 and Figure 10 illustrate, the fishing method has a major impact on the GHG emissions resulting from the fishing stage. The set-up of fishing gear is one of the key skills of a fisherman. Fishing gear is often adapted for local conditions encountered and so the same type of gear can vary enormously from one fishery to another. The impact of gears will also be a consequence of the scale of gear, which is often related to the scale of the vessel.

Figure 9 Comparison of GHG emissions for tuna production methods



Source: Tan, 2009

Figure 10 Energy use in the lifecycle of Norwegian lobster: creel fishing and conventional trawl



Source: Ziegler & Valentinsson, 2008

There are many variables associated with fishing method, but a number of general typologies are possible with a first order level perhaps consisting of:

- Seines;
- Trawls;
- Dredges;
- Hooks & lines;
- Gillnets;
- Pots & traps

Tyedmers (2004) presents a summary of results from the 1980's and 1990's showing fuel use and edible protein EROI for certain gear types.

The appropriate level of detail to be used when defining gear type will be determined by the goal of assessment. The importance of fishing method in relation to GHG emissions means that detail here is likely to be more important than species; it may not matter what species of tuna is captured, but

Figure 9 shows that how it is captured is highly significant. Some company assessments may consider individual vessels, but for broader assessments (e.g. of the Taiwanese fishing fleet by Hua & Wu, 2011) some generalisation and averaging across vessels in the same fleet segment is likely to be necessary.

Aquaculture production method

As with fishing methods, aquaculture systems vary enormously with performance and GHG emissions differing from farm to farm. Some general methods can however be distinguished (see Box 8) and due to the importance of feed use, would include the intensity of an operation: intensive, semi-intensive and extensive. Intensity is defined by the level of intervention; mainly stocking density and feed inputs, but establishing these in clear, quantifiable terms is more difficult; semi-intensive in one region may be viewed as intensive in another.

The location of aquaculture operations is also a defining feature. They may be marine-based systems using cages or land-based systems using full recirculation technology, in man-made tanks, raceways or using natural freshwater bodies. This characteristic will influence for example the amount of energy required to maintain growing conditions, for example in pumping water.

Many small-scale systems in developing countries reduce risk by adopting polyculture practices. Some involve the use of manure as pond fertilizer and therefore the non-fish production can be treated as an input into the fish production system. Assessing systems where more than one species is grown will require allocation, as with fishing operations catching several species.

Scale of production system

The scale of production systems should certainly be defined, but it is not clear to what extent scale in itself should be a defining criteria. This is a consequence of most research considering relatively large-scale production systems. Few studies to-date have explored how different scales within the same production system affect GHG assessment results. It could be expected that the scale of operation will affect an assessment as economies of scale are evident, but without the inclusion of capital goods, the main GHG emissions should be proportionate to operational inputs such as vessel fuel or feed input. These are then brought back to the same functional unit, e.g. a kg of fish. This issue is particularly important for the seafood sector, which is often characterised by many small-scale operators in both developed and less developed countries.

System boundaries

The setting of appropriate system boundaries for emissions data collection is one of the critical challenges facing seafood GHG assessment and LCA research in general.

Table 3, summarising some recent seafood LCA and GHG assessments, shows the wide variety in scope and variation in system boundaries. Researchers provide reasons for the inclusion or exclusion of certain elements, which is often driven by data availability and resource constraints, as well as assumption about major and minor contributions to impacts.

If such assessments are to be worthwhile for broader objectives or a wider audience such as customers, there must be consistency in the definition of seafood life stages and what is included in direct, indirect, and other emissions.

The iterative process of these assessments should determine the focus of research efforts, i.e. the level of detail required for each element within a system rather than determining what is included and excluded. A common approach to system boundaries is needed so that consistent elements are assessed. The identification of minor contributors or a lack of data should not result in exclusion, but rather the use of default data. Scoping should identify the approach to assessment required for each.

The inclusion of capital goods is one aspect that requires clarity. PAS 2050 currently excludes capital goods and their inclusion certainly adds further complexity. Many LCA and GHG researchers suggest that future GHG assessment standards should include capital goods.

The average lifespan of vessels, infrastructure, etc. will vary significantly between fishing fleets and aquaculture operations and is in part a consequence of economic performance; some would reinvest regularly while others maintain out-dated equipment to avoid a large capital cost.

Determining the lifespan of products is likely to be based on generic data and assumptions. Many LCA and GHG researchers suggest that future GHG assessment standards should include capital goods – even based on secondary data – for the calculation of carbon footprints, especially for the assessment of agricultural products and seafood from extensive aquaculture practices.

Approach

LCA researchers in many sectors increasingly have the option to use existing data in a tier 1 approach. While best practice advises against using tier 1 for key categories to ensure country-specific or technology-specific data is used in a tier 2 approaches, using default data does enable the more extensive uptake of LCA research. For seafood a tier 1 approach is not possible as to date the body of data available has not been sufficient to allow this.

The approach has implications for the level of capacity required to undertake assessments and the cost of data collection. A tier 2 or 3 approach should result in increased accuracy in assessment, but at some point there will be a diminishing return on the amount of improvement in the assessment results achieved compared to the additional research effort required. The challenge for seafood is to establish what level of accuracy is good enough and does that need to be the same in all circumstances?

Emission factors and data

There is a lack of existing Emission Factor resources that are relevant to fisheries and aquaculture. This is somewhat of a 'catch 22' situation as the lack of data resources is a barrier to the creation of more research data. LCAFood contains some data, but this is associated with a specific region (Northern Europe) and certain fisheries systems. A challenge for seafood LCA and GHG assessment is to create a readily accessible data resource that has good coverage of all regions and production methods.

Benton et al (2010) identify that the lack of sufficient data on agri-food production and processing in less developed countries (LDC) puts them at a disadvantage in terms of being able to complete assessments. Most data is derived from and available for the industrialised economies of Europe and North America and Australasia.

Electricity mix and emissions factors are available for most countries e.g. from the Energy Information Administration (2006), but many fossil fuel types are aggregated into 'conventional thermal' leading to inaccuracies and researchers in most countries would seek a more accurate breakdown. Country-specific data are not readily available for some LDCs. A similar lack of coverage is found for land use change data that are critical for land-based production for feed in aquaculture.

Data for use in GHG assessment ranges from default data within EF inventories, through data from comparable systems previously studied, to the collation of data that is specific to the subject of assessment. There is now the possibility to use smart-meters at a company's production units to collect data that enables real-time carbon footprinting and reporting via software packages (e.g. Simapro's Carbonworks). Such data will help to inform corporate assessments, but would be commercially sensitive and unlikely to be available for use in wider research. There is therefore a danger that the move to more sophisticated collection techniques makes less data available for those without the resources to gather primary data.

A challenge associated with seafood LCAs is how country and technology-specific data can be made available to enable GHG assessments to be conducted. This will require data ownership issues to be addressed and a better understanding of how specific data must be fit for purpose.

Reporting

COFI is seeking a better understanding of GHG emissions from fisheries and aquaculture, which suggests some form of global assessment and subsequent assessments or monitoring to gauge progress in reducing GHG emissions.

Some form of regular international reporting could be developed similar to a seafood sector IPCC report that is supported by a common methodology. This reporting could be prioritised, e.g. more detailed reporting by those countries where fisheries and aquaculture are particularly significant.

The FAO Global Record (http://www.fao.org/fishery/global-record/en) could eventually be used to provide comprehensive fleet data and for some regions existing reporting could be harnessed. For example in Europe the EC Data Collection Requirement (DCR) results in an Annual Economic Report detailing the scale and performance of each Member State fishing fleet. This presents data per fleet segment, which could be used for generic GHG emission factors. The DCR has also recently been extended to include details of aquaculture production and the fish processing sector.

A challenge is to establish regular global assessment and country reporting without creating an excessive reporting burden for less developed countries and disadvantage those with limited resources.

Additional constraints in assessments of seafood production

Fisheries management

Fisheries management decisions often affect fleet characteristics, fishing effort, and fishing practices, and by extension, management decisions may influence fuel use patterns (Driscoll and Tyedmers, 2010).

LCAFood notes that ‘the environmental impact associated with wild fish demand would be determined by fishing processes and processing in fish industry if the quota regime was removed from fishing and the extent of fishery was determined by the market. This is an important distinction as the harvesting of fish is often limited by quota and therefore individual fishing operations are often not catching to their maximum capacity per fishing trip (LCAFood, 2011).

Management measures and resource health will impact fishing efficiency (e.g. affecting catch per unit effort) and therefore will influence GHG emissions. Most fisheries are operating sub-optimally, but this varies by species, region and fleet segment and often on an annual basis with changing quotas. A challenge for those conducting seafood GHG assessments is how these factors are taken into account. Assessments could present estimates based on the current management situation, on a theoretical optimal basis where management constraints are removed. Management measures could be used as part of the sensitivity analysis to establish the consequences of various management measures.

It may be argued that the energy associated with the enforcement of management measures should also be included in the total emissions associated with a production system. Enforcement in fisheries can involve the use of aerial and vessel surveillance, which would result in GHG emissions. This aspect was not, however, included in the scope of any of the studies reviewed and such an extension of system boundaries is not evident in other LCA research. It would create some difficulties with allocation and the inclusion of emissions resulting from enforcement could result in well-managed fisheries being penalised. It is therefore suggested that only the impact of management measures on fishing operations themselves be a consideration within GHG assessment.

Highly dynamic sector

Fishing has always had to adapt to changing conditions. Reducing the use of fossil fuels in fishing operations has become a major area of fisheries technology research driven by increasing oil prices. This has taken the form of developing alternative fuels (e.g. bio-diesel), fuel-efficient engines, alternative propulsion (e.g. deploying kites & sails), and reducing the weight and drag of vessels and fishing gear (e.g. many vessels within the Dutch flatfish fleet are in the process of replacing beam trawls with the ‘sumwing’ hydrofoil). These innovations and their adoption by fleets are very welcome but cause further complexities in GHG assessment due to the changing nature of fish production methods.

Aquaculture also shows continued growth of the sector in terms of scale, species cultured and technology employed, which means that assessments (and associated default data) may quickly become out of date. Even the post-harvest sector is relatively dynamic as new supply chains emerge with changing sources of raw material, processing technology and product development.

Technical advancement is a challenge to be faced for all sectors assessed in LCA research. The increased fishing efficiency over time through technology, termed ‘technical creep’, is a recognised phenomenon in fisheries. However the rate of technical creep differs between fisheries and is difficult to identify and quantify. Therefore how to account for the varying dynamism across the sector is a further challenge for those attempting seafood LCA and GHG assessments.

Conclusions and options for seafood assessment

The final section of this background paper provides conclusions and a number of suggestions for consideration by participants at the proposed forthcoming workshop in January 2012.

Methods

There are a wide range of LCA and carbon footprinting methods and tools. Process LCA using a bottom-up approach summing the various inputs into a production system is the most widely applied, and appears appropriate for GHG assessment of the seafood sector.

Many LCAs of fisheries products and production systems have adopted the ISO standard (14040) for assessment, which includes the assessment of GHG emissions under the Global Warming Potential (GWP) impact category. An ISO standard for carbon footprinting (ISO 14067) is under development, but standards such as the BSI’s PAS 2050 and the GHG protocol already exist. These are widely used, including in the agri-food sector. Both approaches could be applied to pilot fisheries & aquaculture production systems (with and without the modifications proposed below) to test their efficacy and to compare results.

Pilot seafood systems should include small-scale producers and production in less developed economies to consider the resources required to carry out the assessments, the method of calculation chosen and the reporting of results.

Goals

The goals of assessments will continue to vary as different stakeholders (companies, customers, government and NGOs) recognise the benefits of assessing GHG emissions in seafood production and supply chains. Identifying and then reducing GHG emissions may have direct and indirect economic and social costs as well as benefits. Broader national or fleet level assessments may be required to balance environmental, economic and social objectives as part of GHG assessment. Mitigation measures may not only address the reduction of GHG emissions, but also any economic and social costs associated with reduction measures.

Scope

Refrigerants are identified as a significant element in some fisheries and post-harvest assessments. Methane and other gases can be significant GHG contributors in agricultural production, which is important for aquaculture systems in terms of components of fish feed. Therefore the scope of assessments should include all Greenhouse gases (rather than just CO_2) and should be presented in carbon equivalent units.

The contribution of emissions associated with supplies is significant, particularly for the aquaculture sector where feed production is often the single largest contributor. Comprehensive assessments should therefore include ‘direct emissions’ from the producers, ‘indirect emissions’ from energy generation used by the producers and ‘other emissions’ resulting from suppliers. Where ‘other emissions’ from suppliers are not included this needs to be clearly stated, ideally using common terminology to avoid confusion.

Subject

The subject of assessment differs according to the goals of the assessment. On a commercial basis the subjects are likely to remain at product or corporate level. For national and international governance purposes, the subject of assessment could be based on production systems or species groups.

Existing detailed data on a species group basis (i.e. Fishstat) may make this an appropriate basis for a global assessment of GHG emissions. However, to inform governance and policy development, assessments related to type of production system may be of more use. Ahead of a global record for fishing vessels being in place and similar recording of aquaculture systems, allocation of species produced to production systems would be required.

Landings and aquaculture production can be allocated to production systems: per fleet segment for fisheries, and per type and intensity of production system for aquaculture. Fisheries and aquaculture production systems should be defined using standardised typologies (see section 0 for proposed groups). This will enable common system boundaries to be established.

System boundaries

Common system boundaries for fisheries production, aquaculture and post-harvest should be determined. These boundaries should also be clearly stated in the reporting assessments.

For fisheries the point of landing may be a suitable end point to the system (equivalent to the ‘farm gate’ for land-based systems), at which point the fish enters a post-harvest system.

Within the fishing stage, addressing the allocation of emissions to on-board processing is also necessary, particularly if a post-harvest stage is not included in the scope of assessment. To an extent, the inclusion or exclusion of processing may be addressed through the use of a suitable functional unit, i.e. one kg of live weight fish.

The collection or production of seed to supply aquaculture can be a significant contributor to GHG emissions. Comprehensive assessments of aquaculture systems should therefore include seed or fingerling production.

The post-harvest stage can extend to end-of-life stages (post-consumer waste). The inclusion of the whole supply chain can be important to product-focused GHG emissions, but may not be necessary for broad assessments of production methods where system boundaries may stop at the point of product being supplied to wholesaler.

There is no current consensus on the inclusion or exclusion of capital goods within assessments. As the level of technology differs so markedly between fisheries and aquaculture production systems, the inclusion of capital goods may be important for the purposes of international comparison. This would be a modification to the existing standardised methods and could be tested by the pilot assessments.

Approach

A tier 2 approach, which uses country and technology-specific data wherever possible and default data from similar situations where resources are limited, is the most commonly adopted approach for seafood assessments. This may be most appropriate approach for national and international assessment, but commercial assessments may still identify benefits of applying a tier 3 approach when assessing their own operations.

Allocation

Researchers have used a variety of allocation methods, each with their own benefits and disadvantages; there are recent examples of mass, economics and nutritional value approaches. The use of mass allocation may be more appropriate for high-level assessments (product group, country, fleet, etc.) as it is comparatively straightforward without the need to address variation over time as seen in economic allocation or the need to agree the most important nutritional aspects and how to calculate these. There may, however, be clear benefits in using economic or alternative allocation methods in certain circumstances to illustrate the true drivers at work in a system (i.e. when considering a high value target species and by-catch). Again the chosen method should be clearly stated.

Emissions factors

The knowledge base for LCA research related to seafood continues to grow, but information and data are dispersed across a large number of academic journals. A compendium of fisheries-specific data and emissions factors could be developed to enable quicker and cheaper assessments. This coupled with the development of common methods that are appropriate given data constraints of small-scale producers and less developed countries, will enable more assessments to take place and more accurate global assessments of GHG emissions in the future.

The seafood GHG assessments carried out to date show that impacts associated with different production systems and value-chains can be very varied, but most point to a few priority stages. In fisheries production the fishing stage is found to account for the majority of impacts and two key areas where emission factor data resources would be useful are vessel engine performance and refrigerant use. For vessel engine performance, engines could be categorised and data established across a range of fishing activities (fishing, steaming, idling, hauling, etc.). Researchers could then focus on collecting less technically complex data on fishing patterns. Data on specific engine models could also be sought from manufacturers and service companies and/or engine testing agencies.

For aquaculture a key impact area is feed use. The formulation of feed is highly variable and developing an EF database related to aquaculture feed would aid researchers with limited resources. A feed EF database could take a hierarchical form, establishing average values for various feed types (e.g. in line with the typology proposed by Hall et al, Box 8) as well as data on commercially available feeds if permissions are given.

The post-harvest stage can benefit most from existing LCA default data associated with the agri-food and transport sectors. Supply chains can be complex involving a variety of modes and countries. Therefore country-specific data for transport and electricity mix will be important as will the collation of data on specialist seafood processing methods.

Data

A certain amount of data could be commercially sensitive. Applying details of the performances of specific makes and models of equipment may not result in significantly more accurate overall assessment results. This aspect of detail against uncertainty could be explored as part of sensitivity analysis in the pilot fisheries. The process could engage with commercial manufacturers to establish the level of detail required for the necessary levels of certainty and how this data could be made available.

Reporting

Regular international reporting could be developed to increase the knowledge base and for the benchmarking of progress in emission reduction measures. This will also enable aggregation for global assessments and could be aided by the development of comprehensive data collection frameworks such as the FAO Global Record. A pro forma reporting structure could be developed that recognises the resource and capacity limitations in some circumstances.

Management measures

Where fisheries are subject to management measures such as quota or effort limits, this will impact on the levels of GHG emissions from production, particularly in fisheries. The level of this impact is likely to be highly variable between fisheries and therefore may be a significant factor for consideration in GHG assessment. The extent and consideration of the effect of management measures on GHG emissions could be another aspect that is tested within the pilot fisheries.

Including GHG emissions resulting from the enforcement operations themselves (i.e. vessel and aerial surveillance) may add an additional emissions source that is not evident in the seafood GHG assessments or the agri-food LCA research reviewed. Monitoring control and surveillance (MCS) could be viewed as a category specific to fisheries that warrants inclusion or that management activities are not included in other production systems and therefore should not be included.

Highly Dynamic sector

Seafood is known to be a highly dynamic sector with rapid changes observed in fisheries (fuel-efficient gear developments, management measures), aquaculture (improved feed efficiencies) and post-harvest (new processing methods and supply routes). This has implications for the use of default data that should be taken into account in EF resources and assessment methods. It will therefore be important to determine or at least recognise the 'lifespan' of data used as default sources.

Table 6 Challenges of GHG assessment in seafood production systems

Issue	Challenge	Options
Methods	Use existing or bespoke methods?	Agree modifications of existing standards. Test modified PAS 2050, GHG protocol approaches and any other agreed approaches with pilot production systems. Include small scale and LDC-based systems in pilot production systems.
Goals	Risk of costs as well as benefits	For high-level GHG assessments consider including environmental, economic and social objectives Mitigation measures could be extended to addressing any negative social and economic consequences of reduction.
Scope	Should all greenhouse gases be assessed?	Ideally include all GHG included due to importance of refrigerants and non-carbon in agri systems. Ideally include direct emissions from producers, indirect from electricity and 'other emissions' from suppliers due to the importance of the latter. Explore the consequences of inclusion and exclusion in pilot assessments. Develop a common terminology to clarify the scope of assessments.
Subject	Determine the subject of assessment	A common typology of fisheries, aquaculture and processing systems could be developed to enable comparison and aggregation. High-level assessment for comparison and aggregation could be by species group or production system; each may require an agreed method of allocation based on available data sources. Explore the benefit of commercial assessments adopting a common approach against bespoke assessment of individual products/companies.
System boundaries	Agree common system boundaries	Explore whether common system boundaries can be agreed across all seafood production systems and if so, also agree common terminology to clearly explain system boundaries used in assessments. Test the inclusion of capital goods in pilot assessments Explore how to best address on-board processing, e.g. with use of functional units
Approach	Level of detail to apply (tier 1,2 or 3)	The impact of using different tiers of approach on results as well as costs/resource requirements could be explored by the pilot assessments.
Allocation	Allocation method	Explore the implications of using mass allocation, economic allocation, and nutritional allocation in assessments and test these in pilot assessments.

Emission Factors	Lack of fisheries-specific EF resources	Look at how to best develop an accessible seafood-specific EF resource, and data ownership. Identify priority data requirements (e.g. vessel engines & refrigerants for fisheries, feed supplies for aquaculture, processing methods)
Data	The trade off between detail & uncertainty. Access to commercial data	Engage with commercial operators to seek relevant data and how this can be made available. Use pilot production systems to conduct sensitivity analysis on use of differing levels of detail in data.
Reporting	How to encourage wider GHG assessment & use	Develop a pro forma reporting template that supports the agreed common methods; to enable comparison and aggregation; facilitate GHG assessment in resource and capacity-limited
Management	How to incorporate effect of management measures.	Test the inclusion of management measures effects in pilot production systems; this could be via agreed scenarios e.g. current position v theoretical optimum. Explore the difficulties in allocation and consequences of including emissions from management agencies e.g. enforcement.
Dynamism	Addressing technical advances in production systems	Agree 'lifespan' for data to be used in default databases. Explore whether country and production system-specific factors could be applied to data to account for expected or actual technical advances.

Bibliography

AMR Research. 2010. *Sustainability reporting and greenhouse gas management—sensing market trends and evolution in U.S. manufacturing.*

API. 2004. *Compendium of greenhouse gas emissions methodologies for the oil and gas industry*. American Petroleum Institute.

ARB. 2004. *State of California Environmental Protection Agency Air Resources Board (ARB). Statewide commercial harbor craft survey*. Final Report. Stationary Source Division Emissions Assessment Branch.

Aubin *et al*. 2009. Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment. *Journal of Cleaner Production*, 17: 354–361.

Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C. & Williams, A. 2009. *How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050*. FCRN-WWF-UK.

Ayer, N. & Tyedmers, P. 2009. Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. *Journal of Cleaner Production*, 17(3): 362–373.

Bellarby, L., Foereid, B., Hastings, A. & Smith, P. 2008. *Campaigning for sustainable agriculture*. Amsterdam, Netherlands, Green Peace International.

Brenton, P. Edward-Jones, G. & Jensen, M.F. 2010. *Carbon footprints and food systems: do current accounting methodologies disadvantage developing countries?* World Bank Books.

BSI. 2008a. *PAS 2050:2008 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*. British Standards Institute.

BSI. 2008b. *Guide to PAS 2050: How to assess the carbon footprint of goods and services*. British Standards Institute.

CRS. 2008. *China's greenhouse gas emissions and mitigation policies*. Congressional Research Services report for US Congress.

Cuong, N.M. 2007. *Activities on GHG Emissions inventories in Vietnam*. Training Workshop on GHG emission inventories Bangkok, 1–3 May 2007. Research Center for Climate Change and Sustainable Development,

Dalgaard, R. 2007. *The environmental impact of pork production from a life cyde perspective.* Aalborg University, Denmark. p. 135. (PhD thesis).

Discoll, J. & Tyedmers, P. 2010. Fuel use and greenhouse gas emission implications of fisheries management: the case of the New England Atlantic herring fishery. *Marine Policy*, 34: 353–359.

Durban Platform. 2011. *Establishment of an Ad Hoc Working Group on the Durban Platform for Enhanced Action*. Draft decision /CP17.

EBRD. 2009. *EBRD methodology for assessment of greenhouse gas emissions: guidance for consultants working on EBRD-financed projects*. Version 3, February 2009.

Ellingsen, H. & Aanondsen, S.A. 2006. Environmental impacts of wild caught cod and farmed salmon – a comparison with chicken. *Int. J. LCA.*, 1(1) 60–65.

EPA. 2009. *Mandatory Reporting of Greenhouse Gases Rule (74 FR 56260)*. United States Environmental Protection Agency.

Eshel, G. & Martin, P.A. 2006. Diet, energy, and global warming. *Earth Interactions*, 10.

Gabriel, U.U., Akinrotimi, O.A., Bekibele, D.O., Anyanwu, P.E. & Onunkwo, D.N. 2007. Economic benefit and ecological efficiency of integrated fish farming in Nigeria. *Scientific Research and Essays*, 2(8): 302–308.

Garnett, T. 2008. *Cooking up a storm. Food, greenhouse gas emissions and our changing climate*. UK, Food Climate Research Network, University of Surrey.

Garnett, T. 2010. *Intensive versus extensive livestock systems and greenhouse gas emissions*. UK, Food Climate Research Network, University of Surrey.

Goodwin. 2009. *EMEP/EEA Emission Inventory Guidebook 2009*.

Haliweil, B. & Nierneberg, D. 2008. Meat and seafood: the global diets most costly ingredients. *In*: *State of the world: innovations for a sustainable economy*, Chapter 5. The World Watch Institute.

Hall, S.J., Delaporte, A., Phillips, M.J., Beveridge, M. & O'Keefe, M. 2011. *Blue frontiers: managing the environmental costs of aquaculture*. Penang, Malaysia, The WorldFish Center.

Houghton, J.T., Meira Filho, L.G., Lim, B., Tréanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J. & Callander, B.A., eds. 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. Paris, Intergovernmental Panel on Climate Change, IPCC/OECD/IEA.

Hua, J. & Wu, Y. 2011. Implications of energy use for fishing fleet—Taiwan example. *Energy Policy*, 39: 2656–2668.

IPCC. 2002. Establishment of a database of greenhous gas emissions factors. Katarina Mareckova SHMU, Tinus Pulles TNO presentation, New Delhi.

IPCC. 2006. *Guidelines for National Greenhouse Gas Inventories. Volume 1 General Guidance and Reporting*.

IPTS. 2006. *Environmental Impact of Products (EIPRO): analysis of the life cycle environmental impacts related to the final consumption of the EU-25*. Institute for Prospective Technological Studies for European Commission.

Iribarren, D., Moreira, M.T. & Feijoo, G. 2010. Life cycle assessment of fresh and canned mussel processing and consumption in Galicia (NW Spain). *Resources, Conservation and Recycling*, 55: 106–117.

Iribarren, D., Vázquez-Rowe, I., Hospido, A., Moreira, M.T. & Feijoo, G. 2010. Estimation of the carbon footprint of the Galician fishing activity (NW Spain). *Science of the Total Environment*, 408: 5284–5294.

Iribarren, D., Vázquez-Rowe, I., Hospido, A., Moreira, M.T. & Feijoo, G. 2011. Updating the carbon footprint of the Galician fishing activity (NW Spain). *Science of the Total Environment*, 409: 1609–1611.

ISO. 2006. *14040 – Life Cycle Assessment: Principles and Framework*. International Organisation for Standardization.

Kim, B. & Neff, R. 2009. Measurement and communication of greenhouse gas emissions from U.S. food consumption via carbon calculators. *Ecological Economics* [online]. doi:10.1016/j.ecolecon.2009.08.017

King. 2010. Integration of emissions inventories and energy audits conducted aboard ships. Energy in Fisheries Symposium, Seattle, 2010.

Kitts. 2010. Measuring total fuel use in northeast U.S. commercial fisheries. Energy in Fisheries Symposium, Seattle, 2010. NOAA Fisheries Service.

LCA Food. 2011. [online]. [Cited December 2011]. www.lcafood.dk

Macleod. 2008. Carbon footprint measurement and labelling of products: UK activities. DEFRA presentation.

Mitchell. 2010. Seafood and climate change. Carbon issues in the seafood industry – consumer perceptions and commercial realities. A seafood processor's perspective. Energy in Fisheries Symposium, Seattle, 2010.

Papatryphon, E., Petit, J., Kaushik, S.J. & van der Werf, H.M.G. 2004. Environmental impact assessment of salmonid feeds using life cycle assessment. *Ambio*, 33(6): 316–23.

Pelletier, N.L. & Tyedmers, P.H. 2011. An ecological economic critique of the use of market information in life cycle assessment research. *Journal of Industrial Ecology*.

Pelletier, Tyedmers, Kruse, S.A., Flysjo, A., Robillard, G., *et al*. 2007. Impact categories for life cycle assessment research of seafood production systems: review and prospectus. *Int. J. Life Cycle Ass*., 12: 414–421.

Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. & Penman, F.W., eds. 2003. *Good practice guidance for land use, land-use change and forestry*. IPCC National Greenhouse Gas Inventories Programme.

Pimentel, D. 2004. Livestock production and energy use. *In* C. Cleveland, ed. Encyclopaedia of energy, vol. 3, pp. 671–676. San Diego, USA, Elsevier.

Raggi, A. 2010. Key considerations from LCA case studies in the food and drink sector. DASTA – University G. d'Annunzio, Pescara, Italy EC JRC, Ispra, Italy, 14 June 2010.

Rawitscher & Mayer. 1977. Nutritional outputs and energy inputs in seafood. *Science*, 198.

Schau, E.M., Ellingsen, H., Endal, A. & Aanondsen, S.A. 2009. Energy consumption in the Norwegian fisheries. *Journal of Cleaner Production*, 17: 325–334.

SEPA. 2011. *National Inventory Report 2011 Sweden*. Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Swedish Environmental Protection Agency.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. 2006. Livestocks long shadow. Environmental issues and options. Livestock Environment and Development Directive. FAO.

Sumaila & Chung. 2010. *Cost of adapting fisheries to climate change*. World Bank discussion paper.

Svanes, E., Vold, M. & Hanssen, O.J. 2011. Effect of different allocation methods on LCA results of products from wild-caught fish and on the use of such results. *Int. J. Life Cycle Assess.*, [online] DOI 10.1007/s11367-011-0288-4.

Thomas, G., O'Doherty, D., Sterling, D. & Chin, C. 2010. Energy audit of fishing vessels. *Proc. IMechE*, Vol. 224 Part M: J. Engineering for the Maritime Environment.

Thrane M. 2003. *Environmental impacts from Danish fish products*. Aalborg University (Denmark), Department of Development and Planning. (PhD dissertation)

Tyedmers. 2000. Salmon and sustainability: the biophysical cost of producing salmon through the commercial salmon fishery and the intensive salmon culture industry. Unpublished. University of British Columbia, Vancouver, Canada. (PhD thesis)

Tyedmers. 2004. Fisheries and energy use. *Encyclopedia of Energy*, Volume 2. Elsevier Inc.

Tyedmers, Watson & Pauly. 2005. Fuelling global fishing fleets. *Ambio*, 34(8).

UNEP-DTIE. 2003. UNEP-DTIE. Evaluation of environmental impacts in life cycle assessment. United Nations Environment Program; Division of Technology, Industry and Economics.

UNFCCC. 2011. National greenhouse gas inventory data for the period 1990–2009. Subsidiary Body for Implementation Thirty-fifth session, Durban, 28 November to 3 December 2011.

U.S. Environmental Protection Agency (EPA). 2003 *Control of emissions of air pollutions from non-road diesel engines and fuel*. Proposed Rule, vol. II.

Vázquez-Rowe, I., Moreira, M.T. & Feijoo, G. 2011. Environmental assessment of frozen common octopus (Octopus vulgaris) captured by Spanish fishing vessels in the Mauritanian EEZ. *Marine Policy*, 36: 180–188.

Walmart. 2009. *Supplier sustainability assessment. Guidance to suppliers*.

Watanabe, H. & Uchida, J. 1984. An estimation of direct and indirect energy input in catching fish for fish paste products. *Bull. Jap. Soc. Sci. Fish.*, 50(3): 417–423.

Weber, C.L. & Matthews, H.S. 2008. Quantifying the global and distributional aspects of American household carbon footprint. *Ecological Economics*, 66: 379–391.

Weidema, B.P., Thrane, M. Christensen, P., Schmidt, J. & Lokke, S. 2008. Carbon footprint. A catalyst for life cycle assessment? *J. of Ind. Ecol.*, 12: 3–7.

Wiedmann, T. & Minx, J. 2008. A definition of 'carbon footprint'. *In* C.C. Pertsova. *Ecological economics research trends*, pp. 1–11. Hauppauge, USA, Nova Science Publishers.

Winther, U., Ziegler, F., Skontorp Hognes, E., Emanuelson. A., Sund, V. & Ellingsen, H. 2009. *Carbon footprint and energy use in Norwegian seafood products*. SINTEF.

WRI & WBCSD. 2004. *The green house gas protocol. a corporate accounting and reporting standard.* Revised Edition. World Resources Institute & World Business Council for Sustainable Development.

WRI/WBCSD. 2011. The Corporate Value Chain (Scope 3) Standard.

Ziegler, F. & Hansson, P. 2003. Emissions from fuel combustion in Swedish cod fishery. *J. Clean Prod.*, 11: 303–314.

Ziegler, F. & Valentinsson, D. 2008 Environmental life cycle assessment of Norway lobster caught along the Swedish west coast by creels and conventional trawls- LCA methodology with case study. *Int. J. Life Cycle Assess.*, 13: 487–497.

A pragmatic approach to assess global GHG emissions in aquaculture food production systems
J.F. Muir

Introduction

According to current statistics aquaculture contributes approximately 50% of global aquatic supplies for human consumption, and trends suggest that this share will increase, as the sector becomes the primary source of expanded supply to meet growing population and market demands (see eg FAO, 2010). Aquaculture has distinctly different production characteristics from capture fisheries, in terms of location, resource rights, species selection, control of inputs and costs, risks, product control and supply chain presence. However, like capture fisheries, it is carried out at a range of scales, and has a notable diversity of forms. As with fisheries also, it has a range of upstream and downstream linkages, and shares a common destination in post-harvest and distribution systems, entering the broader food network of retail, food service and domestic consumption.

The role of the food sector in greenhouse gas (GHG) emissions has been broadly described (eg UK Foresight 2011), and key components in crops and livestock have been given further definition, though the need for further assessment is widely recognised (FAO, 2009). Data for the fishery sector is even less developed, and within this only a relatively small number of analyses have been carried out for aquaculture (see eg Colt, 2008, Ayers and Tyedmers 2009, Pelletier and Tyedmers, 2010, Bosmah et al 2011, Henriksson et al, 2011, Wright, 2011). This paper aims to use typical examples from small-scale and industrial aquaculture, mapping out specific supply chains, and illustrating the most important GHG characteristics and issues, to develop a pragmatic approach to building up a perspective of global GHG emissions. In the current IPCC terminology (IPCC 2007) this is equivalent to 'Tier 1' assessment approach, from which more specific and detailed approaches might be derived, typically at more case-specific levels. These can then be further applied to develop more detailed global data. The discussion and conclusion sections suggest how these approaches may be developed further.

Background

Aquaculture is carried out in a wide range of systems and environments, with production processes ranging from relatively unmanaged systems in semi-open waters relying on wild seed and natural fertility to highly engineered systems with intensive stocking of hatchery seed, external feeding highly managed water and waste treatment processes (Muir, 2005). Support functions range from simple manual labour inputs to highly mechanised transport, handling and husbandry operations dependent on external energy inputs. With very close interactions with supporting aquatic ecosystems, the GHG linkages for aquaculture, both in terms of outputs and potential uptake, depend on these interactions, their scope, scale and dynamics (Bunting et al, 2009). In some cases, particularly where ecosystems are only slightly modified, the distinction between natural and aquaculture-attributable processes may be difficult to quantify. However, these typically very low-yield systems are now less common globally, and inputs and processes in most forms of aquaculture are distinctive and additional enough to be subject to specific GHG assessment approaches.

The primary GHG related to aquaculture is CO_2, linked with fuel and energy use in direct production and with the production of key inputs, the most significant of which is the input of feeds. Respiration of aquatic stocks also produces CO_2, most of which however is taken up in the carbonate-bicarbonate system in the water, or in photosynthetic uptake by aquatic micro-organisms or plants, and is only in limited circumstances directly released to the atmosphere. In global settings the other main GHGs, CH4 and N2O, are emitted from both natural and anthropogenic sources. For CH_4, natural sources are estimated to produce 37 % of the total annual flux into the atmosphere, the largest source of which is natural wetlands, contributing 170 Tg CH4/yr. Lakes are estimated to contribute 30 Tg CH4/yr, estuaries and rivers 1.3 to 2.3 Tg CH4/yr. Human activities have significant potential to change these both directly (e.g., decreased CH4 from wetlands, due to draining and filling, or increased CH_4 from rice paddies, potentially rising further in rice-fish systems) or indirectly through climate change (e.g., increased CH4 emissions from wetlands due to rising temperature). Estuaries and rivers cover limited areas, yet are highly biologically and physically active, enabling CH4 produced in adjacent wetlands and shallow-water environments to be rapidly released to the atmosphere. Methane production is greater in areas under freshwater and in shallow waters with highly organic sediments, though In general, surface waters are relatively small sources of CH4 to the atmosphere.

N2O is also produced by bacteria; natural sources contribute about 64 % of total inputs to the atmosphere, the largest being soils (6.6 Tg N/yr) and oceans, rivers, and estuaries (5.4 Tg N/yr). However, it is uncertain what fraction of emissions associated with rivers and estuaries are of natural origin, as they may be driven primarily by anthropogenic contributions (e.g., from agricultural runoff). (EPA 2010). There are no direct measurements or estimates of N_2O deriving from aquaculture systems, though it is a potential stage in nitrogen metabolism in growth, feed proteins being broken down primarily to ammonia, NH_3, some of which can be released directly to the atmosphere in higher pH conditions, most of the rest ultimately being oxidised to nitrite (NO_2) and then nitrate (NO_3), which normally remains in water as dissolved salt.

The overall connections between aquaculture production elements and GHG features are summarised in Table 1.

Table 1 GHG-related elements in aquaculture

Component	*Key GHG characteristics*	*Note/issues*
Land clearance for inland or coastal ponds	Potentially significant one-time release of $C0_2$ and CH_4 as surface vegetation and soils are broken up and exposed to atmosphere	Relatively unrecorded, but analogous to land-clearing role in agriculture, potentially adding significantly to overall impacts. May also reduce longer-term sequestering potential
System structures	Primarily related to CO_2 links with energy and materials in construction – soils, cement, bricks, tiles etc, also cage frames, netting, moorings	Relatively modest and reduces with system intensity as product output per unit of area or volume increases. Can usually use standard industry conventions for GHG content, though wear/depreciation rates may be higher in cases
Feeds	Primarily related to CO_2 links with energy for fish capture, fishmeal/oil production, or fertiliser and other inputs for terrestrial raw materials, energy for process wastes, plus compounding energy, etc.	An important factor in aquaculture GHG - varies widely with sources and combinations of raw materials, with use and application, and effective food conversion ratios. The current shift to terrestrial sources may in some cases raise potential GHG impacts
Fertilisers	Mainly energy and CO_2 related to inorganic fertiliser production, also source, collection, transport of organic fertilisers	Primarily in extensive to semi-intensive pond aquaculture systems; small overall role, depends on application rates and productivity
Water exchange	Mainly energy and CO_2 related to pumping/circulating water	Many systems rely on natural water exchange – otherwise varies with system intensity, pumping efficiency – usually relatively small GHG impact
Gas management	Mainly energy and CO_2 related to aeration, oxygenation, sometimes water treatment, occasionally including CO_2 stripping	Only in more intensive systems including recycle (RAS) units, usually a relatively small GHG impact

Temperature control	Energy and CO_2 related to heating or cooling aquaculture water or surrounding air volumes.	Limited importance - limited applications, often for high value stock. Heat pumps, heat recovery, solar energy devices may all act to reduce this.
Ancillary functions	Energy and CO_2 related to vehicle and vessel movement, office and staff functions, materials and power for feeders, controllers, handling devices, also ice, packing materials, cool storage, etc	Varies widely with production system and operating conditions, may have important effect on overall system efficiency, usually limited GHG impacts in themselves.
Solid wastes	Potential release of CH_4 from anaerobic decomposition of sediments in pond bottoms or below cages; otherwise energy and CO_2 linkages with transporting and disposal	In some circumstances could be a notable contributor to GHGs but most waste carbon is taken up in aerobic processes, very limited evidence of major direct CH_4 release.
Soluble wastes	Might in some circumstances drive enrichment of process/surrounding water, possible added CO_2	Very ,limited evidence of effect, unlikely to be a significant GHG contributor per se, unless a tipping factor to necessitate specific treatments.
Other wastes	Energy and CO_2 related with collection and disposal of domestic and process waste materials	Usually an insignificant GHG contributor

As noted more broadly in defining system functions and impacts, and in using approaches such as life-cycle assessments (LCAs) in determining the overall performance of a given system or production process, setting system boundaries is a critical element in establishing effective bases for comparison across and within systems. Table 2 outline some of the system boundary options that might be considered in assessing GHG characteristics and attributing these to aquaculture products.

Table 2 System boundary options for aquaculture

System definition	*Scope of measurement*	*Constraints/issues*
Fish input-output model	Seed source/characteristics feed type, source and level of application, growth, survival, biomass and quality	Basic biological model – feed focus for GHG estimates may account for 70-80% of total, ideally based on whole fish populations; can also provide GHG/net yield; cannot be used to estimate/control other GHG factors
Artisanal production	Fertiliser and feed input, possibly also local transport to markets	Can cover most of GHG relationship, may be difficult to monitor quality and quantity of inputs; possible multiple outputs
Basic commercial output	As for fish input/output model plus other operating inputs, including direct waste disposal, to point of first hand sale	Adds main energy, consumed material and direct waste disposal elements to analysis, allows more complete estimate/ control of these
Comprehensive inventory	As above plus depreciation/ disposal of all capital items, longer term environmental factors, allocation to operation	More comprehensive comparison embracing capital structures, can explore possible tradeoffs with operating efficiency across systems

Complete supply chain	As above, with accounting for whole process to point of consumption and ultimate disposal	Most comprehensive approach and useful for strategic perspectives but may be difficult to make more detailed comparisons across systems due to wide diversity and possible allocation issues

At this stage there are insufficient case details of LCA based GHG analyses across a range of aquaculture systems to identify where particular issues of assessment or interpretation are likely to cause discrepancies or misunderstanding. However, at a preliminary stage it is clear that feeds and their sourcing and composition will be the main issue for feed-based aquaculture (Tacon and Metian, 2008) , which were estimated to account for more than 46% of global production in 2008 (Tacon et al 2011), and that land use/sediment/sequestration interactions are likely to be more important for fertilised/low-feed pond based systems, and for those involving substantial new land clearance. Accounting for GHG related to CH_4 outgassing from solid wastes below intensive cage systems, or released from sedimentation tanks or ponds treating discharge water may be an issue in some systems, and would be subject to great variability depending on operating conditions and treatment environments. The role of methane production in flooded rice-fields and the possible exacerbating effects of growing fish in these areas is a potentially important subject in its own right and will require much more detailed assessment, not least because the practice is associated with major economic benefits, linked also with the reduction of pesticide use. Standardising issues, such as accounting for travel to work distances for employees (and possible accommodation in remote sites), defining GHG ratios for centrally generated electrical power, and others are likely to apply in aquaculture as for any other sector, and are apparently relatively insignificant in total GHG terms.

Aquaculture supply chain examples

To outline some of the possible approaches related to different types of aquaculture system/supply chain, the following tables have been developed.

- *Industrial cage-based salmon aquaculture*

This would be typical of the major commercial sector for cage rearing of Atlantic salmon, now a highly developed aquaculture product, entering most of the world's modern retail and food service outlets as well as traditional outlets. It is normally sold fresh, whole steaked or filleted, or smoked, both forms of which are increasingly key components in value-added, mainly chilled products. Produced mainly in Norway, Chile, Scotland, Canada Ireland and Tasmania, with widespread distribution links, increasingly reaching secondary markets, the industry has steadily consolidated, with horizontal and vertical integration, and increasingly uses state of the art husbandry, handling, slaughter, post-harvest and distribution systems with high levels of product traceability from 'egg to plate'. It therefore has organisational and system monitoring features which could facilitate GHG accounting, but is also in a highly competitive environment in which data would have to be well sourced, verified and used in a positive context.

Table 3 GHG supply chain for cage based salmon culture

Supply chain elements	*Possible measurement*	*Notes*
Seedstock	Supplied by hatchery producers – including broodstock holding and feeding, early rearing feeds, health treatments, water supply and management, transport to ongrowing site	Typically represents around 1% of final biomass so overall GHG input not likely to be critical – more important for assurance
Feeds	Basic feed characteristics supplied by feed producers, together with storage, food conversion and other data from ongrowers	Transport data for feeds to ongrower to be supplied by each feed producer (several feed sources may be used)
Production	Capital items and turnover/depreciation rates, seed survival/yield, feed data as above, plus other operating inputs, including packing, wastes, to point of despatch	Standard protocols for each site, allocation rules needed for inputs multiple stocks/year-classes
Post-harvest/processing actions	Yields, capital and operating characteristics of process elements to final packaged product form – developed an supplied by process agents, at least for generic inputs and products	Will vary with product size and quality, throughput – allocation rules would be required; increasing range of secondary products, including process wastes for aquaculture feeds
Distribution	Means of distribution, weights and distances – based at least on standard factors and range of options chosen .	Some generic data likely – allocation issues possible for mixed loads; fuel efficiencies likely to be very critical.
Retailing/food service	Storage and display volumes/refrigeration space, residence time, transformation waste	Wide variations possible, and may be proprietary information, though generic data possible from anonymised assessment
Consumption	Estimates of household travel to purchase, storage time, wastes, disposal - data from generic food use/waste surveys	Wide variations across households and probably also for different product forms.

- *Pond-based pangasius culture*

This is based on the hugely successful Asian production of pangasius catfish, now primarily using relatively simple pond-based systems, increasingly moving from locally produced feeds, traditionally based on local ‘trash’ fish, towards modern compound diets and more managed water exchange and quality control (SEAT, 2011). Much of current production derives from Vietnam, where it is directed to contemporary standard processing plants near production regions, for filleting, packing and despatch to major global markets. Production is also increasing in Thailand and Bangladesh. Clean, white-fleshed and relatively unflavoured, the product is highly versatile and price competitive, and has gained strong market positions in Europe and N America, particularly as a component in fish meals and other options. It also has a growing impact in domestic Asian markets, where it is also starting to enter Western model retail outlets as well as fast food catering.

Table 4 GHG supply chain for pangasius culture

Supply chain elements	*Possible measurement*	*Notes*
Seedstock	*Based on data from seed suppliers, or as % estimate based on numbers/biomass*	Likely to be small contribution – seed producers becoming more centralised
Feeds	*From major feed suppliers or based on far inventories of locally manufactured feed, plus conversion ratios*	Quality of data will vary, but feed traceability becoming a more important issue
Production	Pond construction, land clearance, capital items and turnover/depreciation rates, seed survival/yield, feed data as above, plus other operating inputs, including packing, wastes, to point of despatch	National/provincial data on pond development may be available (Vietnam) – larger co-operative producer groups also improving data and accountability
Post-harvest/processing actions	Yields, capital and operating characteristics of process elements to final packaged product form – supplied by process agents, at least for generic inputs and products	Export market processing data likely to be available in major units – local market data less certain though moving to same standards.
Distribution	Means of distribution, weights and distances – based at least on standard factors and range of options chosen.	Wide range of conditions depending on export or domestic market circumstances
Retailing/food service	Storage and display volumes/refrigeration space, residence time, transformation waste	Will vary substantially whether export or domestic markets
Consumption	Estimates of household travel to purchase, storage time, wastes, disposal - data from generic food use/waste surveys	Range of circumstantial/cultural conditions.

- *Small-scale tilapia cage culture*

This example would be typical of a range of aquaculture applications where small cages – commonly 1-100 m^3 of rearing volume are set up in open water bodies – lakes, lagoons, reservoirs, flooded borrow-pits – of a range of sizes and environmental characteristics. Stocked with tilapia fingerlings, either produced on site or increasingly from local hatcheries/nurseries, fed using locally produced, relatively simple low-protein diets, stocks are harvested partially or completely for farm-gate fresh sales to consumers or small traders/local catering outlets, or transported to local markets for similar sales. In some cases, small producers may be linked in cooperative marketing arrangements supplying larger quantities to larger markets or to processors.

Table 5 GHG supply chain for small-scale tilapia cage culture

Supply chain elements	*Possible measurement*	*Notes*
Seedstock	Most likely as % estimate based on numbers/biomass	Small contribution – seed producers may be too small to provide data
Feeds	Sample farm inventories of locally manufactured feed, plus conversion ratios	Quality of data will vary – simple estimates needed
Production	Pond construction, land clearance, various small capital items, turnover/depreciation rates, seed, feed data, other small operating inputs to points of sale	Limited and varied data; wide range of efficiency; co-operative producer groups may have better co-ordinated source data
Post-harvest/processing actions	Limited relevant data unless going to local smokers/filleters, or entering small local processing units	May only derive from small number of sample cases
Distribution	Means of distribution, weights and distances – local transport, walking cycling, shared motor transport.	In some cases may pass along considerable distance, particularly if smoked/dried.
Retailing/food service	Limited data from small food shops/cafes	Will vary substantially – small impacts
Consumption	Estimates of household travel to purchase, storage time, wastes, disposal - data from generic food use/waste surveys	Range of circumstantial/cultural conditions.

- *Integrated smallholder pond culture*

This case would be based on a smallholder mixed farm, typically 0.1 to 5 ha in area, in which fish or prawn culture would be integrated with a range of other farming activities, the pond being fertilised by livestock and vegetable wastes, possibly some locally produced feeds, water storage functions from the pond typically used for irrigation, tree crops on pond banks, pond sediments used to fertilise soils. Stocks are harvested partially or completely for farm-gate fresh sales, or transported to local markets. In some cases, cooperative marketing may be used to supply larger quantities to larger markets or to processors.

Table 6 GHG supply chain for integrated pond culture

Supply chain elements	*Possible measurement*	*Notes*
Seedstock	Most likely as % estimate based on numbers/biomass	Small contribution – seed producers may be too small to provide data
Feeds	Sample farm inventories of local feeds, plus conversion ratios	Quality of data will vary – simple estimates needed
Production	Land clearance, pond construction, small capital items, turnover/ depreciation rates, seed, feed data, other small inputs to points of sale	Limited and varied data; attribution to other products, wide range of efficiency; co-operative producer groups may have better source data
Post-harvest/processing actions	Limited relevant data unless entering small local processing units	May only derive from small number of sample cases
Distribution	Means of distribution, weights and distances – local transport, walking cycling, shared motor transport.	Links with distribution of other farm products?
Retailing/food service	Limited relevance	Will vary substantially – small impacts
Consumption	Estimates of household travel to purchase, storage time, wastes, disposal - data from generic food use/waste surveys	Range of circumstantial/cultural conditions.

- *Integrated multi-trophic aquaculture*

This form of aquaculture has primarily been developed at an experimental level, though zonal-scale coastal aquaculture development eg in areas of Japan, Korea and China have similar attributes. The aim is to integrate more intensive aquaculture, commonly high value intensively fed fish based cage culture, though pond or cage based shrimp culture is also a potential component, with a mix of molluscs, seaweeds and other low trophic level species which will take up the waste nutrients and produce useful biomass. At this stage few systems have been optimised, but their characteristics are sufficiently well defined to permit a possible GHG map.

Supply chain elements	*Possible measurement*	*Notes*
Seedstock	Some cases may have hatchery data, otherwise as % estimate based on numbers/biomass;	Small contribution to overall GHG – some seed producers may be too small to provide data
Feeds	From major feed suppliers or based on far inventories of locally manufactured feed, plus conversion ratios	Quality of data will vary
Production	Where relevant, land clearance, pond construction, small capital items, turnover/ depreciation rates, seed, feed data, other small inputs to points of sale	Limited and varied data; attribution to other products, wide range of efficiency;
Post-harvest/processing actions	Where relevant, yields, capital and operating characteristics to final product form – supplied by process agents, at least for generic inputs and products	Processing data likely to be available in major products/units – local market data less certain.

Distribution	Means of distribution, weights and distances – based at least on standard factors and range of options chosen.	Wide range of conditions depending on product mixes and export or domestic market circumstances
Retailing/food service	Where relevant, storage and display volumes/ refrigeration space, residence time, transformation waste	Will vary substantially whether export or domestic markets
Consumption	Household travel to purchase, storage time, wastes, disposal - data from generic food use/waste surveys	Range of circumstantial/cultural conditions.

Global accounting for the sector

At this stage the prospects of global accounting for aquaculture are limited by the availability of generic data on systems, and on methodological issues associated with different LCA applications. According to Burg et al (2011), current life cycle analysis (LCA) results do not show a significant difference in energy use or global warming potential per kg fillet of plaice or cod from capture fisheries, or salmon, tilapia and pangasius from aquaculture. Though there are some differences in the mean values, the variance in the data is too great. Nor do current LCA results show significant differences in acidification potential per kg filet of these species. However, eutrophication potential of plaice and cod is lower than that for salmon, tilapia and pangasius, primarily because of feeding and wastes. Comparing wild caught fish with farm animals, energy use for plaice and cod is higher than for beef, pork and chicken. The GWP (global warming potential) of plaice and cod is comparable to that of pork and chicken and lower than that of beef. This is explained by the non-CO_2 greenhouse gas emissions from animals and manure. However, aquaculture products were not directly compared, and as noted earlier, non- CO_2 GHGs may also be important.

In many respects, fed aquaculture in particular can be used as a basis for defining CO_2 outputs form aquaculture, and with better inventories (eg Tacon et al, 2011), it may be possible to obtain estimates of global output. Global energy use assessments are also being developed (FAO, 2012) which also incorporate non-feed energy use and CO_2-based GHG implications. In other sectors such as agriculture, infrastructure is commonly excluded from LCAs as it has little effect on overall impact values, and can be complex to acquire reliable data. Some fishery sector studies include the impacts of the use of refrigerants, as their production and use can result in high GHG emissions, though this depends on the type of refrigerant. As noted earlier, however, the accounting for CH_4 and N_2O is likely to provide the greatest challenge to global estimates for GHG outputs from aquaculture, both in terms of identifying their flows in typical aquaculture systems and management regimes, and in establishing reliable estimates of the scope and scale of these systems globally.

The selection o practical approaches

Based on the overviews above, together with other related literature (Poseidon 2011, Muir 2012, Parker, 2012), a number of points can be considered in selecting practical approaches for assessing GHG relationships for aquaculture:

- *The applicability of the LCA (or variants) approach*

Table 2 above has outlined some of the possible levels of scope for LCA approaches associated with GHG assessment for aquaculture and has noted the respective merits and drawbacks, and Poseidon (2011) have provided an updated overview for the broader fisheries sector. Work is also underway in developing PAS 2050 standard methodologies (PAS 2050, 2008) for fisheries and aquaculture related LCAs for GHGs. Recognising that there may be different objectives, including the setting of national targets, sectoral benchmarking, certification for various market chains, and internal monitoring and that there is commonly a tradeoff between scope and detail, and the time and cost of carrying out LCAs of GHG characteristics, as much use as possible should be made of standardised approaches. These should be as consistent as possible with international and sectoral standards across the food sector. For simplicity in monitoring purposes, key indicators can also be used as proxies for full GHG valuations.

- *Utility of the approach across/linking with the wider sector*

Some aspects of aquaculture are likely to lend themselves relatively easily to wider sector approaches, for example the use of feeds, which should carry comparison with other intensive livestock operations. Ecosystem interactions associated with land clearance have some parallels with the issues and measures applied for forest clearance, but together with rice-fish CH_4 interactions would require further evaluation to determine how much the connections can be extended. Forward linkages to postharvest and processing functions are also likely to carry some analogies to those in the wider food sector, particularly in areas such as chilled prepared meals, and some food service areas, but specific aspects of perishability and distribution characteristics and waste issues may create differences.

- *Pragmatic / realistic boundaries setting and utility of modelling of the system*

Ideally, assessment systems should be based as far as possible on data which would commonly be complied for management and other reporting purposes within the aquaculture supply chain, together with data provided by key suppliers such as cage and equipment manufacturers, seed and feed suppliers, and waste disposal contractors. Management data would typically involve quantities and costs of key inputs, process efficiencies, and outputs. In some cases allocation decisions may need to be made, and standard approaches for doing so should be developed, based or linked with similar approaches described in ISO and other standards.

- *Level of detail required and availability of data*

The level of detail required will depend on the purpose of the assessment, but as noted earlier, a substantial part of GHG output in intensive production systems may be accounted for in feed sourcing and use. However, based on the information obtainable from a wider range of systems and contexts the significance of other factors can be more readily defined. Ecosystem interactions, if important, may be more problematic to assess, though data could potentially be developed in conjunction with the environmental monitoring commonly required for more intensive forms of aquaculture. It may be more difficult to assess less intensive aquaculture systems in less well resourced countries or communities, though if aquaculture proves to be more of a national priority for GHG reduction, financial incentives could be linked in with local assessment and monitoring, possibly with an auditing arrangement (see emerging issues/possible solutions for REDD system). Across all systems a web-based data resource would be valuable, also possibly allowing anonymised inputs to create better cross-sectoral data.

- *Costs of data collection and complexity / errors associated with upscaling*

These will depend on the complexity of approach chosen, and the extent to which data can be easily derived from existing management information as noted above. Invariably, precision will be lost in moving from specific batches of aquaculture product to whole sites, to multi-site enterprises and to national and global accounts, though as GHG accounting becomes more widely operational, these could be systematically reduced.

- *The rationale for selecting key species to which the approach could be applied*

The tables above have been based on a small selection of aquaculture species and systems, chosen to illustrate the range of contexts potentially involved. They are not intended to be detailed and accurate representations of the sectors involved. This will require a more systematic approach in defining typologies and compiling representative data. To develop data further across these and other species/systems the following criteria are likely to be relevant:

  - Significance of specific subsectors to global or national output and potential GHG.
  - National interests in developing cross-sectoral GHG inventories.
  - Supply chain interests/incentives for compiling better GHG information, and preparedness of key suppliers to provide product related GHG information.
  - Ready access to useful representative data.

Policy initiatives

A number of potential policy initiatives could be relevant to encourage transformation of the aquaculture sub-sector's approach to energy use and GHG emission reductions. These are likely to emerge from or align with concerns for national GHG accounting, with harmonising criteria for trade and competition, and with investment needs to improve sectoral efficiency. The specific detail of these would depend on international or national contexts and policy processes, but the following may be relevant:

- Establishing national or other area-based inventories and system typologies.
- Developing reporting requirements for aquaculture supply chain actors – eg seed, feed supply, producers, processors; engaging/supporting small-scale sectors.
- Identifying or creating R&D incentives to explore industry-level GHG data and strategies to reduce these.
- Linking with/developing access to carbon markets to provide access to financial incentives for better GHG performance.
- Developing other fiscal instruments, and/or other constraints/incentives (eg GHG limits per land or water use) for improving sector performance on equal terms to other food or natural resource sectors.
- Supporting ongoing comparative assessments between aquaculture/other sectors and improving exchanges/methodology approaches.

Conclusions

A number of areas for further work can be identified, including the need to:

- Develop a more comprehensive framework in which the GHG characteristics of a range of aquaculture systems were presented – if not based on actual case data, using estimates based on agreed principles and source data; based on current subsectoral growth trends, develop estimates of GHG consequences, and likely areas where these could be controlled.
- Develop a specific framework for identifying potential GHG implications of aquaculture feed sources, compositions, manufacturing and supply options, as far as possible linking these with equivalent agriculture sector norms and protocols.
- Assess in more detail the rice-fish GHG implications in a range of current and emerging practice (seasonal water level variations, fertilising rate, rice varieties, fish stocking practice).
- Assess more clearly the implications of land clearing in inland and coastal areas, both on the shorter term release of GHGs from soils and vegetation and the lost capacity for sequestration (eg mangrove systems, and explore possible compensatory actions.
- Consider the GHG implications of changing land use associated with rising sea levels and possible transitions from agriculture to aquaculture.
- Further explore opportunities for carbon offsetting / sequestering in aquaculture production systems.
- Set out in broad terms the comparative features of different aquaculture systems, their comparisons with other food sectors, and the implications for strategic food choice and global/national GHG reduction policy.
- Based on the above approaches, identify at global, regional and system level where GHG efficiencies could be most readily achieved, how and by whom these might be carried out, and what barriers might exist to these being done.
- Examine comparable incentives for GHG reductions and set out key enabling policy initiatives that could encourage transformation of the sub sector's approach to energy use and GHG emission reductions.

References

Ayers, N.W. & Tyedmers, P. 2009. Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. *Journal of Cleaner Production*, 17: 362–373.

Bosma, R., Anh, P. & Potting, J. 2011. Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. *Int. J. Life Cycle Assess*., 6(9): 903–915.

Bunting, S.W., Pretty, J. & Muir, J.F. 2009. Carbon and energy consumption futures for fisheries and aquaculture. University of Essex, UK, Interdisciplinary Centre for Environment and Society, and University of Stirling, UK, Institute of Aquaculture.

Burg, S.W.K. van den, Taal, C., de Boer, I.J.M., Bakker, T. & Viets, T.C. 2011. *Environmental performance of wild-caught North Sea whitefish; a comparison with aquaculture and animal husbandry using LCA*. LEI report 2011-090. ISBN/EAN: 978-90-8615-555-2.

Colt, J. 2008. *Conceptual integrated closed confinement systems*. Paper No 6. National Advisory Workshop on Potential Technologies for Closed Containment Saltwater Salmon Aquaculture.

Fisheries and Oceans Canada. 2008.

EPA. 2010. *Methane and nitrous oxide emissions from natural sources*. Office of Atmospheric Programs (6207J) EPA 430-R-10-001. Washington, DC.

FAO. 2009. *Low greenhouse gas agriculture: mitigation and adaptation potential of sustainable farming systems*, by U. Niggli, A. Fliessbach, P. Hepperly & N. Scialabba.

FAO. 2010. *The situation and outlook for fisheries and aquaculture*. Rome.

FAO. 2012 (in press). *Fuel and energy use in the fisheries sector*. FAO Fisheries and Aquaculture Circular. Rome.

Henriksson, P.J.G. Guinée, J.B., Kleijn, R. & de Snoo, G.R. 2011. Life cycle assessment of aquaculture systems—a review of methodologies. *Int. J. Life Cycle Assess*.

IPCC. 2007. *Intergovernmental Panel on Climate Change, Fourth Assessment Report*.

Muir, J.F. 2005. Managing to harvest? Perspectives on the potential of aquaculture. *Philosophical Transactions of the Royal Society B*, 360: 191–218.

Muir, J.F. 2012. *An outline of GHG and related performance metrics for the fisheries sector*. Background paper for FAO Expert Workshop on GHG and LCA methodologies in the fisheries sector Jan 23–26, 2012, FAO, Rome.

Parker, R. 2012. *Review of life cycle assessment research on products derived from fisheries and aquaculture*. Final report. Edinburgh, UK, Sea Fish Industry Authority.

PAS2050. 2008. *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (October 2008)*. British Standards Institute (BSI), Department for Environment, Food and Rural Affairs (Defra, UK) and the Carbon Trust (UK). (also available at www.bsigroup.com/en/Standards-and-Publications/Industry-Sectors/Energy/PAS-2050/).

Pelletier, N. & Tyedmers, P. 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.

Poseidon. 2011. *Lifecycle analysis and greenhouse gas emissions methods in seafood production systems*. Background paper for FAO Expert Workshop on GHG and LCA methodologies in the fisheries sector. Jan 23–26, 2012, FAO, Rome.

SEAT – the Sustainable Ethical Aquaculture Trade project. 2011. EU FP7.

Tacon, A.G.J. & Metian, N. 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospect. *Aquaculture*, 285: 146–158.

Tacon, A.G.J., Hasan, M.R. & Metian, N. 2011. *Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects*. FAO Fisheries and Aquaculture Technical Paper No. 564. Rome, FAO.

UK Foresight. 2011. *Global food and farming futures review*.

Wright, A.S. 2011. Salmon aquaculture GHG emissions - a preliminary comparison of land-based closed containment and open ocean net-pen aquaculture. SOS Marine Conservation Foundation's Save Our Salmon Initiative.

An outline of GHG and related performance metrics for the fisheries sector. J.F. Muir

Glossary/acronyms

ADP	Abiotic Depletion Potential
CDM	Clean Development Mechanism
CFC	Chloroflourocarbons – major ozone depleting substances
CH4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent – of global warming potential over specified time
GHG	Green house gas
GWP	Global warming potential – of gases compared with CO2 over defined period
Gt	Gigatonne
HCFC	Hydrochloroflourocarbons – less ozone depleting than CFCs
HFC	Hydroflourocarbons – non ozone-depleting substitutes for CFCs, HCFCs
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
LCA	Lifecycle assessment/analysis
N_2O	Nitrous oxide
ODP	Ozone depleting potential – relative to CFC-11
ODS	Ozone depleting substance
UNFCCC	UN Framework Convention on Climate Change
WMO	World Meteorological Organisation

Introduction

The contribution of various sectors of human activity to atmospheric change and global warming is an area of growing political and economic importance, and there are increasing concerns to mitigate this, whether through national policy action or sectoral incentives. A primary feature in global warming regardless of the originating process, is the role of gas composition in the upper atmosphere and its reactive conditions (Fuglestvedt et al, 2003). The consequent absorptive, transmissive and radiative properties define heat gain and the greenhouse effect whereby energy is retained and temperature rises in the geosphere. Though complete correlations for theoretical and observed properties of gases in the upper atmosphere are still being explored, the fundamental measure for effect is that of greenhouse gas (GHG) concentration and the contributing elements in natural and anthropogenic processes. Normally expressed in carbon dioxide equivalents (CO_2e) this provides a common measure for various gases, including methane, nitrous oxide, ozone, various fluorocarbons (UNEP, 2011), using standard conversion factors based on the greenhouse heating effect of specific molecules (see Box 1). These are linked in turn with the lifespan of specific gases in the upper atmosphere to determine the greenhouse warming potential (GWP), and can also be developed to define various carbon footprint related indicators (JRC-IES, 2007), DECC, 2009)

However while this measurement convention (IPCC 2007) is not in itself much contested or open to misrepresentation, the means by which the GHG contributions of various processes and activities is quantified can be much less clearcut (Solomon et al, 2007). It is rarely possible or feasible to measure gas flows or mass balances directly, and so a range of indirect approaches commonly needs to be employed, with varying measurement conditions and assumptions, and a range of accuracy. Furthermore, in a complex, multi-component activity typical of those in the fisheries sector – whether in specific manufacturing of a product, or in the operation of a complete supply chain, often with a mix of natural and anthropogenic processes, the definition and standardisation of GHG measurement, and the net attributable GHG to a specific process or output becomes a notable challenge (see eg Henriksson et al 2011. An additional but related question concerns the extent to which GHG measures can be linked with other parameters, such as resource use efficiency, salient production features, or social and economic performance, and that wider comparative evaluations can be carried out, and where appropriate, trade-offs can be defined (see eg Hospido et al, 2010, deBoer et al, 2011).

This paper provides a basic overview of current and emerging concepts for measuring the greenhouse gas (GHG) emissions and related features which may be relevant to the fisheries sector, with the aim of defining practical and reliable approaches for specific and comparative analysis, both within and across the sector and in wider contexts of climate change mitigation and adaptation. The paper considers issues such as the value of GHG in the contexts of carbon trading, and potential impacts in other economic and policy arenas, but does not address implications in meeting strategic aims for aquatic or fisheries resources or for issues such as food supply, employment or economic output.

The fisheries sector in the GHG context

In overall terms the global food production sector, primarily agriculture, is estimated to account for some 12% of global total GHG emissions; Table 1 summarises key elements in this Complete food system GHG data is rather limited, apart from some national and regional reviews. Food was estimated to contribute 31% of the EU-25's total GHG emissions, and including the hotel and restaurant sector, (EIPRO, 2006) food related activities accounted for up to 40% of total consumption related emissions. According to Kim and Neff (2009) upwards of 15% of GHG emissions were reported to arise from food consumption in the United States; an equivalent of 28% was calculated for Australia (ACF, 2007), while (Garnett, 2008) estimated some 30% for the UK food sector, with agriculture, food, manufacturing and transport respectively accounting for 40%,12% and 12% of this. Home food related activities contributed 9%, while retail activities and packaging each accounted for 7%, and catering 6%. Comparable values in developing country contexts are less well developed, though data is improving (see eg Pathak, et al, 2010).

Box 1 Contributions of key GHGs

Radiative forcing is commonly defined as the "rate of energy change per unit area of the globe as measured at the top of the atmosphere," in units of watts per square meter (W/m2). As of 2005, atmospheric CH_4 and N_2O are the second- and third-largest contributors to radiative forcing among greenhouse gases, after CO_2 (IPCC, 2007): where CO_2 contributes 1.66 W/m2, CH_4 0.48 W/m2 and N_2O 0.16 W/m2. The 100 year GWP of the key GHGs are 25 as high as CO_2 for CH_4 and 298 as high for N_2O.

Table 1 Agriculture sector greenhouse gas emissions

Source	GHG	Gt CO_2e	%age
Primary processes			
Enteric fermentation	CH_4	1.792	27.0
Manure	N_2O	0.413	6.2
Fertilised soils	N_2O	2.128	32.1
Biomass burning	CH_4,N_2O	0.672	10.1
Rice production	CH_4	0.616	9.3
Industrial factors			
Fertiliser production	CO_2, N_2O	0.410	6.2
Farm machinery	CO_2	0.158	2.4
Irrigation	CO_2	0.369	5.6
Pesticide production	CO_2	0.072	1.1
Total		6.558	100
Strategic factors			
Land use changes*	CO2	5.880	
Total		12.438	

Source: UK Foresight Global Food and Farming Futures, 2011

Data defining the role of the fisheries sector at this level is relatively undeveloped so far, though estimates based on fuel and energy use suggest global contributions of the order of 0.128 Gt for capture fisheries, 0.038 G t for aquaculture and 0.012 Gt for post-harvest and processing (FAO,2012). In terms of methodology for the fishery sector as in any other focus area, estimates of GHG emissions vary according to the approaches used, broadly falling into either "bottom-up" or "top-down" categories.

The first of these extrapolate from specific smaller –scale measurements of flux (release or uptake of a gas) to larger scales, or are based on models of processes controlling fluxes, applying to a larger scale. "Top down," or inverse, methods use atmospheric concentration measurements, tracer analyses, atmospheric transport models, and statistical methods to estimate emissions from individual sources

(EPA 2010). Within most practice for product-related sectors, the first approach is more commonly used, based as far as possible on common use and conversion factors (eg input and output quantities, mass conversions or balances, fuel consumption to GHG output, etc). In some areas, such as waste disposal and CH_4 or N_2O output, atmospheric based methods might also be considered.

While GHG emission linkages may be defined for one specific aspect of a process or product – eg fuel use in a fishing trip, power consumption for refrigeration or freezing, or GHG associated with a feed component, the common aim is to assemble a total GHG profile of all the composite elements in a product at a specific stage in its production or use. This is most often carried out on the basis of a complete inventory of all the elements involved, from starting inputs to final disposal, ie a life cycle analysis or assessment (LCA). Widely used to evaluate specific environmental performance, for example defining key resource inputs, energy use, or specific environmental impacts, the same approach can readily be considered for GHG accounting, and can in principle use related approaches and datasets. The primary stage in LCA is commonly to define the system, its functional components and their relative significance. As a generic rule, components and their system linkages can be defined and classified by their significance, their measurement characteristics and the certainty of data quality and availability (see eg PAS 2050 a,b).

However, while this concept of accounting the 'cradle to grave' profile of a product within a specific system of production is intuitively attractive, many common processes embrace a wide range of manufactured capital items, varying mixes of input resources, widely varying conversion ratios, multiple product outputs, and a variety of outcome/disposal destinies. As a consequence, similar products can have widely differing values for their measured characteristics, and the GHG outputs attributed to fishery sector products could vary substantially, and potentially be open to misinterpretation in commercial and strategic terms. As discussed in more detail elsewhere (Poseidon, 2011), issues of system boundaries and input or output allocation to specific products within an output mix are critical in the overall definition of system processes and input/output relationships, and in establishing bases for comparisons within and outside the sector (see eg Aalde et al 2006, Guinee and Heijungs 2007).

Nonetheless, relatively standardised approaches have been developed for LCA issues such as allocation, such as the ISO 14044 procedure (Box 2). According to Guinee et al (2004), the first step in developing an approach for a typical multi-component production system involves an inventory analysis of apparent inputs and outputs, modeling of the product system, setting system boundaries, describing processes and quantifying process flows. Multiple function/output problems can be identified and simpler components divided. The second step concerns solving the remaining multifunctionality problems, for which various approaches have been proposed and applied, including mass, energy of food value, market/economic value, avoidance of negative social or environmental burdens, etc.

Box 2 ISO 14044 allocation procedure (ISO 2006a,b)

Identify the processes shared with other product systems and deal with them according to the following stepwise procedure:

Step 1: Wherever possible, allocation should be avoided by:

1. Dividing unit process to be allocated into two or more sub-processes and collecting input and output data for each
2. Expanding the product system to include the additional functions related to the coproducts.

Step 2: Where allocation cannot be avoided, inputs and outputs of the system should be partitioned between different products or functions to reflect underlying physical relationships; i.e., how inputs and outputs are changed by quantitative changes in products or functions delivered by the system.

Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between coproducts in proportion to their economic value.

With regards to the fisheries sector in total, the following features of GHG interaction and measurement can be considered (Table 2):

Table 2 – key characteristics and issues of GHG relationships in fishery sub-sectors

Subsector	GHG characteristics	Issues
Capture fisheries	Primary GHG association with fuel use and catch quantities/values, also ice/refrigeration, crew supplies, mobilisation inputs, directly measurable or derived from cost and earnings surveys; GHG links with capital goods – vessels, fishing gear, service facilities, based on category ratios, mass/process conversion factors, use and disposal	Allocation to landed species, variation in vessel performance within fleet level assessments, effects of key subsidies, use of infrastructure, residual value/write-down/disposal of capital items, impacts on ecosystems, services
Aquaculture	Primary GHG association with feed use; also fertiliser, fuel/electricity , water supply, waste treatment seedstock, labour, chemicals, input packaging, directly measurable or estimated from costs and earnings surveys; GHG links with capital items including holding facilities, buildings, husbandry equipment, service vessels/ vehicles, based on category-based ratios, mass/process conversion factors, use and disposal	Feed composition and sourcing, water use values and impacts, variation in performance across production categories, accounting for landuse change and soils disturbance, methane impacts in fish-rice systems, possible mitigation effects in water/soils, impacts on ecosystem services, infrastructure
Post harvest processes	Wider range of GHG associations depending on process, mainly fuel/electricity, water supply/treatment, cleaning, waste disposal, packaging, labour; capital items including buildings, process equipment, vessels/vehicles based on category-based ratios, mass/process conversion factors, use and disposal	Boundaries in supply chain, yield variations, allocation to products, byproducts, value added product mixes; usage/disposal of wastes; values associated with water use; role of refrigerants
Distribution	Primarily depend on mode of transport, temperature, pack options, distance – fuel use; capital items include storage/distribution depots, air transport, vessels, trucks, handling and IT systems; GHG estimates based on allocated use rates, category-based ratios	Effects of loading levels, handling/ storage stages, route efficiency, infrastructure investment, fuel pricing, product losses, refrigerants
Retail and consumption	Range of GHG associations depending on products, on retail, food service conditions and consumption characteristics – power for lighting/cooling, home storage, cooking; wastes, packaging disposal	Variations across systems, food cultures, energy sources for storage, food preparation, refrigerants, regulatory impact on losses, wastes, infrastructure

In most cases, GHG outputs are associated predominantly with operating conditions and can be linked with operating costs, primarily for feeds in aquaculture and for energy and fuel use in other subsectors. Boundary and allocation issues can be important in most subsectors, and potentially large sources of variation can be recognised across different systems and within specific system categories, within and across geographical boundaries. However, once specific systems and contexts are defined, a large number of elements are potentially measurable and could be done so with reasonable accuracy.

The more problematic issues concern the selection of representative cases within system categories, tracking the potentially complex GHG interactions of the variety of aquaculture feed ingredients, environmental interactions (Lafoley and Grimsditch, 2009, Mcleod et al 2011) and the resolution of various technical matters such as infrastructure and water supply/treatment allocations and the handling of ecosystem service impacts, land-use changes and waste discharges for aquaculture.

Potential performance metrics for the fisheries sector

As noted earlier, the primary metric for GHG related performance is the GHG (CO_2 eq) output per unit of production, commonly based on landed/produced/marketed weights. In some cases, comparisons can also be made on the basis of first sale or retail value or in terms of food value, commonly based on calorific energy output. Depending on the system and processes involved, these may also be linked with more specific performance targets related to system characteristics. Table 3 summarises the more common areas of metrics and their current or potential linkages with GHG assessment.

Table 3 Summary of performance metric relationships

Performance metric	**Typical units**	**Link with GHG metric**	**Notes/issues**
Fuel/energy use	t fuel/t catch; kWH/t output	Primary element in many sector areas, could be used as a strong predictor/correlator for GHG	Measurement of fuel or energy use and allocation to specific products
CPUE (catch/unit effort)	t catch/vessel-day, hours	Effort may be associated with energy use per output – possible indirect measure	Range of products and values – wide variations within fleets
Aquaculture yields/productivity	t/ha or m3 –year	More intensive systems tend to have higher input levels – feed, water exchange, hence higher GHG	Natural productivity varies, and other factors will also affect GHG
Aquaculture food conversion	t food/t product	Can be a primary definer of GHG – strong correlator	Depends on food composition, sourcing
Aquaculture survival/ seed yield	% stock out/stock in; kg or t product/seed no	Limited correlation with most GHG performance, but indirect measure of system/management efficiency	May be more linked for unfed systems with high GHG seed supply
Fish in/out ratios	t fish in food/t product	Where fish input is major GHG factor may be a strong determinant, otherwise a general system efficiency measure	GHG levels would also depend on other food components – eg soybean
Aquaculture water use	m3/t produced	Indirect as more intensive systems usually have higher water use; more direct links if water exchange and/or treatment a major energy use	Recycle systems may have high GHG levels but low water use; reverse for seaweed, mollusc culture
Process yield	t product/t material	Comparative GHG generally lower if yield increases, but not main definer	Varies widely with source; may also be by-products
Process energy use	kWh/tonne product	May be a strong correlator for GHG but also depends on raw materials	May be more complex links with cooling energy and CFCs
Process water use	m3/tonne product	Not usually a primary definer, but could be more important if water supply/treatment a key energy use	Wastes in water stream could be important GHG contributors

Labour productivity/ value added	t output/FTE labour, value added/FTE	May be more relevant for ratios of social benefit/GHGs and tradeoffs concerned; a general link with system intensity and higher GHGs	Wide variation across sector and within sub-sectors.

Further developments/application of performance indicators

As shown in Table 3, linkages with other sectorally relevant performance indicators vary in their strength, though energy and feed use measures may be relatively good proxies for GHG characteristics in the absence of more specific data. In such cases, it might be feasible to consider simple multipliers, eg if it were established that fuel use or costs and the related GHG outputs represented an approximately constant percentage of total costs or GHGs for a specific subsector, total GHG levels could be extrapolated from fuel-based GHG outputs. However, a range of case examples would need to be developed, and be subject to ongoing adjustment to reflect changing conditions and performance benchmarks.

Information and data exchange platforms

Current and emerging concepts for information and data exchange platforms would need to be developed to ensure that GHG-related metrics were set out and applied across a range of production systems, validated and updated, with suitable confidence levels. Ready access to these to allow producers to enter further data and derive benchmarked performance characteristics would also be critical; in ensuring the effectiveness of GHG management.

Potential costs and benefits to the sector

Whether or not simpler indicators can be used as proxies, defining and recording GHG performance within and across the sector will demand a range of resources and will place costs on those engaged in production, marketing and consumption. This in turn may yield benefits of establishing more reliable GHG features for the sector, providing a basis for comparative review, and enabling a strategic approach for sectoral GHG reduction to be established. An outline of the costs and benefits to the sector and to its related stakeholders would be valuable to develop.

A staged approach to development and use

A staged approach to development and implementation of GHG measurement may be required– built initially around simple core cases, typically where data is relatively accessible and commercial or other interests are sufficiently strong. It would then be appropriate to identify technical areas of uncertainty/poor resolution/potential conflict, and through resolving these, build an increasing portfolio. The potential role of FAO and other support, knowledge and development agencies would also be critical, in developing sound and verifiable data, extending guidance to users and interacting with other stakeholders inside and beyond the sector to place sectoral GHGs and their reduction strategies within an effective policy framework.

Conclusions

The development and application of GHG performance matrices in the fishery sector is an important feature of its strategic evolution within an increasingly competitive resource context. It is necessary also to have a clear perspective of these and to recognise the potential trade-offs between specific accuracy and wider, simpler applicability.

It is also important to recognise a range of functions for the definition and use of GHG performance – whether for national policy, trade and competition, or consumer information/choice, and ensure there is an adequate level of continuity and coherence across these.

Ideally, a more extensive GHG strategy would commence with robust and well-linked approaches based on clear and sound principles, with the means to define the significance of boundary and allocation choices and relative sensitivity of proposed GHG measurement results to these.

It will be necessary to develop effective data compilation and exchange systems, with wide access – possibly tiered according to user group and intended aims, supporting the potential for routine meta-analysis of compiled observations, and the means to update and develop existing data assemblies, to meet changing understanding of key relationships. It would also be necessary to develop guidelines for application and interpretation.

References

Aalde, H., Gonzalez, P., Gytarsky, M., Krug, T., Kurz, W.A., Lasco, R.D., Martino, D.L., McConkey, B.G., Ogle, S., Paustian, K., Raison, J., Ravindranath, N.H., Schoene, D., Smith, P., Somogyi, Z., van Amstel, A. & Verchot, L. 2006. Chapter 2: Generic methodologies applicable to multiple land-use categories. *In*: *IPCC guidelines for national greenhouse gas inventories. Agriculture, forestry and other land use*, vol 4. Geneva, Switzerland, Intergovernmental Panel on Climate Change.

ACF (Australian Conservation Foundation). 2007. Consuming Australia: main findings, based on data collected and analysed by the Centre for Integrated Sustainability Analysis at the University of Sydney, 2007. (available at www.acfonline.org.au).

de Boer, J.M., Cederberg, C., Eady, S., Gollnow, S., Kristensen, T., Macleod, M., Meul, M., Nemecek, T, Phong, L.T., Thoma, G., van der Werf, H.M.G., Williams, A.G. & Zonderland-Thomassen, M.A. 2011. Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment. *Current Opinion in Environmental Sustainability*, 3: 423–431.

DECC (Department of Energy and Climate Change). 2009. *Carbon valuation in UK policy appraisal: a revised approach*. London, Climate Change Economics, Department of Energy and Climate Change.

EIPRO (Environmental impact of products). 2006. *Analysis of the life cycle environmental impacts related to the total final consumption of the EU 25*. European Commission Technical Report EUR 22284 EN, May 2006.

FAO. (2012, in press). *Fuel and energy use in the fisheries sector*. FAO Fisheries and Aquaculture Circular. Rome.

Garnett, T. 2008. *Cooking up a storm: food, greenhouse gas emissions and our changing climate*. UK, Food Climate Research Network, Centre for Environmental Strategy, University of Surrey.

Guinée, J.B. & Heijungs, R. 2007. Calculating the influence of allocation scenarios in fossil fuel chains. *Int. J. LCA.*, 12(3): 173–180.

Guinée, J.B., Heijungs, R. & Huppes, G. 2004. Economic allocation: examples and derived decision tree. *Int. J. LCA.*, 9(1): 23–33.

Henriksson, P.J.G, Guinée, J.B., Kleijn, R. & de Snoo, G.R. 2011. Life cycle assessment of aquaculture systems—a review of methodologies. *Int. J. Life Cycle Assess.*, [online]. DOI 10.1007/s11367-011-0369-4.

Hospido, A., Davis, J., Berlin, J. & Sonesson, U. 2010. A review of methodological issues affecting LCA of novel food products. *Int. J. Life Cycle Assess.*, 15: 44–52.

IPCC. 2007. *IPCC 2007, Fourth Assessment Report*. 2007_4AR_Changes in atmospheric constituents and in radiative forcing_IPCC.pdf" P212-213 .www document.

ISO. 2006a. *ISO 14040. Environmental management — Life cycle assessment— Principles and framework.* Second edition, 2006-07-01. Geneva, Switzerland.

ISO. 2006b. *ISO 14044. Environmental management — Life cycle assessment — Requirements and guidelines.* First edition, 2006-07-01. Geneva, Switzerland.

JRC-IES. 2007. *Carbon footprint—what it is and how to measure it*. European Platform on Life Cycle Assessment. European Commission — Joint Research Centre, Institute for Environment and Sustainability; Ispra. (also available at http://lca.jrc.ec.europa.eu/Carbon_footprint.pdf).

Kim, N & Neff, R. 2009. Measurement and communication of greenhouse gas emissions from U.S. food consumption via carbon calculators. *Ecological Economics*, 69: 186–196.

Lafoley, D.d'A. & Grimsditch, G. 2009. *The management of natural coastal carbon sinks*. Gland, Switzerland, IUCN.

Mcleod, E., Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Lovelock, C.E., Schlesinger, W.H. & Silliman, B.R. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front. Ecol. Environ*., 9(10): 552–560 [online]. doi:10.1890/110004

PAS2050. 2008a. *PAS 2050:2008 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (October 2008)*. British Standards Institute (BSI), Department for Environment, Food and Rural Affairs (Defra, UK) and the Carbon Trust (UK). (also available at www.bsigroup.com/en/Standards-and-Publications/Industry-Sectors/Energy/PAS-2050/).

PAS2050. 2008b. *Guide to PAS 2050: How to assess the carbon footprint of goods and services (October 2008)*. British Standards Institute (BSI), Department for Environment, Food and Rural Affairs (Defra, UK) and the Carbon Trust (UK). (also available at www.bsigroup.com/en/Standards-and-Publications/Industry-Sectors/Energy/PAS-2050/).

Pathak, H., Jain, N., Bhatia, A., Patel, J. & Aggarwal, P.K. 2010. Carbon footprints of Indian food items. *Agriculture, Ecosystems and Environment*, 139: 66–73.

Poseidon. 2011. *Lifecycle analysis and greenhouse gas emissions methods in seafood production systems*. Background paper for FAO Expert Workshop on GHG and LCA methodologies in the fisheries sector.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. & Miller, H.L., eds. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, and New York, USA, Cambridge University Press.

UK Foresight. 2011. *Global food and farming futures review*.

UNEP. 2011. HFCs: a critical link in protecting climate and the ozone layer. United Nations Environment Programme. 36 pp. (also available at www.unep.org/dewa/Portals/67/pdf/HFC_report.pdf).

Typologies for GHG framework and strategy for the aquatic food sector
Outline concept/discussion paper. J.F. Muir

Introduction

The needs for GHG (greenhouse gas) assessment in the fisheries sector, and the scope for doing so are becoming increasingly significant issues in sectoral policy. Key issues are outlined in associated reviews (Poseidon 2011, Muir 2012), recognising both the market and consumer led concern for responsible sourcing and the increasing importance given to national carbon accounting and the shaping of policy across and between sectors to realise mitigation targets. Whether or not the company or activity-level assessment of GHG emissions can be fully integrated with strategic whole-sector assessments, the need to establish, collate and connect data is a common concern. The fisheries sector is characterised by a wide diversity of production systems and supply chains, and consequently there is a significant challenge in building GHG-related data effectively and economically to create a sound sectoral perspective. The aim of this paper is to consider the extent to which simplifying typologies – various forms of subsectoral categories – could usefully be defined and developed within a broad framework for GHG assessment for the sector, and could help to meet its various needs.

Key objectives/characteristics

A typology is a system of organising diverse forms of generally collected but variously dissimilar classes of phenomena, objects or entities into recognisably functional groups which have more common elements within each group than between them. These can then be used for within-group or between-group comparisons, for simplifying large and diverse sets into smaller numbers, for exploring trends within and across groups, and for scaling up or generalising from samples within groups to give better levels of confidence about the values associated with the total population. This last area is one of particular significance for an issue such as GHG assessment, where complete census data (ie derived from the whole population) is unlikely to be available, and limited by time and cost, but where reasonably sound and representative information is needed relatively quickly to enable policies to be formulated and actions to be taken.

Typologies are commonly based on salient features – eg size, behaviour, location, on subjective judgement and/or historical convention, or may be derived from statistical techniques such as correspondence analyses, which identify how and with what characteristics various examples can be grouped together. Given that in an economic sector such as fisheries there are numerous identifying characteristics, whether based on location, stocks, capture/production methods, social or economic groupings, markets, product groupings or other factors, typologies could be set out across a range of factors. However, this could very quickly lead to the generation of multiple typologies with very little coherent structure, confusing selection criteria and very limited potential to generate more effective meaning. To develop a practical approach therefore, a number of objectives are proposed:

- While recognising global diversity of the sector, to identify clusters of similar practice – for example, fishing or aquaculture method, species focus, specific markets and products; system and component cases – potentially capturing or connecting to a broad enough cross-section of the sector as a whole, and as far as possible avoiding the omission of any part of the sector having a distinct identity and sufficiently significant presence.
- Where possible, to identify areas/subsectors where strong data sets are easily available and/or can potentially be extended – to provide an initial base from which broader information, possibly in less defined categories, can be developed.
- If possible within these areas, to identify options or specific cases with strong representative power, covering a good spread of practice – possibly also to define how characteristic they are of that grouping, potentially described by the range around mean/median values.
- To specify where comparative features between different groups can be usefully set out and used where possible to support a larger framework of understanding, eg scaling up to the whole sector. This would include issues such as total ranges of values for key characteristics, relative importance of key groups, links with other features/characteristics).

- In connection with these, to provide adequate geographical, political, economic and resource spread, with examples linking if possible with common category selections for other purposes – eg regional examples of specific types of fishing or aquaculture.
- To provide or develop a range of cases which are accessible and explainable for a range of stakeholders, and in which collaborative approaches can be developed for building and extending data and analyses. Here, typologies should be recognisable by local users so they can classify their systems and/or practices, and obtain/develop data accordingly.
- Be cost-effective to develop and sustainable to operate, whether through specific studies or surveys, or through collaborative developments.

Clearly, not all of these objectives can necessarily be met simultaneously; rather the practical aim is to set out typologies which are simple and accessible enough, usually trading off high levels of detail to create smaller numbers of simpler categories, but with each category easily recognisable and capable of connecting with accessible and testable data.

Possible approaches

Approaches by which an effective sector typology could be developed would include:

- Developing meta-analyses of existing sectoral systems/species groups/products for which GHG and related data exists, to explore the spread of GHG and other values, the extent of clustering, and to choose the subsector groups which cover this spread most effectively. This would be the potentially the most statistically robust approach, with greater methodological rigour, but on the basis of current reviews (see eg Poseidon, 2011, Seafish 2012) might require substantially more data and case examples to create. The use of different LCA (lifecycle analysis) approaches may also make it difficult to standardise GHG values sufficiently to create valid clusters. There is also a risk that the categories so developed (ie with best statistical correlations) would be less intuitively connected with practical classifications, and more difficult to group together operationally – eg for further data collection or for developing industry responses.
- Use existing, commonly recognisable sub-sector definitions/typologies (eg fleet/gear types, fishing scale, culture species or system types, market or product groups) and add selected GHG metrics to each of these. Thus for example average and range values could be determined for GHG outputs per vessel in defined type/size categories, per tonne landed catch, per unit of aquaculture system area/volume, per tonne of aquaculture feed used, per tonne culture product, per tonne or kg of processed product for various process categories, per kg of marketed product at retail level. Distinctions could also be made for each to define whether GHG production related simply to the input-output process, or was based on a more widely specified LCA (life-cycle analysis) approach. This approach has the advantage of being more systematic with respect to categories, and potentially linking in with other sets of criteria for which data is commonly collected – eg technical or economic values. However, care would be needed to ensure that categories could be sufficiently simplified for widespread use, and that there we not too many competing/cross-over category definitions.
- A further approach, to some extent a hybrid between the first two, would be to set out a typology structure, based as far as possible on data from existing GHG information cases, linked with known and readily definable areas of the fisheries sector, and identify/address specific gaps in coverage which might arise. Thus in capture fisheries, examples of fleet energy consumption, catch levels and economic performance could be relatively easily obtained for N European examples, based approximately on species/gear categories (FAO, 2012). In aquaculture, much more data currently exists for marine cage-based salmon aquaculture in N Europe or N America, with small numbers of studies on highly traded species such as shrimp, tilapia and pangasius catfish. Here the typology structures can be built around these better documented cases and extended further as needed. While this has a great merit of simplicity and could give a relatively accurate picture of highly recognisable parts of the sector, the relative lack of a systematic structure could create limitations in extrapolating to less well defined areas.
- A more extreme example of this approach would be to take specific examples or cases, without a necessary requirement for a typology, and extend as and where needed to explore specific

aspects/dynamics within those examples. This could be used for addressing more specific issues of a national sector, or exploring different production options for an aquaculture system, for example the alternatives to sea cage salmon rearing. This approach could also be applied if it were known, for example that certain kinds of system were likely to be more critical for GHG implications than others, or were more important for other policy objectives (eg reducing bycatch. Here, if applied at all, typologies are defined at the sub-sectoral level – eg local vessel size categories, net pens, pumped or recycle systems, filleting lines etc. This can give relatively direct and simple comparisons but may be limited in application outside the immediate field of enquiry.

Outline typology and measurement objectives

There could be cases for adopting any of the above typology approaches, though in practice, much is likely to be defined by the available data for the sector, how it is structured, and how easily existing groupings of categories, perhaps defined for a range of different purposes, can be linked together. A starting typology for existing data and current studies may simply be established on the basis of the complexity of the methodology used. With a range of life-cycle analysis (LCA) approaches and coverage levels (ie from simplified assessments focusing only on significant features, to more complex, detailed and inclusive analyses of every possible life-cycle component and input), an initial typology might therefore be:

- Primary assessment systems, using simple indicators such as fuel and energy use (fish capture, processing and distribution) and feed/fertiliser use (aquaculture) linked with output and yield levels to produce generic sectoral information, potentially suitable for sub-sector, national or international level assessments, relatively easily and simply updatable based on standard industry data. This would be most immediately suitable for generic cross-sector comparisons, for national level GHG accounting, for trend description, and for initial scoping analyses to identify those sectoral areas for which more detailed assessment might be justified. Measurement objectives here are simplicity, rationality, use of existing data sources, and plausibility for explanatory and comparative uses.
- Intermediate assessment systems, using more detailed indicator mixes to provide more specific information and more accurate values of GHG characteristics; as above linked with output and yield levels to produce more specific information, typically by production subsector or other typology definition. Here the indicators could be selected by applying a simple cut-off, eg those factors potentially providing more than 5% of total GHG amounts for the specific area of assessment. These would be useful for more finely graded comparative assessments, and could be used for many industry and market-based assessments but depending on the indicators used, may require more specific studies to generate data of adequate quality. If appropriate, several intermediate levels could be defined, based on the detail of the indicators used. Measurement objectives would be based on the tradeoff between simplicity/data availability and the greater explanatory and explorative power of using more detailed data.
- Complex assessment systems, would use a wide array of inputs to develop highly precise measures of GHG values, potentially relating these to very specific conditions of system and operating characteristics, and defining much more specifically the significance of particular factors and their potential for changing overall performance. These would be relevant for methodology research, for specific and detailed industry and market-based analyses, and could also act as a quality control mechanism for simpler approaches, ensuring that the choices for simplification and the estimate values used were appropriate and sufficiently accurate. However, the complexity of these assessments and the need for carefully measured multiple source data would normally require specially commissioned studies. Here, measurement objectives would relate to the added quality/explanation to be gained for more detailed and methodology-driven areas of enquiry.

This assessment based typology is broadly similar in concept to the IPCC Tier system for assessment (Poseidon, 2011), but can be tailored specifically for the fisheries sector. It can also be seen to constitute a functional sector assessment framework, where by applying principles of economy (ie defining and using only what is necessary and sufficient), a default level of primary assessment is used wherever possible, moving into more detailed levels only where inaccuracies are suspected, definition is inadequate or new conditions require further analysis.

A more specific typology/categorisation within the sector can be based on the component position within the supply and value chain – as opposed for example to grouping by factors such as size or type of enterprise, degree of capitalisation, fuel price regime, national or regional location, or average distance to market. Some of the key typology and measurement objectives are outlined below for the common fisheries sub-sectors.

Capture fisheries production; for energy and GHGs, classic descriptors of vessel and gear types (eg active/passive gear, trawl, dredge, seine, gillnet, longline, traps) have shown distinctively different characteristics (see FAO, 2012), but with considerable overlap of values (eg tonne of fuel or CO_2e per tonne of output) across categories, depending on local vessel and gear characteristics, catch levels, fishing and market conditions. These deficiencies may be balanced however by the use of existing classifications in collecting data, and the potential to cross-correlate with other data areas. Attention can also be given to those subsectors representing the largest share of national and global catch/value and GHG output, potentially producing a ‘supply curve’ of production and cumulative GHG, identifying areas where reductions would have least supply/value impact. Further exploration through meta-analysis could be used to highlight more accurately the factors influencing GHG values within each category. Areas such as particulate ‘black’ carbon are also becoming increasingly recognised for GHG potential and could add significantly to current fuel use based estimates, but will need to be further explored. Links between GHG performance and vessel size are likely to be less important than those associated with access to fishing and catching performance. Given that fuel is a relatively high proportion of operating costs, GHG performance is also likely to be connected with profitability, though the influence of fuel subsidies on fishing activity and vessel returns may also be important. Measurement objectives would include where needed the development of reliable inventories of vessel/gear types, setting out and assessment of primary and secondary influencing factors for GHG output, data access and simplicity of measurement – options for industry reporting, monitoring and data quality issues, and ease of developing reliable and trustworthy outputs.

- Aquaculture production; in the current state of knowledge, feed is considered to be the primary determinant of GHG output, with fertilisers a secondary input, and hence classifications could be made based on feed/fertiliser use levels, using traditional definitions of extensive (untreated or partially fertilised), semi-intensive (fertilised and/or partially fed) and intensive (completely fed). This has potential advantages in connecting with generally known systems in most areas where aquaculture is carried out, though they cover a wide range of practices. However, feed raw materials vary very widely in potential GHG impacts, formulations vary widely across locations, and can be changed very quickly by producers in response to availability and price. Furthermore, depending on the system, CH_4 and N_2O respectively associated with sediments and soils, and with nitrogen budgets in soils and water could also be important. Though also related to intensifying carbon and nitrogen inputs (hence feed and fertiliser related) in some systems these may outweigh feed-related CO2 emissions. However, more research is required to clarify these relationships. Links between GHG performance and system scale may be less important than those associated with site conditions and operating efficiency. As feed is a primary operating cost feature in many aquaculture systems, feed use efficiency, GHG levels and profitability may be correlated to some extent. As with capture fisheries, a ‘supply curve’ of production and cumulative GHG, could also be developed to identify areas where GHG reductions would have least supply/value impact. If feed-linked CO_2 remains the primary GHG signal this would primarily focus on more intensive systems, but if CH_4 and N_2O were found to be more important, choices would be more complex. Also as with capture fisheries, measurement objectives would include the development of suitable system inventories, the assessment of primary and secondary influencing factors for GHG output, data access and simplicity of measurement – options for industry reporting, particularly for smaller scale units, monitoring and data quality issues, and ease of developing reliable and trustworthy outputs.

- Processing; a wide range of processes are applied in the fisheries sector, ranging from simple artisanal drying and smoking to highly controlled production of seafood preparation using high-specification packaging and labelling. To some extent, these can be further classified by process type, eg basic steps such as cleaning, heading, gutting, shelling, skinning, filleting, portioning, mincing, to transformative/preservative actions such as salting, drying, smoking, cooking, canning, freezing, to advanced processes such as meal preparation. In most cases, energy use is the primary determinant of GHG output, but there are wide variations in performance depending on local practice, input variations (species, sourcing, quantity and quality), and on plant and operating efficiency. Issues such as water use and its GHG links may also be important. Scale of enterprise may have an effect where this is associated with recent expansion and efficiency targeting, but may often be associated with overcapacity-related inefficiencies. Attribution issues (ie allocating GHG outputs across a range of products and byproducts) may be common in multipurpose, multispecies and multiproduct units, and some degree of standardisation would be important for cross-comparisons. Here also, meta-analyses would reveal key interconnections between process and GHG output and potentially provide benchmarks for relatively well performing systems, together with indicators for improving performance. This could also be linked with most commonly used methods/supply flows to provide broader estimates across the sector of the overall GHG contribution of this stage of the supply system. Measurement objectives for the sector would include inventories of key types/subsectors, defining workable attribution rules, the setting out and assessment of primary and secondary influencing factors for GHG output, issues of data access and simplicity of measurement (or reliable proxies) – options for industry reporting, particularly where competitively confidential data may be involved, monitoring and data quality issues, and ease of developing reliable and trustworthy outputs which could be used both within industry and for wider application.
- Distribution; a wide range is known to exist for systems of collecting and distributing raw materials to intermediaries and products to retailers, outlets and final consumers. As the most widely traded global food product, fish may travel considerable distances, in a range of product forms and states of perishability. In most cases, GHG outputs are directly related to fuel use and to energy use in handling and cold/freezer storage, and can be related to delivered product quantities. Broadly defined, the most perishable fresh product requires the most GHG demanding transport method (eg local trucks, live fish vessels and air transport) cooled and frozen product requires less time-critical and GHG demanding methods, including ship-borne reefer/freezer containers, while more stable forms – dried, smoked, salted products, particularly in artisanal supply chains, requires much less critical and usually lower GHG methods. However, much depends on local transport and handling options and the efficiency in which distribution systems operate, and there is significant variability, even for similar products in the same country or regional supply system. Much also depends on GHG accounting protocols, including for example, the extent to which infrastructure is included, and operating issues such as load allocations, return trip load levels, etc. Given also that modern multiple retailers will often have hundreds of seafood products and product forms from a range of seasonal and non-seasonal sources, locally and globally derived, directly supplied or routed through national distribution systems, the complexity of accounting the GHG inputs associated with distribution can be immense. Nonetheless, by concentrating on major product flows, major product form/distribution options, and on major areas where high GHG burdens can be identified, a broad measure of its significance can be made. As with other sector components, measurement objectives would include the development of effective inventories, the definition and assessment of primary and (to a lesser extent) secondary influencing factors for GHG output, efficiency measures, issues of data access and simplicity of measurement, particularly in more commercially confidential environments, options for industry reporting, monitoring and data quality issues, and ease of developing reliable and trustworthy outputs.

A further typology approach is to classify complete supply systems within the sector by their complexity and spatial features, using a composite of characteristics such as those outlined above.

This would be better revealed once more data emerges across the sector, suitably adjusted for LCA methodology. An example of such an approach would be as follows:

- Simple supply systems – autoconsumption-based, with artisanal fishing or aquaculture primarily focused on supply of food directly to producer and close community, via family rights, barter, etc, with fresh product consumed directly in the household, with very little spoilage loss or waste; with low- input production methods overall GHG per kg produced and per kg consumed is likely to be extremely low. Large numbers of individuals are involved, with local variations in practice, etc and representative data may be difficult to acquire though estimates can potentially be made.
- Locally marketed supply chains – produce from artisanal and (usually) smaller commercial fishery or aquaculture sources moved by basket/bicycle/motorcycle/small van/bus transport to local processors and markets for direct retail and small commercial sales; some localised processing – cleaning, portioning, gutting, drying, smoking, varying levels of ice usage – moderate amounts of spoilage and waste; hand or simple local transport to shops, catering outlets and homes; low to moderate levels of GHG would normally be associated with production but higher inputs may arise from other supply chain stages. These may also have wide variations in conditions and practice, and it may be difficult to define representative data, though local supply chain studies are becoming more common, and it may be feasible to provide estimates of some GHG related values from these.
- Nationally marketed traditional supply chains – traditionally with a number of intermediaries, production usually from commercial fishery or aquaculture suppliers at various scales, from simple hand/bicycle/motorcycle/bus/light truck transport usually short distances to entrepots or intermediate processors from which materials are usually transported by truck to larger market centres with varying degrees of holding/preservation facilities, thereafter further breaking of bulk to small vehicles, carts, etc in urban centres, and in larger quantities to supermarkets and food service outlets; varying degrees of supply chain shortening as major retail outlets simplify supply options, though distribution efficiency may vary. Range of GHG levels may be observed- these tend to be higher due to processing and distribution inputs.
- Highly transformed national/regional product systems – typical of more modern supply systems, with raw materials from fishery or aquaculture sources increasingly bypassing traditional market centres, drawn into major corporate processing and distribution systems, commonly associated with significant value addition, technical innovation, use of byproducts, much greater levels of packaging, sophisticated distribution logistics, increasingly across national boundaries. Though GHG levels related to value addition and distribution may be higher than those in simpler supply chains, scope for waste reduction and improved system efficiencies may compensate.
- Simple global supply chains – commonly based on lower value materials, traditionally from high volume fisheries, originally salted, dried or smoked, later canned or frozen, using relatively simple, low energy/GHG transport systems to reach major markets – commonly distributed at destinations via traditional routes. Catching methods often low-GHG linked (eg purse seine, gill nets, longlines), and relatively low supply chain additions; total varies widely with transport distances and post-transport distribution characteristics.
- Complex global supply systems – contemporary systems commonly supplying major higher value centres of demand, with multiple sourcing of wide ranges of product and highly mobile options for raw material movement, processing, adding value, normally feeding in to major multiple retail or food service outlets with a range of distribution networks prioritising process costs, speed of access, highest quality global products. Some production and process efficiencies but transport and distribution can carry significant GHG burdens; emerging issues of energy prices and GHG reporting likely to shift priorities.

These systems can potentially co-exist within a specific country, fishing sector or aquaculture species/system complex, though some approximations can usually be made of the relative volumes and values of material entering different supply chain systems, hence the overall pattern of GHG characteristics and the likely drivers for change.

Strategies for comparative analysis

The means by which typologies could be used for comparative analysis in the fisheries sector would vary with scope and aims. Primary level comparisons could be drawn with other food sectors or between national fishery sectors, and linked with trend analyses to provide projection estimates for GHG levels in various subsectors to guide policy directions and consumption choice. At more detailed levels, supply chain efficiencies could be explored and options defined for GHG reduction. Potential tradeoffs could be identified between these and other production characteristics, ideally identifying win-win options where reductions also delivered other benefits, whether environmental, economic and/or social. Depending on the extent and quality of data available, multi-component models, regression analyses and other tools can be used to define in more detail various GHG production functions and correlative features. By developing more accurate GHG values per key output level (eg tonnes of raw material, kg or serving of product) and clarifying the correlative factors which determine these, typologies can be used for better estimates of total output and for implications of changes in systems and practices. A number of issues and themes may be relevant, including

- type, scale and/or location of production process, in fisheries or aquaculture;
- aquaculture feed sources, processes, water, soil and sediment management;
- process options, energy sources, efficiencies, product streams, waste recovery;
- management conditions for fisheries, aquaculture resource use, environmental control;
- type, scale and functions of market systems, product flows, wastes;
- transport options – location, type, allocation, use levels, efficiency, logistics.

Cross-sectoral scale-up and synthesis

The simplest approaches for scale-up and synthesis from typology structures are based round sectoral inventories, for example fleet sizes, vessel size and gear categories, aquaculture system types, process and distribution options as outlined above, together with estimates of respective material and product flows through each category. These can be carried out with varying levels of accuracy – commonly moving from initial scoping level estimates to define the most important areas for GHG output and change, through to more detailed fine-tuning of performance features and options. Full inventories may not always be feasible to develop, unless already being assembled for other purposes (eg vessel or producer registration), though typologies can be helpful in defining which areas are likely to be the most important and potentially justifying further specification. Likewise material and product flows may need to be estimated in many instances, and may often vary with seasonal or cyclical changes in supply, market demand and/or economic conditions. Again however, the key characteristics can usually be identified adequately to determine where further information is required.

Conclusions

- Typologies are potentially useful tools for structuring and explaining complex multi-element systems, for setting out similarities and difference between different classes of systems, and for developing relatively robust models allowing data from smaller sample sizes to be scaled up to represent the entire population.
- As such they are potentially valuable for the fisheries sector in permitting assessment of national, industry-wide or global characteristics of GHG outputs and their trends.
- A number of typology systems for GHG outputs can be considered for the fisheries sector, based on existing classifications for other purposes, focused around specific issues, or defined by statistical clustering.
- Formal statistical based approaches are unlikely to be widely usable for typology definition and development given current levels of data but are worth considering for more focused analyses where data can be developed.
- A number of possible examples are provided, based on the level of detail required in the assessment system, and ranging from traditional categories, to supply chain subsystems, to typologies based on characteristics of the whole supply chain.
- Though no final approach is proposed, the options and implications are noted. The purpose of analysis should be a major determinant for typology choice, and in many cases (eg national

assessments, industry comparisons) existing classifications can be used for structuring data, particularly if this facilitates data collection and assembly, and allows GHG data to be correlated with other characteristics.

- These classifications can be modified if it becomes evident that existing typologies do not describe the sector adequately, do not match the reality of its range of features, or do not allow data to be scaled up adequately. If specific typologies are applied within a subsector or national/other context, there should be a process of data and information exchange with other related exercises so that composite approaches can be developed, eg linking typologies from one area to another.

References

FAO. 2012, in press. *Fuel and energy use in the fisheries sector: approaches, inventories and strategic implications*. FAO Fisheries and Aquaculture Circular. Rome.

Muir, J.F. 2012. *An outline of GHG and related performance metrics for the fisheries sector*. Background paper for FAO Expert Workshop on GHG and LCA methodologies in the fisheries sector, 23–26 January 2012, FAO, Rome.

Poseidon. 2011. *Lifecycle analysis and greenhouse gas emissions methods in seafood production systems*. Background paper for FAO Expert Workshop on GHG and LCA methodologies in the fisheries sector, 23–26 January 2012, FAO, Rome.

Seafish. 2012. *Review of life cycle assessment research on products derived from fisheries and aquaculture*. A report for Seafish as part of the collective action to address greenhouse gas emissions in seafood. Edinburgh, UK, SeaFish Industry Authority.

APPENDIX 4

OPENING STATEMENT

by

Árni M. Mathiesen
Assistant Director-General
FAO Fisheries and Aquaculture Department

Distinguished delegates, friends and colleagues:

On behalf of the Director-General of FAO, Mr Graziano da Silva, it gives me much pleasure to welcome you to this Expert workshop on "Greenhouse Gas Emission Strategies and Methods in Seafood".

I have followed closely the preparations for the meeting and I am delighted that FAO has been able to assemble such an impressive group. As you know each Expert here today, in his or her personal capacity, has been chosen because of the unique professional and geographical experience he or she would bring to the Workshop.

Turning to the issues of energy use and food production, the global agricultural and food industry is dependent on energy inputs. Meeting the global food demand of a growing world population over the past century has, at least in part, been achieved by significantly increasing the fossil fuel inputs along the entire agri-food chain, from petroleum fuels for boats and tractors, natural gas to manufacture chemical fertilizers and pesticides, electricity and heat for processing and packaging, liquid fuels for transport, electricity for refrigeration and a range of fuels used for cooking. However, this high dependency of the food system on fossil fuels is now becoming cause for concern.

For the agri-food sector to become 'energy-smart' at both the small family and large corporate scales will require strong and long-term supporting policies and innovative multi-stakeholder institutional arrangements. Examples exist of successful and cost-effective policy instruments and inclusive business schemes that have supported agri-business development throughout the sector. These instruments will need to be significantly scaled up if a cross-sectoral landscape approach is to be achieved at the international level. Enabling policies to ensure full benefits are achieved will require investment in applied research development & deployment of technologies; introducing, sharing and adapting energy-smart technologies; fiscal support mechanisms; capacity building; support services; education and training. A policy environment without allocation of resources for implementation, up-scaling and facilitating the desired smart-energy changes may prove to be unsuccessful.

For the fisheries and aquaculture sector, the use of fossil fuels has significantly helped feed the world over the last few decades, mainly through their contribution to increased mechanization of fishing vessels, processing and transport to markets. Future increases in productivity may be constrained by the limited future availability of cheap fossil fuel supplies. However, most fishing techniques in use today have their origin in an era when fisheries resources were abundant, energy costs were dramatically lower than current levels, and when less attention was paid to operating efficiency and negative impacts of fishing on marine and atmospheric ecosystems. Current high energy prices and greater awareness of ecosystem impacts are realities and present major challenges for the viability of fisheries. This may be especially true in developing countries where access to and promotion of energy efficient technologies has been limited.

Distinguished delegates, friends and colleagues: by 2030 it is expected that as a result of continued population and economic growth the global demand for energy will rise by 40%, water use by 40% and food demand by 50%. To add to the challenge, these increasing demands will have to be met in the context of climate change impacts, an already stressed natural resource asset and limited availability of productive sea and landscapes. The magnitude and complexity of the challenge, and the need for urgent action, explains the current importance now being given to the energy-water-food nexus. For fisheries and aquaculture, this “perfect storm” of factors will result in impacts on the aquatic environment at local, national and global levels. Indeed, the global economy will have to make a major transition from business-as-usual to address these challenges. We will have to “do more with less”. To move in that direction, the global agri-food sector will require innovative capacity and action to be taken by all stakeholders regarding agricultural/fisheries practices, technology development, new policies and institutional arrangements at all levels.

At the Twenty-ninth session of the Committee on Fisheries (COFI), FAO reported that Net greenhouse gas (GHG) contributions of fisheries, aquaculture and related supply chain features are poorly studied and the paucity of data on GHG emissions across fisheries and aquaculture supply chains is a key factor constraining the development of strategies to address energy use. FAO also reported that the transition to energy-efficient and low foot print aquatic food production systems would be facilitated through the development of: standardized methodologies for energy and emissions calculations throughout the food chain; collection of data within this framework; and (iii) the development of policy and technologies associated with energy use and greenhouse gas emission reductions. Further, the 29th session of COFI recommended that FAO should provide Members with information on possible fishing industry contributions to climate change, and on ways to reduce the sector’s reliance on, and consumption of, fossil fuels, respecting the principles embodied within the United Nations Framework Convention on Climate Change (UNFCCC). And it is in this context that this expert workshop has been developed.

The main objective of this Expert Workshop is to seek practical performance metrics in GHG assessment for policy guidance, industry and producer use, consumer information and purchase choices. These must be applicable across the seafood sector and its supply chain, accessible to a range of stakeholders, and consistent with wider methodologies, standards and indicators.

Addressing the food/energy/climate nexus is crucial, complex and challenging. It therefore justifies significant and sustained efforts at the local, national and international governance levels.

Last but not least, I would like to acknowledge the financial support provided by the Government of Norway, FAO’s regular programme, Seafish, researchers at Dalhousie University, and others for this workshop.

I wish you well for a fruitful and successful meeting and hope that your time in Rome will provide you with an opportunity to see this beautiful city.

Thank you very much.

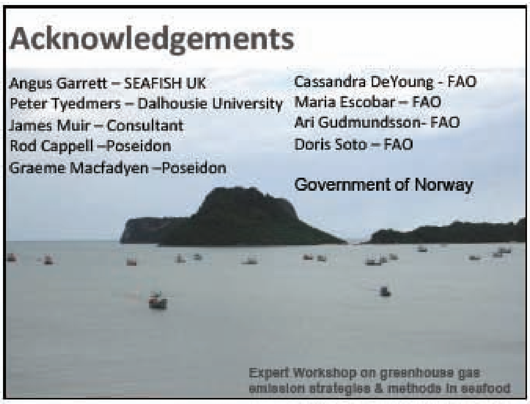
APPENDIX 5

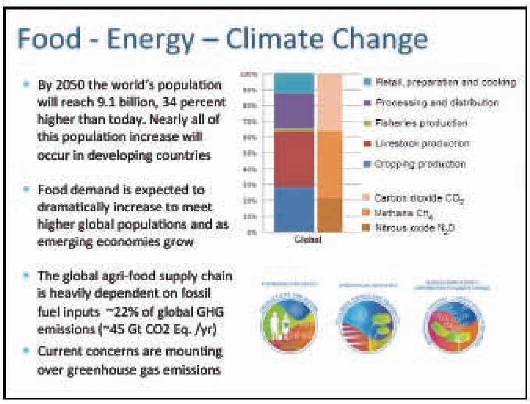
PRESENTATIONS MADE DURING THE WORKSHOP

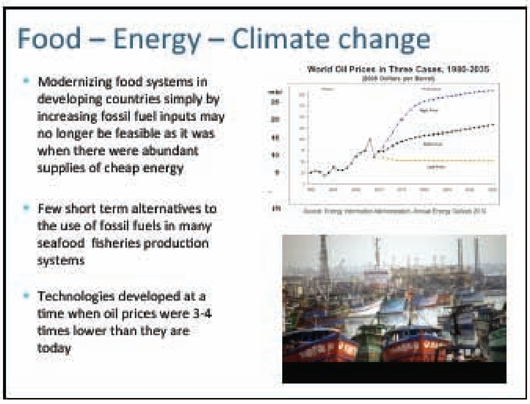
The following presentations were made during the Workshop, and are provided in this appendix

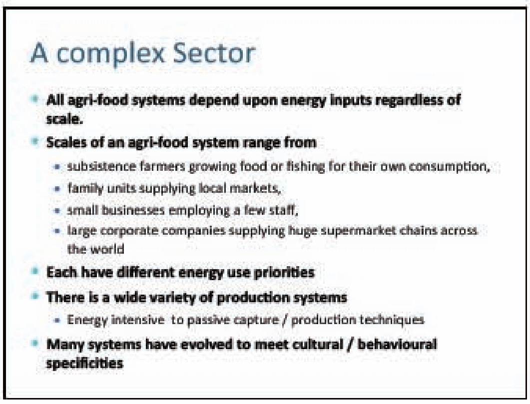
Presenter	**Presentation title**
Francis Chopin, FAO	Energy Smart Food Systems: Reducing our carbon footprint. What role for fisheries and aquaculture?
Angus Garrett, Seafish	Collective Action on GHG emissions in seafood systems
Peter Tyedmers, Dalhousie University	GHG Emissions & Seafood: context, patterns and challenges
Rod Cappell, Poseidon	Methods of GHG emissions assessment in fisheries and aquaculture
James Muir, University of Stirling	Performance Metrics in GHG emissions assessment in Seafood
Brian Such, BSI	The Use of Standards in Carbon Management
Michael Macleod, FAO	Analysing Livestock's Environmental Performance
Marc Taconet, FAO	The Fishery Resources Monitoring System (FIRMS)

Energy Smart Food Systems: Reducing our carbon footprint. What role for fisheries and aquaculture?
F. Chopin





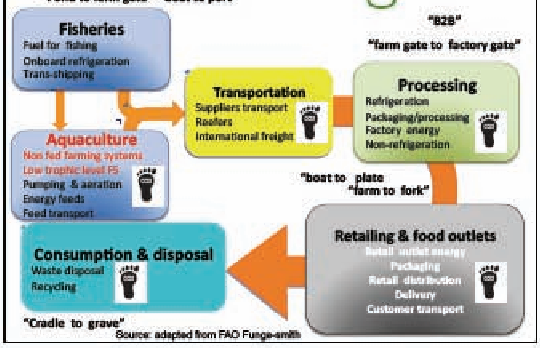




Aquaculture - fisheries and Carbon emissions

- **GHG contribution of fisheries, aquaculture and related supply chain features are poorly studied**
  - Considered relatively small in global terms
  - Fuel use alone in global capture fisheries generates 90-130 million tonnes of CO_2
- **Estimates vary**
  - cover different parts of supply chain
  - may not be directly comparable to other sectors

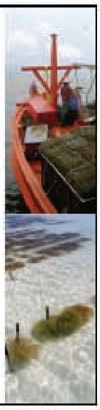
Where can we reduce emissions?



Source: adapted from FAO Funge-smith

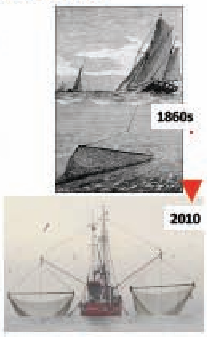
Need holistic view of GHG in production systems

- **A supply chain approach can identify hotspots for GHG emissions**
- **Likely that fishing vessels are the largest GHG emitters in the sector**
  - followed by processing plants
- **Aquaculture seems relatively lower than fisheries**
  - main GHG emission from feed production & transport
- **Different transportation methods**
- **Fishing vessels**
  - All vessels not the same GHG emissions



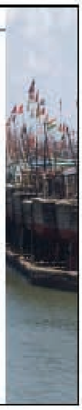
Are practical and realistic changes achievable?

- **Capture fisheries have a challenge to become more fuel efficient**
  - Vessel designs originated pre-motorization, pre-diesel
  - Not designed for fuel efficiency
- **Many capture techniques have their origin when oil was <$20 per barrel**
  - Reluctance to change
  - Costs to upgrade
- **Transition from active to passive fishing not always possible**
  - Design constraints
  - Difficult to assess benefits



Greenhouse gas emission strategies & methods in seafood – Where are we and what road will we take?

- Do we have the appropriate data (range and quality) to enable the development of effective policies and programmes?
- Small-scale fishing and farming is different from large industrial fishing and farming. Are we confident that future policy developments will not favour large-scale systems?
- Data for energy use and related GHG emission factors along the agri-food chain are limited, particularly for Low-GDP countries. Will future GHG policies unfairly impact Low-GDP countries?
- Will standardizing the metrics for measuring GHG emissions in the agri-food chain assist or become a an unnecessary burden?

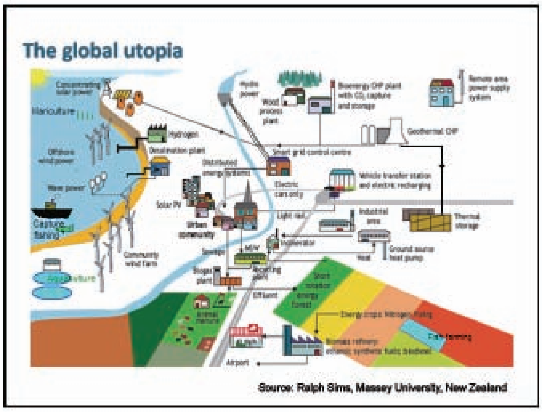


Greening the Economy with Agriculture

Seven draft interim messages from FAO

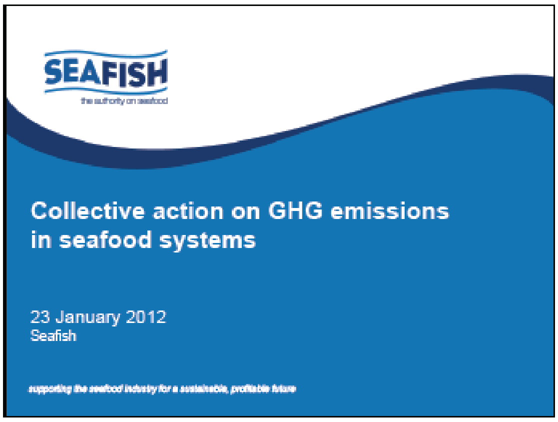
1. There can be no green economy without sustainable growth in agriculture
2. Wise management of natural resources is fundamental for agriculture.
3. Agriculture can ensure sustainable food security and proper nutrition for 9 billion people in 2050
4. Decisions by farmers, livestock keepers, fishers and agribusinesses will determine whether the world succeeds or fails in achieving a green economy
5. Policy reforms are needed to facilitate the transition to sustainable agriculture, build resilience and manage trade-offs
6. Targeted public investment must underpin private investment to realize sustainable agriculture
7. Improved governance is the key

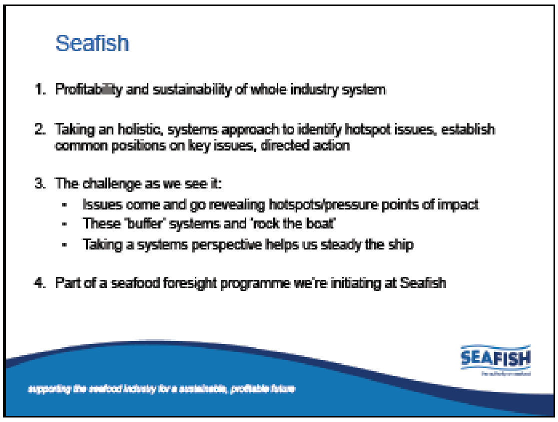
Source: Peter Holmgren FAO

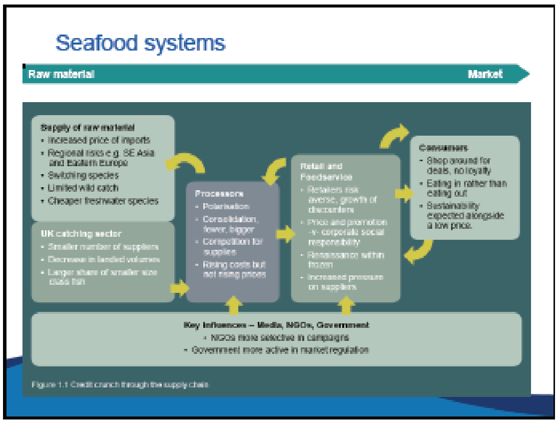

The global utopia
Hydrogen
Desalination plant
Offshore wind power
Wave power
Solar PV
Urban community
Community wind farm
Hydro power
Wood process plant
Bioenergy CHP plant with CO2 capture and storage
Remote area power supply system
Geothermal CHP
Smart grid control centre
Distributed energy systems
Electric cars only
Vehicle transfer station and electric recharging
Light rail
Industrial area
Thermal storage
Incinerator
Ground source heat pump
Heat
Sewage
MSW
Biogas plant
Effluent
Fish farming
Airport
Source: Ralph Sims, Massey University, New Zealand

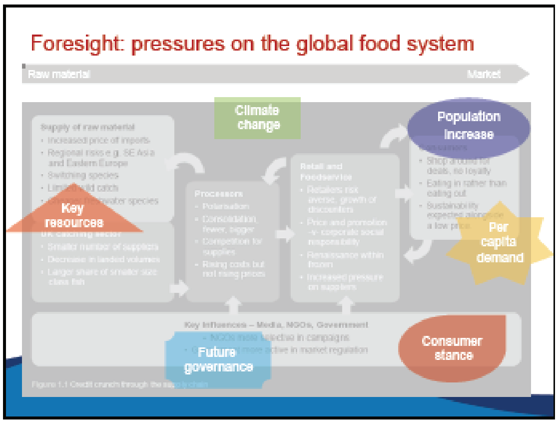
Collective Action on GHG emissions in seafood systems

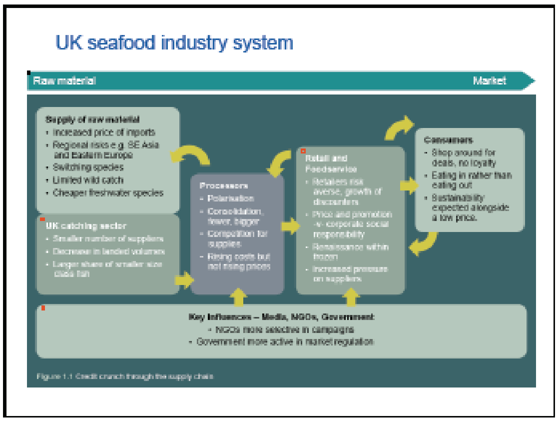
A. Garrett











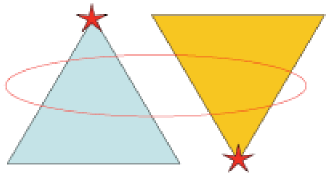
Why look at these issues and GHG emissions in particular?

1. Industry reputation, industry survival
2. Planet in danger of getting warmer, ocean acidification, etc
3. Economic austerity …. we need to act and do so with limited resources
4. But we also have challenges….

…We have a managerial legacy which privileges "information generation and decision-making" over "sense making and shared understanding to guide action"

supporting the seafood industry for a sustainable, profitable future

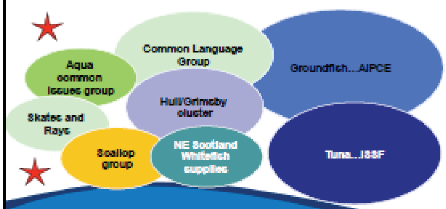
What are the challenges?



supporting the seafood industry for a sustainable, profitable future

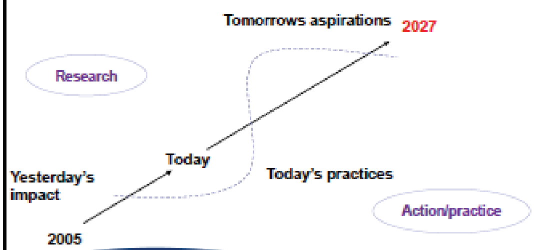
Industry – communities of practice

1. Industry and other stakeholders in the centre of the plate
2. *Overlapping communities and networks…*



supporting the seafood industry for a sustainable, profitable future

A path forward



supporting the seafood industry for a sustainable, profitable future

Industry emissions group – key points

1. Industry should be active in this area, *show where improvement is taking place*
2. Collate existing research and practice:
   - GHG related initiatives – cases and research in train
3. Identify where new research may be required
4. Methodological/standards issues
5. Focus on priority areas

supporting the seafood industry for a sustainable, profitable future

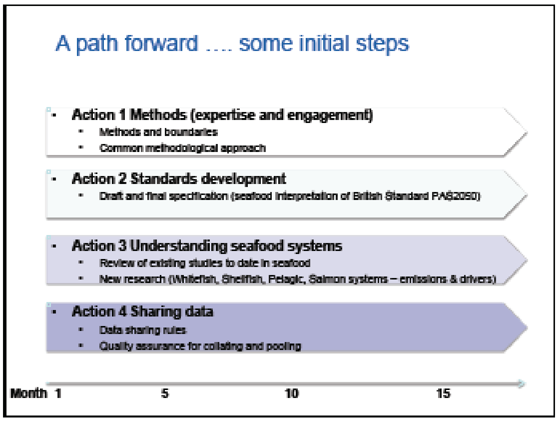
A path forward

What we are looking to achieve…

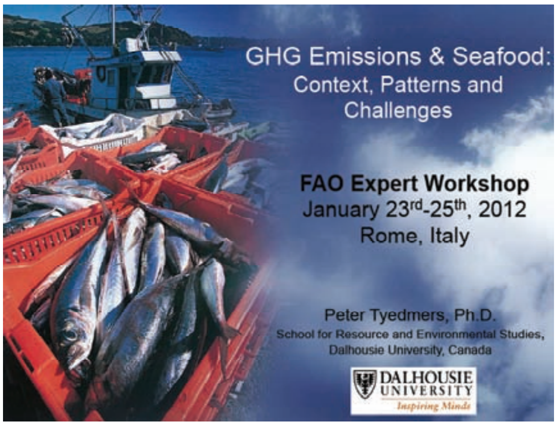
- A long term framework for action (long term issues need long term responses)..

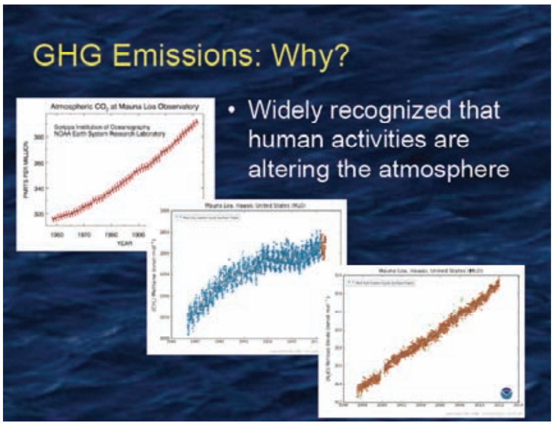
…in order to…."Collectively understand seafood systems; identify hotspots, and change practices to drive down emissions"

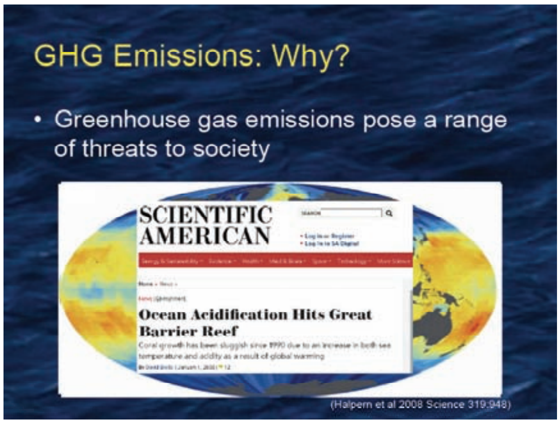
supporting the seafood industry for a sustainable, profitable future


A path forward …. some initial steps
Action 1 Methods (expertise and engagement)
Methods and boundaries
Common methodological approach
Action 2 Standards development
Draft and final specification (seafood interpretation of British Standard PAS2050)
Action 3 Understanding seafood systems
Review of existing studies to date in seafood
New research (Whitefish, Shellfish, Pelagic, Salmon systems – emissions & drivers)
Action 4 Sharing data
Data sharing rules
Quality assurance for collating and pooling
Month 1
5
10
15

GHG Emissions & Seafood, Context, Patterns and Challenges
P. Tyedmers



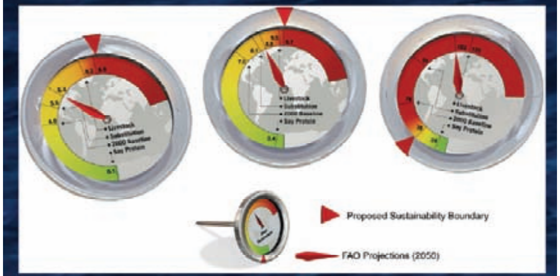




GHG Emissions: Why?

- Mounting pressure to address these challenges across society
  - Estimates indicate that food and beverage sector may account for ~30% of global GHG emissions (production through consumption)
  - A large portion (>50%?) of this results from provision of animal protein from all sources

GHG Emissions: Role of livestock?



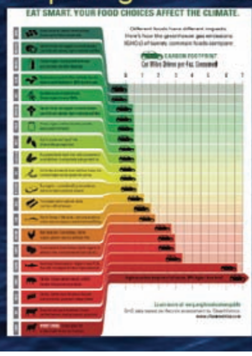
(Pelletier & Tyedmers 2010 PNAS 107(43): 18371)

GHG Emissions: Comparing Sources

Protein source (production modes/locale)	GHG emiss. (tonnes CO_2-e/t)
Beef (feedlot, hybrid, pasture/U.S.)	15 – 19
Swine (conventional, niche/U.S.)	2.5 – 3.3
Poultry (battery/U.S.)	1.7
Farmed trout (flow through/France)	2.8
Farmed seabass (net-pen/Greece)	3.6
Farmed salmon (net-pen/Nor., Can., Chile, UK)	1.8 – 3.3
Farmed tilapia (lake & pond/Indonesia)	1.5 – 2.1
Lobster (trap/Nova Scotia)	4.1
Tuna (purse-seine/Atl., Pac. & Indian ocean)	1.6 – 2.2
Salmon (purse-seine, gillnet, troll/Alaska)	0.2 – 1.7
Herring (purse-seine, trawl/New England)	0.07 – 0.4

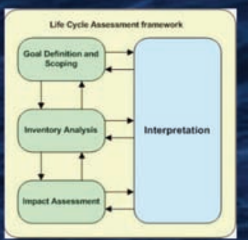
GHG Emissions: Comparing Sources

- Other organizations have started to attempt more direct comparisons between foods (often drawing on existing datasets)
- These efforts leave a lot to be desired



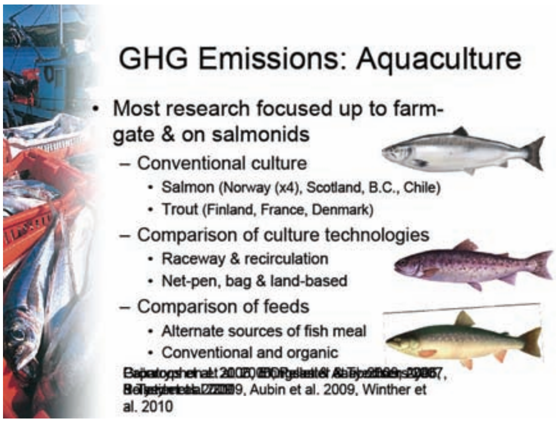
GHG Emissions: How Assessed?

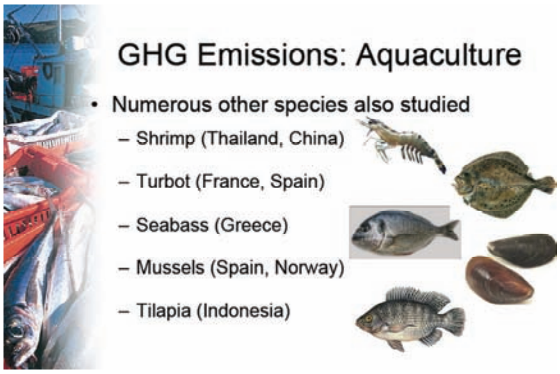
- With some minor exceptions most analyses of GHG emissions of seafood systems have employed some form of life cycle assessment (LCA)
  - mostly process-based
  - some input-output

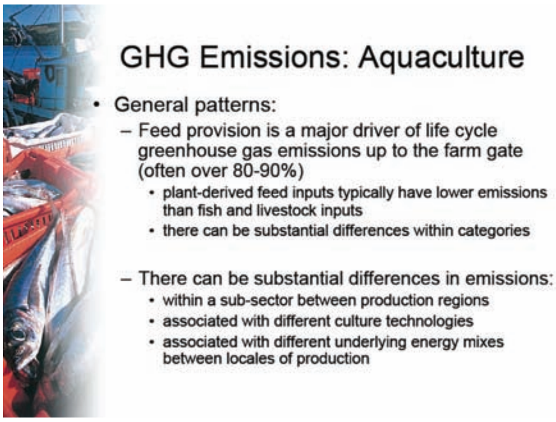


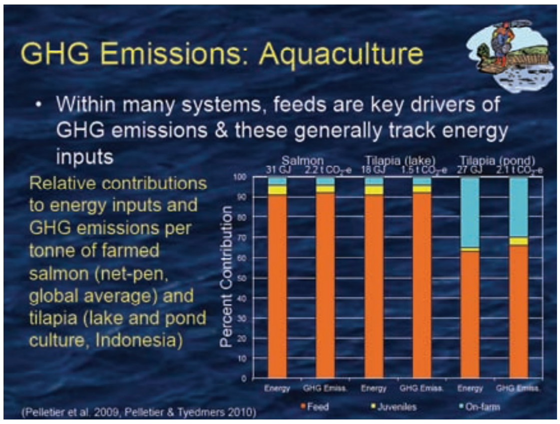
GHG Emissions: Patterns in Seafood

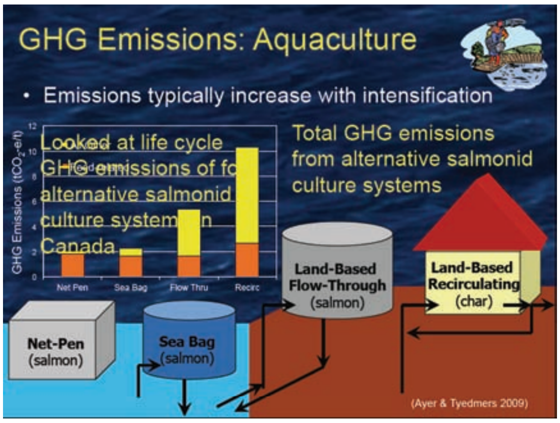
- Let's consider some of what we know about GHG emissions from fisheries and aquaculture from LCA research

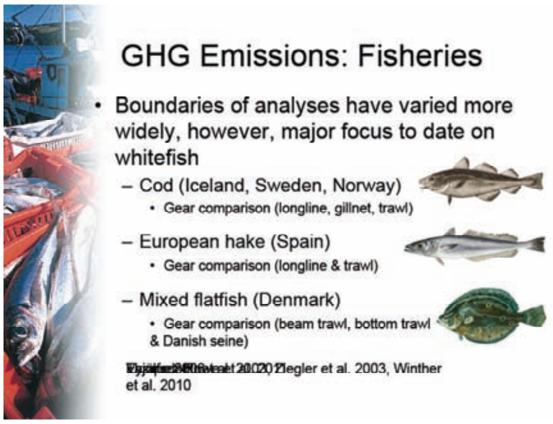

GHG Emissions: Aquaculture
• Most research focused up to farm-gate & on salmonids
– Conventional culture
• Salmon (Norway (x4), Scotland, B.C., Chile)
• Trout (Finland, France, Denmark)
– Comparison of culture technologies
• Raceway & recirculation
• Net-pen, bag & land-based
– Comparison of feeds
• Alternate sources of fish meal
• Conventional and organic
9, Aubin et al. 2009, Winther et al. 2010

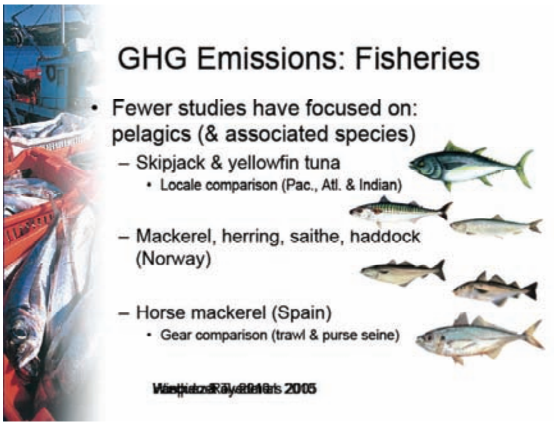

GHG Emissions: Aquaculture
• Numerous other species also studied
– Shrimp (Thailand, China)
– Turbot (France, Spain)
– Seabass (Greece)
– Mussels (Spain, Norway)
– Tilapia (Indonesia)

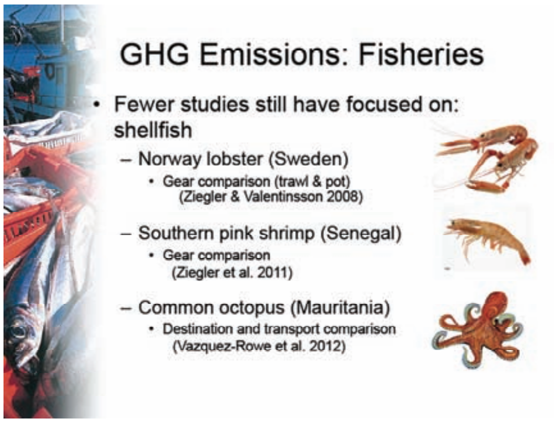

GHG Emissions: Aquaculture
• General patterns:
– Feed provision is a major driver of life cycle greenhouse gas emissions up to the farm gate (often over 80-90%)
• plant-derived feed inputs typically have lower emissions than fish and livestock inputs
• there can be substantial differences within categories
– There can be substantial differences in emissions:
• within a sub-sector between production regions
• associated with different culture technologies
• associated with different underlying energy mixes between locales of production

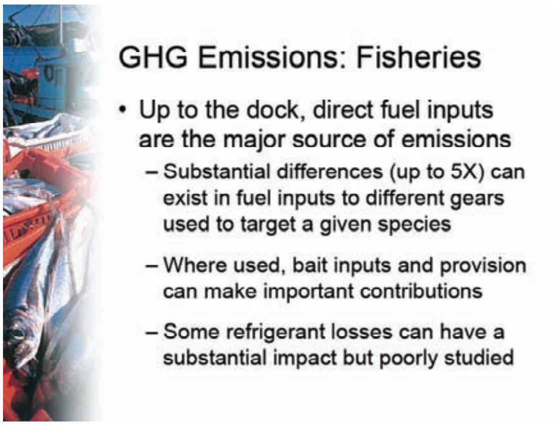

GHG Emissions: Aquaculture
• Within many systems, feeds are key drivers of GHG emissions & these generally track energy inputs
Relative contributions to energy inputs and GHG emissions per tonne of farmed salmon (net-pen, global average) and tilapia (lake and pond culture, Indonesia)
Salmon
Tilapia (lake)
Tilapia (pond)
Percent Contribution
Feed
Juveniles
On-farm
(Pelletier et al. 2009, Pelletier & Tyedmers 2010)

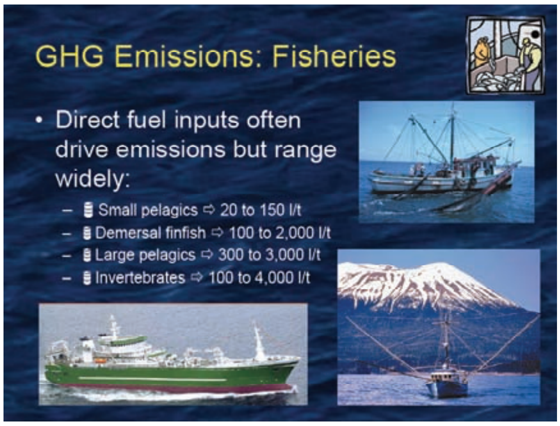

GHG Emissions: Aquaculture
• Emissions typically increase with intensification
Looked at life cycle GHG emissions of fo alternative salmonid culture system n Canada
Total GHG emissions from alternative salmonid culture systems
Net Pen
Sea Bag
Flow Thru
Recirc
Net-Pen (salmon)
Sea Bag (salmon)
Land-Based Flow-Through (salmon)
Land-Based Recirculating (char)
(Ayer & Tyedmers 2009)


GHG Emissions: Fisheries
• Boundaries of analyses have varied more widely, however, major focus to date on whitefish
– Cod (Iceland, Sweden, Norway)
• Gear comparison (longline, gillnet, trawl)
– European hake (Spain)
• Gear comparison (longline & trawl)
– Mixed flatfish (Denmark)
• Gear comparison (beam trawl, bottom trawl & Danish seine)
egler et al. 2003, Winther et al. 2010

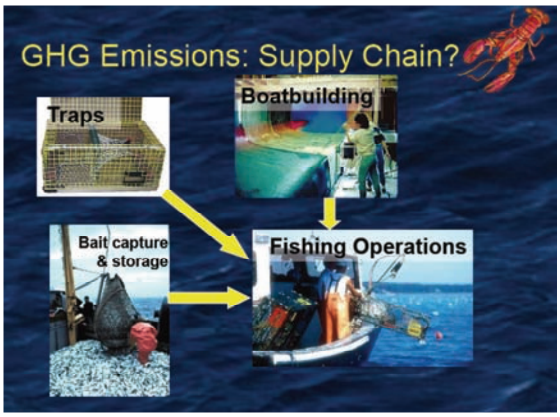

GHG Emissions: Fisheries
• Fewer studies have focused on: pelagics (& associated species)
– Skipjack & yellowfin tuna
• Locale comparison (Pac., Atl. & Indian)
– Mackerel, herring, saithe, haddock (Norway)
– Horse mackerel (Spain)
• Gear comparison (trawl & purse seine)


GHG Emissions: Fisheries
• Fewer studies still have focused on: shellfish
– Norway lobster (Sweden)
• Gear comparison (trawl & pot) (Ziegler & Valentinsson 2008)
– Southern pink shrimp (Senegal)
• Gear comparison (Ziegler et al. 2011)
– Common octopus (Mauritania)
• Destination and transport comparison (Vazquez-Rowe et al. 2012)

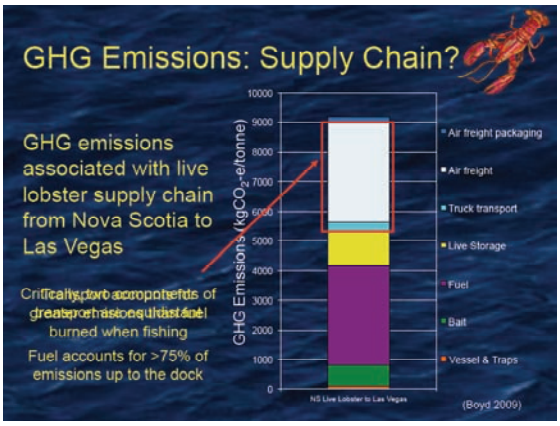

GHG Emissions: Fisheries
• Up to the dock, direct fuel inputs are the major source of emissions
– Substantial differences (up to 5X) can exist in fuel inputs to different gears used to target a given species
– Where used, bait inputs and provision can make important contributions
– Some refrigerant losses can have a substantial impact but poorly studied

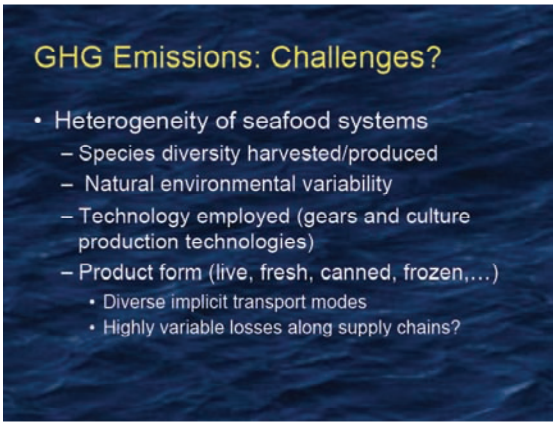

GHG Emissions: Fisheries
• Direct fuel inputs often drive emissions but range widely:
– Small pelagics ⇨ 20 to 150 l/t
– Demersal finfish ⇨ 100 to 2,000 l/t
– Large pelagics ⇨ 300 to 3,000 l/t
– Invertebrates ⇨ 100 to 4,000 l/t

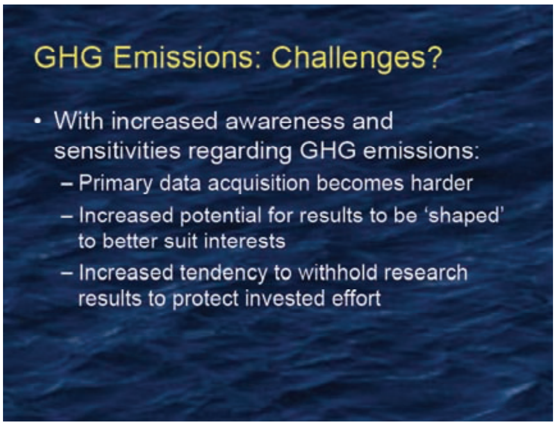

GHG Emissions: Supply Chain?
• Though emissions associated with seafood production are of central importance, other elements of the supply chain can't be overlooked
– consider energy inputs to a luxury seafood supply chain, live Nova Scotia lobster shipped to the U.S.

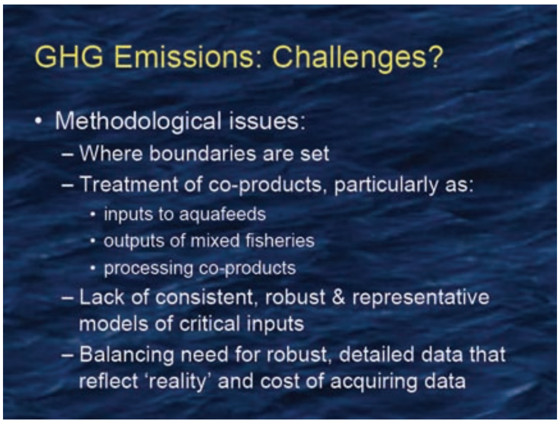

GHG Emissions: Supply Chain?
Traps
Boatbuilding
Bait capture & storage
Fishing Operations


GHG Emissions: Supply Chain?
Fishing Operations
Storage
Delivery
WELCOME
TO Fabulous
LAS VEGAS
NEVADA


GHG Emissions: Supply Chain?
GHG emissions associated with live lobster supply chain from Nova Scotia to Las Vegas
burned when fishing
Fuel accounts for >75% of emissions up to the dock
GHG Emissions (kgCO2-e/tonne)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
NS Live Lobster to Las Vegas
Air freight packaging
Air freight
Truck transport
Live Storage
Fuel
Bait
Vessel & Traps
(Boyd 2009)

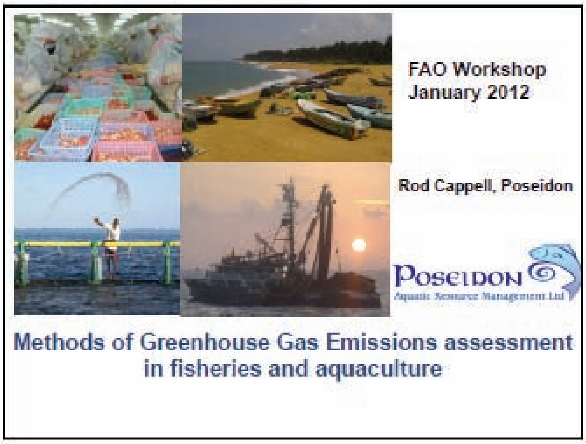

GHG Emissions: Challenges?
• Heterogeneity of seafood systems
– Species diversity harvested/produced
– Natural environmental variability
– Technology employed (gears and culture production technologies)
– Product form (live, fresh, canned, frozen,…)
• Diverse implicit transport modes
• Highly variable losses along supply chains?

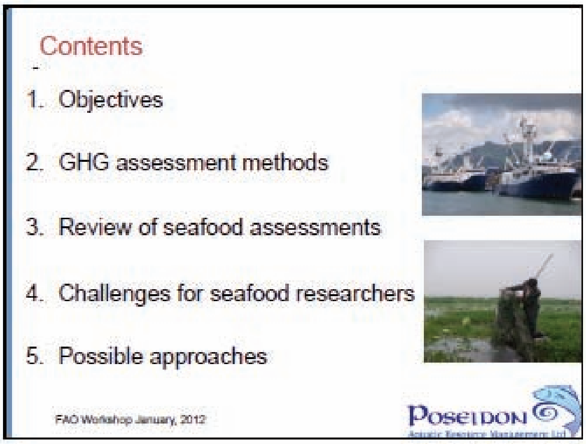

GHG Emissions: Challenges?
• With increased awareness and sensitivities regarding GHG emissions:
– Primary data acquisition becomes harder
– Increased potential for results to be 'shaped' to better suit interests
– Increased tendency to withhold research results to protect invested effort

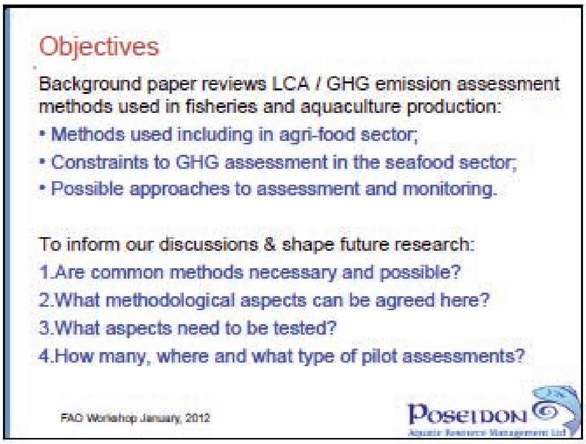

GHG Emissions: Challenges?
• Methodological issues:
– Where boundaries are set
– Treatment of co-products, particularly as:
• inputs to aquafeeds
• outputs of mixed fisheries
• processing co-products
– Lack of consistent, robust & representative models of critical inputs
– Balancing need for robust, detailed data that reflect 'reality' and cost of acquiring data

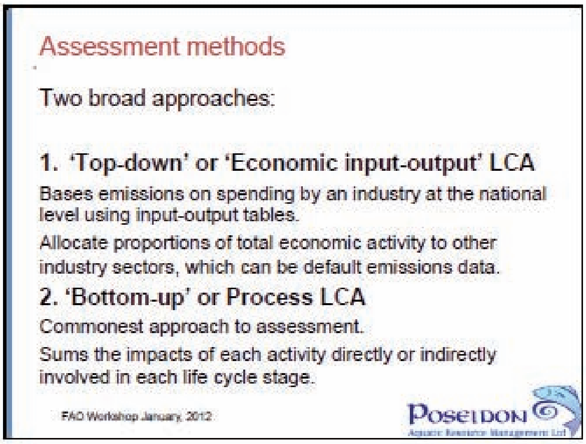

Rest of Our Meeting
• To focus on how and why we're measuring things
– James Muir
and on the methodological challenges associated with doing this work robustly and with rigour
– Rod Cappell
Thank You

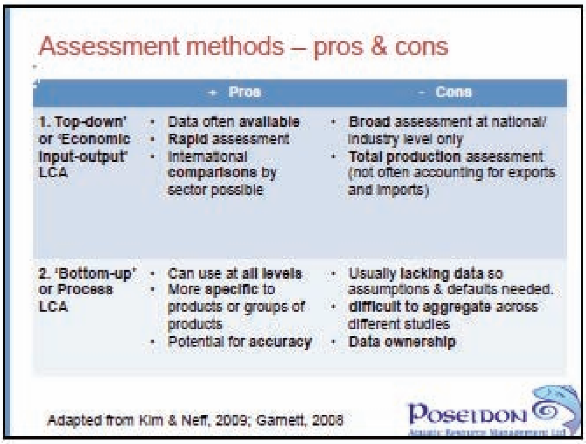
Methods of GHG emissions assessment in fisheries and aquaculture
R. Cappell



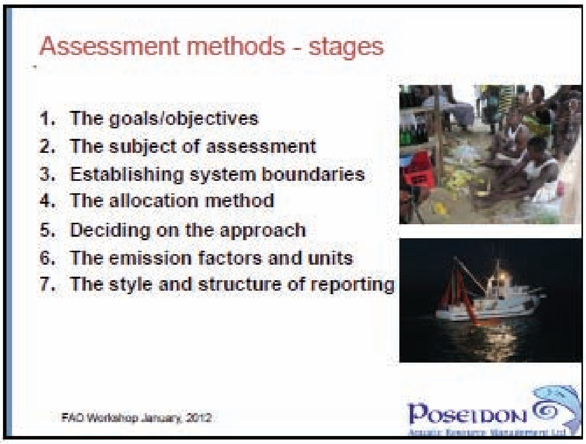








	+ Pros	- Cons
1. 'Top-down' or 'Economic input-output' LCA	• Data often available • Rapid assessment • International comparisons by sector possible	• Broad assessment at national/ industry level only • Total production assessment (not often accounting for exports and imports)
2. 'Bottom-up' or Process LCA	• Can use at all levels • More specific to products or groups of products • Potential for accuracy	• Usually lacking data so assumptions & defaults needed. • difficult to aggregate across different studies • Data ownership



Objectives of Assessments

A company may seek GHG assessment to:

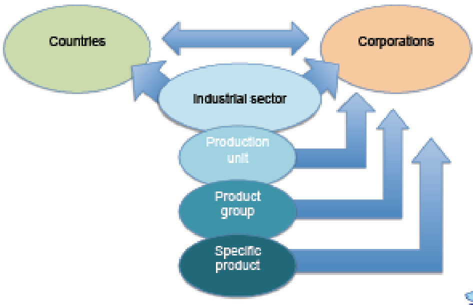
- Manage GHG risks and identifying reduction opportunities;
- Participate in mandatory or voluntary reporting programmes;
- Participate in carbon markets; and
- Get recognition from customers/regulators.

A country may look to:

- Inform policy development
- Establish priorities for action
- Apply taxes
- Corroborate industry reporting

FAO Workshop January, 2012

Subject of Assessment



FAO Workshop January, 2012

Establishing System Boundaries

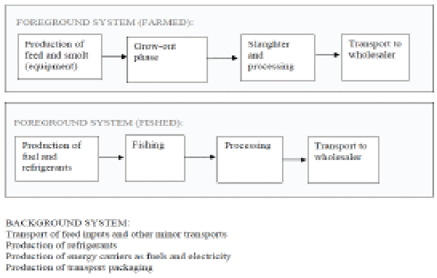
Definition: '*a set of criteria specifying which unit processes are part of a product system*'.

A production system is mapped in a **process flow diagram** to identify each stage requiring assessment of:

- **Direct emissions**: GHG emissions from sources owned or controlled by the organisation;
- **Energy indirect emissions**: GHG emissions from the generation of imported electricity, heat or steam consumed by the organisation; and
- **Other GHG emissions:** a consequence of production, but arise from greenhouse gas sources that are owned or controlled by other organisations (e.g. suppliers).

FAO Workshop January, 2012

Establishing System Boundaries



Source: Winther et al, 2009

Allocation methods

Definition: "*partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems*" (ISO, 2006).

Important where more than one species is caught or more than one product is being processed by a factory

So how much of the calculated GHG emissions should be allocated to the product or group under assessment?

Most studies allocate by weight, some by monetary value, others by nutritional value.

FAO Workshop January, 2012

Approach – level of complexity

Tier 1 method: a 'simple' method using default emission factors from readily available statistical sources.

Tier 2 method: default emission factors should be replaced by country-specific or technology-specific emission factors.

Tier 3 method: May be using just slightly more disaggregated data than Tier 2 or based on complex models.

FAO Workshop January, 2012

Emission factors and functional units

Choice of functional unit may be driven by how the product is typically consumed (e.g. one can of tuna);

For some assessments (e.g. of product groups) it may be easier to collect data and calculate the footprint using a larger unit (e.g. one tonne of tuna).

Emissions are often carbon equivalent per X of tuna.

E.F.s are collated into emission inventories:

Existing EF inventories useful for generic items

Seafood specific data is currently limited

FAO Workshop January, 2012

POSEIDON Aquatic Resource Management Ltd

Style of Reporting

IPCC requires each country to produce a detailed National Inventory Report, Sweden's 2011 report ran to 365 pages.

But messages are distilled & interpreted:

"*The greenhouse gas emission per kg pork is 3.6 kg CO2 eq, equivalent to the amount of greenhouse gas emitted from a 10 km drive in passenger car*" (LCA Food, 2008)

"*…for each tonne of live-weight landed fish product, 1.7 tonnes of CO2 are emitted…*" (Seas at Risk, 2009)

Korea USA Japan UK

POSEIDON Aquatic Resource Management Ltd

Existing standards

An **ISO GHG assessment standard** (14067) is still in development to complement their LCA standards (14044).

British Standards Institute (BSI) produced a publicly available standard **(PAS) 2050** for products (goods and services).

The GHG Protocol:

(a) Product Standard; and

(b) Corporate Standard

Numerous commercial software packages.

POSEIDON Aquatic Resource Management Ltd

Seafood Assessments

- Seafood assessments driven more by academic curiosity than regulation or commercial demand, but changing.
- Production stage is often defined by the species (group) and the production method.
- Most have looked at relatively large-scale systems. The significance of scale is not well understood.
- Examples from Less Developed Countries are limited and so is default data to help future assessments.
- Big variation in scope and system boundaries.
- For fisheries the fishing stage is in most instances the most significant contributor to GHG
- For (intensive) aquaculture feed production is biggest contributor.

POSEIDON Aquatic Resource Management Ltd

Seafood Assessments – potential typology

Product Group	Production system	
	Fisheries	Aquaculture
Whitefish (cod, pollack, etc.)	Trawling, lining, netting	Intensive cage culture
Small pelagics (anchovy, sardine, mackerel)	Seining, trawling	Not cultured
Tuna (various sp.)	Seining, long-lining, hand-lining and pole and lining	Intensive cage culture
Salmon (Pacific, Atlantic and trout)	Netting	Intensive cage culture
Freshwater fish (Carp, tilapia, etc.)	Netting, traps, hand-lines, – mainly small-scale	Intensive to extensive Pond or freshwater cage culture
Bivalves (mussels, clams, scallops)	Dredges	Extensive bottom culture, rope culture
Shrimp (*penaeus & pandalus* sp.	Trawling, creel	Intensive to extensive pond culture

POSEIDON Aquatic Resource Management Ltd

Challenges for Seafood Researchers

Issue	Challenge
Methods	Use existing or bespoke methods?
Goals	Risk of costs as well as benefits – think of LDC & small-scale systems
Scope	Should all greenhouse gases be assessed?
Subject	A common typology for subjects of assessment?
System boundaries	Common system boundaries, include capital goods?
Approach	Level of detail to apply (tier 1,2 or 3)?
Allocation	Allocation method – is a single method needed?
Emission Factors	How to develop fisheries-specific EF resources
Data	Detail v uncertainty trade off. Commercial data use.
Reporting	How to encourage wider GHG assessment & use
Management	How to incorporate effect of management measures.
Dynamism	Addressing technical advances in production systems

FAO Workshop January, 2012

POSEIDON Aquatic Resource Management Ltd

Possible Approaches

- Test modified PAS 2050, GHG and other agreed approaches with pilot production systems.
- Include small scale and LDC-based systems in pilots.
- Include all GHG due to importance of refrigerants and non-carbon GHGs such as methane in agri systems.
- Include direct emissions from producers, indirect from electricity and 'other emissions' from suppliers due to the importance of the latter.
- Use pilots to explore the consequences of inclusion and exclusion of certain elements e.g. capital goods.
- If possible agree common terminology and typologies.

FAO Workshop January, 2012

Poseidon Aquatic Resource Management Ltd

Thank you!

Traditional wind-powered shrimp trawler, Sri Lanka

www.consult-poseidon.com

Poseidon Aquatic Resource Management Ltd

Performance Metrics in GHG emissions assessment in Seafood
J. Muir

Performance metrics for GHG in the fisheries sector– existing approaches & information sources

James Muir
Consultant, FAO

Overview

- Primary estimates – based mainly on energy use, suggest fisheries sector not a major GHG contributor;
- Broad aims for defining and reducing GHGs - links with CO_2, CH_4 and N_2O - refrigerant gases?
- Need rational approaches for measuring GHG characteristics and impacts
- Direct gas emissions not usually feasible to measure routinely – need reliable indirect methods
- Potentially applicable for a range of objectives, sequential assessments
- Role of performance metrics – ways of defining GHG performance, links with other metrics
- Ideally identify simple approaches using existing criteria, data-sets, or at least minimise additional inputs

Agriculture sector greenhouse gas emissions

Source		GHG	Gt CO_2e	%age
Primary processes				
Enteric fermentation		CH_4	1.792	27.0
Manure		N_2O	0.413	6.2
Fertilised soils		N_2O	2.128	32.1
Biomass burning		CH_4,N_2O	0.672	10.1
Rice production		CH_4	0.616	9.3
Industrial factors				
Fertiliser production		CO_2, N_2O	0.410	6.2
Farm machinery		CO_2	0.158	2.4
Irrigation		CO_2	0.369	5.6
Pesticide production		CO_2	0.072	1.1
	Total		6.558	100
Strategic factors				
Land use changes*		CO2	5.880	
	Total		12.438	

Capture fisheries GHG characteristics

GHG characteristics	Issues
Primary GHG association with fuel use and catch quantities/values, also ice/refrigeration, crew supplies, mobilisation inputs, directly measurable or derived from cost and earnings surveys; GHG links with capital goods – vessels, fishing gear, service facilities, based on category ratios, mass/process conversion factors, use and disposal	Allocation to landed species, variation in vessel performance within fleet level assessments, effects of key subsidies, use of infrastructure, residual value/write-down/disposal of capital items, impacts on ecosystems, services

Aquaculture GHG characteristics

GHG characteristics	Issues
Primary GHG association with feed use; also fertiliser, fuel/electricity, water supply, waste treatment seedstock, labour, chemicals, input packaging, directly measurable or estimated from costs and earnings surveys; GHG links with capital items including holding facilities, buildings, husbandry equipment, service vessels/vehicles, based on category-based ratios, mass/process conversion factors, use and disposal	Feed composition and sourcing, water use values and impacts, variation in performance across production categories, accounting for landuse change and soils disturbance, methane impacts in fish-rice systems, possible mitigation effects in water/soils, impacts on ecosystem services, infrastructure

Post-harvest GHG characteristics

GHG characteristics	Issues
Wider range of GHG associations depending on process, mainly fuel/electricity, water supply/treatment, cleaning, waste disposal, packaging, labour; capital items including buildings, process equipment, vessels/vehicles based on category-based ratios, mass/process conversion factors, use and disposal	Boundaries in supply chain, yield variations, allocation to products, byproducts, value added product mixes; usage/disposal of wastes; values associated with water use; role of refrigerants

Distribution GHG characteristics

GHG characteristics	Issues
Primarily depend on mode of transport, temperature, pack options, distance – fuel use; capital items include storage/distribution depots, air transport, vessels, trucks, handling and IT systems; GHG estimates based on allocated use rates, category-based ratios	Effects of loading levels, handling/ storage stages, route efficiency, infrastructure investment, fuel pricing, product losses, refrigerants

Retail and consumption GHG characteristics

GHG characteristics	Issues
Range of GHG associations depending on products, on retail, food service conditions and consumption characteristics – power for lighting/ cooling, home storage, cooking; wastes, packaging disposal	Variations across systems, food cultures, energy sources for storage, food preparation, refrigerants, regulatory impact on losses, wastes, infrastructure

Links across indicators

Performance metric	Typical units	Link with GHG metric	Notes/Issues
Fuel/energy use	t fuel/t catch; kWH/t output	Primary element in many sector areas, could be used as a strong predictor/ correlator for GHG	Measurement of fuel or energy use and allocation to specific products
CPUE (catch/unit effort)	t catch/vessel-day, hours	Effort may be associated with energy use per output – possible indirect measure	Range of products and values – wide variations within fleets
Aquaculture yields/ productivity	t/ha or m3 –year	More intensive systems tend to have higher input levels – feed, water exchange, hence higher GHG	Natural productivity varies, and other factors will also affect GHG
Aquaculture food conversion	t food/t product	Can be a primary definer of GHG – strong correlator	Depends on food composition, sourcing
Aquaculture survival/ seed yield	% stock out/stock in; kg or t product/seed no	Limited correlation with most GHG performance, but indirect measure of system/management efficiency	May be more linked for unfed systems with high GHG seed supply
Fish in/out ratios	t fish in food/t product	Where fish input is major GHG factor may be a strong determinant, otherwise a general system efficiency measure	GHG levels would also depend on other food components – eg soybean

Links across indicators

Performance metric	Typical units	Link with GHG metric	Notes/Issues
Aquaculture water use	m3/t produced	Indirect as more intensive systems usually have higher water use; more direct links if water exchange and/or treatment a major energy use	Recycle systems may have high GHG levels but low water use; reverse for seaweed, mollusc culture
Process yield	t product/t material	Comparative GHG generally lower if yield increases, but not main definer	Varies widely with source; may also be by-products
Process energy use	kWh/tonne product	May be a strong correlator for GHG but also depends on raw materials	May be more complex links with cooling energy and CFCs
Process water use	m3/tonne product	Not usually a primary definer, but could be more important if water supply/treatment a key energy use	Wastes in water stream could be important GHG contributors
Labour productivity/ value added	t output/FTE labour, value added/FTE	May be more relevant for ratios of social benefit/GHGs and tradeoffs concerned; a general link with system intensity and higher GHGs	Wide variation across sector and within sub-sectors.

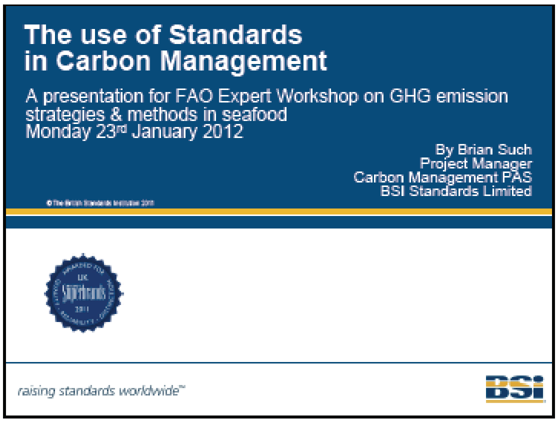
Potential information sources

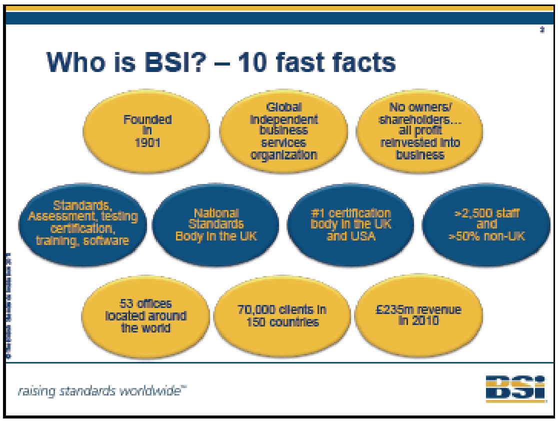
- Standard ratios – generic data
- Industry – supply chain elements – based as far as possible on normal reporting requirements…
- Direct research results – technical sectoral, market consumption
- Global/regional assessments – geo-scale, climate change – IPCC, etc
- More focused studies?
- Issues – access, frequency, reliability, diversity, scalabilty, etc.

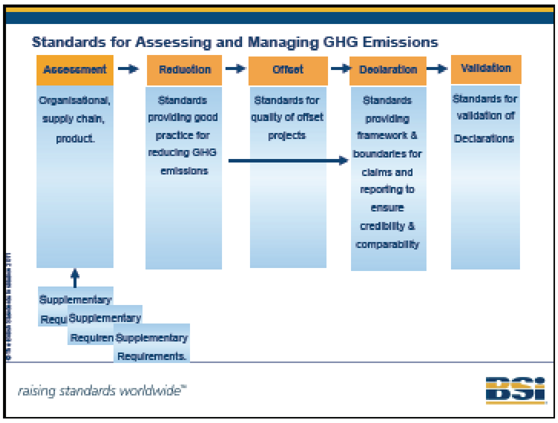
Conclusions

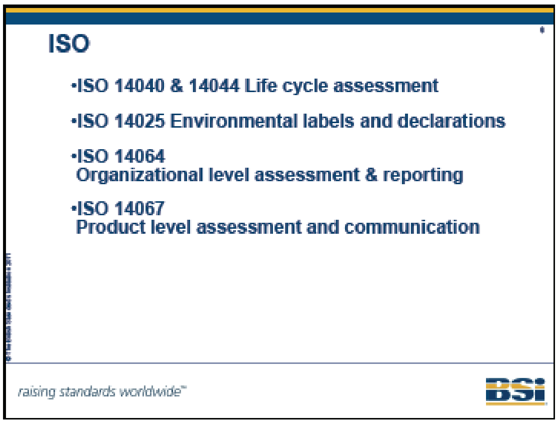
- GHG performance indices in the fishery sector are an important feature of its strategic evolution within an increasingly competitive resource context.
- A clear perspective needed, recognising trade-offs between specific accuracy and wider, simpler applicability.
- Need to recognise a range of GHG themes – national policy, trade and competition, consumer information/choice, and ensure there is an adequate level of continuity and coherence across these.
- A more extensive GHG strategy would commence with robust and well-linked approaches based on clear and sound principles, with the means to define the significance of boundary and allocation choices and relative sensitivity of proposed GHG measurement results to these.
- Need to develop effective data compilation and exchange systems, with wide access – possibly tiered according to user group and intended aims, supporting routine meta-analysis of compiled observations, and the means to update and develop existing data assemblies
- It would also be necessary to develop guidelines for application and interpretation

The Use of Standards in Carbon Management
B. Such









WRI/ WBCSD

BSI

Common Principles

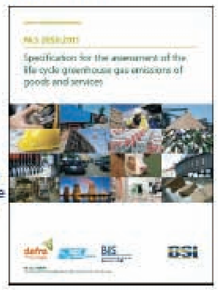
- All based on existing LCA principles
- All provide for whole life cycle assessment
- All address the range of Kyoto gasses
- All single issue focus – GHG emissions

Significant difference

- Approach to reporting/ communication

GHG assessment at the product level: PAS 2050

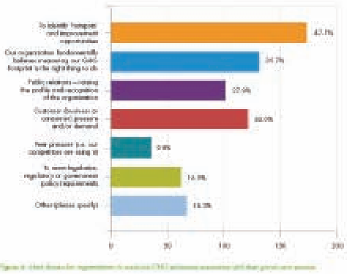
- Standardized approach to product carbon footprinting theory and practice
- Clarity, consistency, a common basis for the assessment of lifecycle greenhouse gas emissions of good and services
- Designed for use by organizations of all sizes and types, in any location, to assess the climate change impact of the goods and services they offer
- Well received and used internationally since publication



Carbon Neutral claims: PAS 2060…

- Common methodology for making credible carbon neutral claims
- Provide robustness to claims of carbon neutral status
- Enable consistent communication of carbon neutral status
- Applicable to any subject or industry sector
- Avoid confusion within companies, across industry sectors, along the supply chain and with consumers

Why did organisations implement PAS 2050?



What did they achieve?

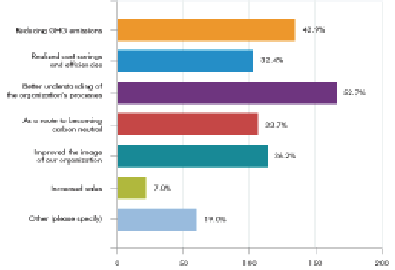


Figure 8 What benefits have been realised from using PAS 2050?

raising standards worldwide™

PAS 2050 Review

Objectives:

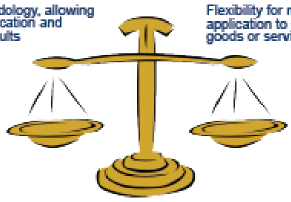
- Clarify ambiguities that have become apparent in the application of the standard
- Take account of advances in knowledge and understanding that have emerged since PAS 2050 was first published
- Reflect user experience as much as possible
- Enhance the level of take-up and application of the PAS 2050 methodology
- Reduce unnecessary differences between the PAS 2050 methodology/its application and other internationally recognized footprint methods (ISO' s and WRI/WBCSD' s)

raising standards worldwide™

PAS 2050 Revision: Supplementary Requirements

Credible methodology, allowing consistent application and comparable results

Flexibility for meaningful application to specific groups of goods or services



raising standards worldwide™

Supplementary requirements – principles and areas of assessment

- Supplementary requirements used in support of PAS 2050 should be:

a) supplementary; b) broadly recognized; c) inclusive and consensus-based; d) scoped appropriately; e) harmonized; f) comprehensive; g) justified; h) publicly available; i) maintained.

- Areas of assessment:

a) unit of analysis; b) setting system boundary (general); c) co-product allocation; d) recycling; e) carbon storage; f) land use change; g) soil carbon; h) capital goods; i) transport and storage; j) use phase/final disposal profiles.

raising standards worldwide™

Product Carbon Footprinting Initiatives

PAS 2050 Assessment of life cycle GHG of products

GHG Protocol Product Standard

ISO 14067 Carbon footprint of products

EU Environmental Footprinting Project

Japanese Carbon Footprint System and Label

French National Experiment on environmental product information: Grenelle 2 Act

Korea Carbon Labelling Initiative

raising standards worldwide™

BSI Supplementary Requirements

- PAS 2050 – 1

BSI is currently working with Productschap Tuinbouw and Ministerie landbouw, natuur en voedselkwaliteit (lnv) in the Netherlands on a project to develop a protocol that will provide supplementary requirements for the application of PAS 2050 in the horticultural industry.

- International approach and application

Investigative workshop held in the Netherlands in 2010 attended by 35 experts from 9 countries. From this workshop a group was formed to undertake the drafting of *PAS 2050-1, Supplementary requirements for the application of PAS 2050 to horticulture products.*

- Due for completion February 2012

raising standards worldwide™

BSI Supplementary Requirements

PAS 2050-2
Title - Assessment of life cycle greenhouse gas emissions – Supplementary requirements for the application of PAS 2050 to aquatic food products

Scope - This PAS establishes supplementary requirements for the application of PAS 2050 to the assessment of lifecycle greenhouse gas emissions from all aquatic food products derived from wild capture and aquaculture conditions.

Project Launch - 9th January 2012

raising standards worldwide™

PAS 2050-2 - Objectives

Ensure process *robust and transparent* to deliver a credible specification that will:

- Assist the aquatic food industry to *more easily assess the GHG emissions* resulting from their activities
- *Provide a specification* so that compliance with the requirements can be verified
- Engage with key international aquatic food and carbon experts to *ensure technical accuracy* of the requirements.
- Help the aquatic food industry introduce an approach for *assessing GHG emissions that is uniform in application and consistent in result to* deliver verifiable and comparable assessment outcomes
- Deliver clear, concise and unambiguous requirements and guidance that reduce the need for *interpretation* in the application of PAS 2050 to aquatic food products.

raising standards worldwide™

PAS 2050-2 – Next Steps:

1 hour session at the end of Day 2 tomorrow to:

- Provide more information to possible stakeholders
- Source further information on industry attitudes & expectations
- Engage key stakeholders in the development of PAS 2050-2

Form Steering Group and Review Panel

Prepare first Draft

Hold first Steering Group Meeting

raising standards worldwide™

Contact details

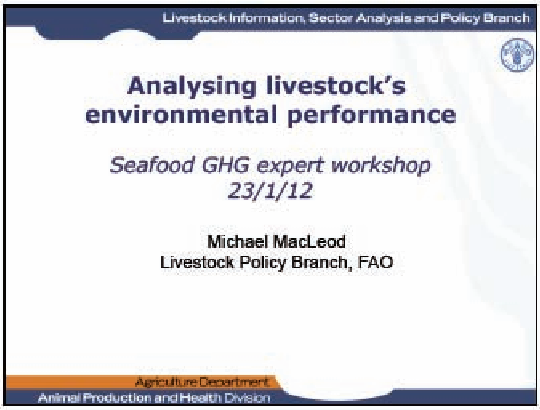
- Brian Such
- briansuch@bsigroup.com
- www.bsigroup.com/pas2050

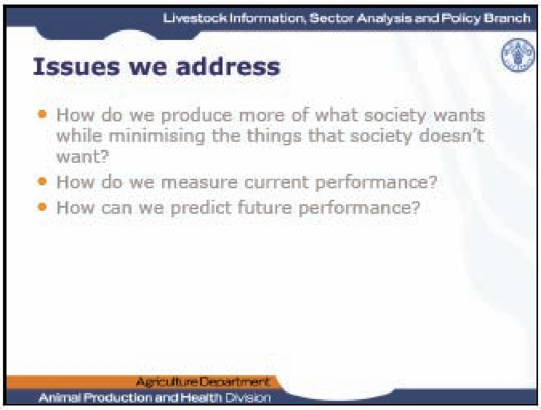
Thank you for your attention - I look forward to discussing the assessment of GHG emissions from aquatic food products in more detail with you, tomorrow.

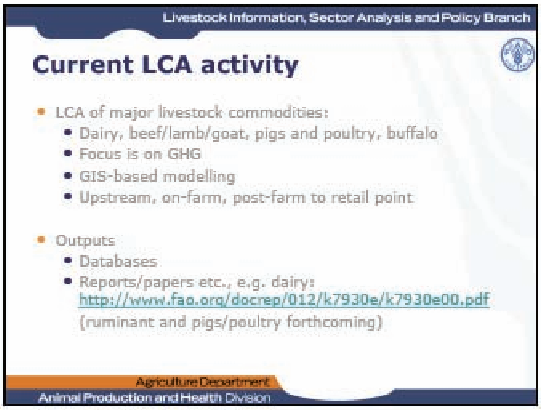
raising standards worldwide™

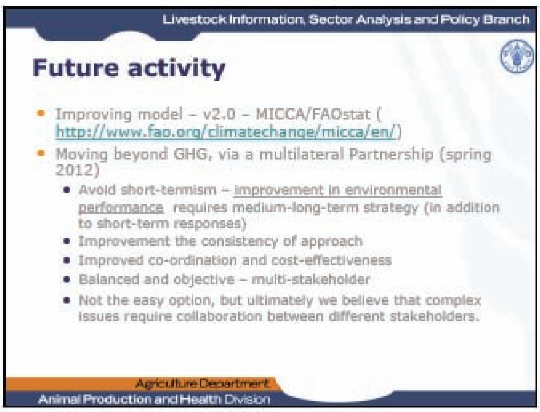
raising standards worldwide™

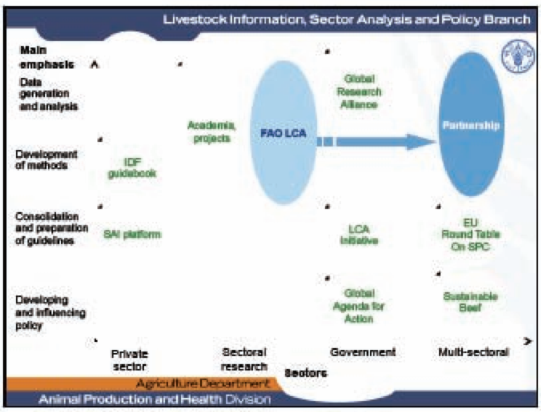
Analysing Livestock's Environmental Performance
M. Macleod

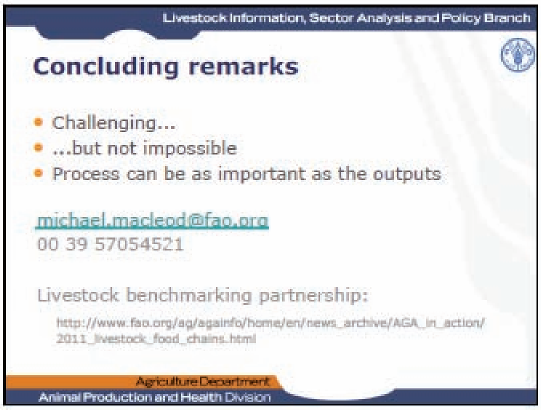











Livestock Information, Sector Analysis and Policy Branch
Concluding remarks
Challenging...
...but not impossible
Process can be as important as the outputs
michael.macleod@fao.org
00 39 57054521
Livestock benchmarking partnership:
http://www.fao.org/ag/againfo/home/en/news_archive/AGA_in_action/2011_livestock_food_chains.html
Agriculture Department
Animal Production and Health Division

The Fishery Resources Monitoring System (FIRMS)
M. Taconet

Fishery Resources Monitoring System FIRMS

The Fishery Resources Monitoring System

http://firms.fao.org/firms

1. Original triggers to FIRMS
2. How does it work – the Partnership
3. What does it produce - FIRMS Products
4. Conclusion – Issues and benefits of information partnerships

Marc Taconet
FAO Fisheries and Aquaculture Department

, 25 January 2012, Rome Italy

Fishery Resources Monitoring System FIRMS

1. Original triggers to FIRMS development

It was difficult to have a clear picture of Status of world marine resources:

- presented in multiple formats (poor consistency)
- difficult to access authoritative information (low visibility)
- sources of S&T statements not obvious (lack of traceability)

Fisheries management performance not enough assessed

- unclear track of follow-up actions between scientific advice and management decisions

Fishery Resources Monitoring System FIRMS

1. FIRMS objectives

An information partnership aimed at facilitating the monitoring of:

- State of world fishery resources
- Status and trends of fisheries and their management

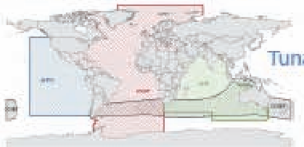
... with authoritative information

IOTC CTOI
ICES CIEM
eurostat
NEAFC
SEAFO
CIAT IATTC

http://firms.fao.org

Fishery Resources Monitoring System FIRMS

Geographic coverage



Tuna Partners

Non-Tuna Partners

http://firms.fao.org

Fishery Resources Monitoring System FIRMS

2. Governance

- FIRMS Steering Committee (FSC)
- FIRMS Secretariat
- FIRMS Technical Working Group

Policy - information sharing mechanisms

1. Conditions under which the information is shared (fact sheets)
   - Data ownership,
   - Dissemination rules,
   - Quality assurance issues

2. Development of information standards (guidelines, inventories)

3. Streamlined workflow mechanisms

http://firms.fao.org

Fishery Resources Monitoring System FIRMS

Information sharing mechanism Streamlined workflow

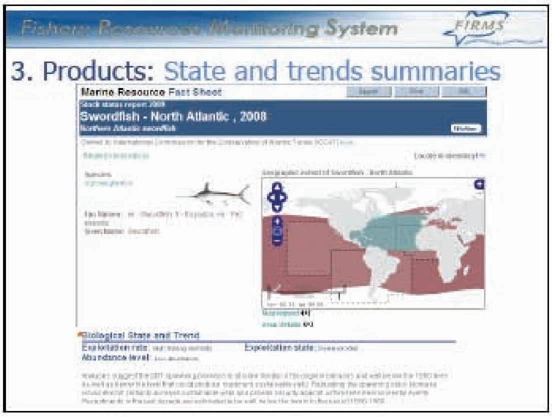
FIRMS processes and reporting

FIRMS partners

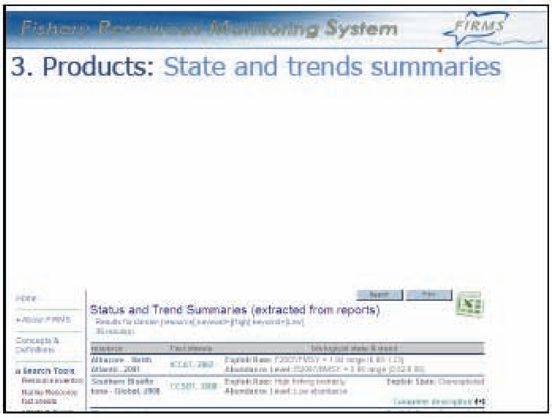
SEAFO NEAFC CIAT IATTC . . .

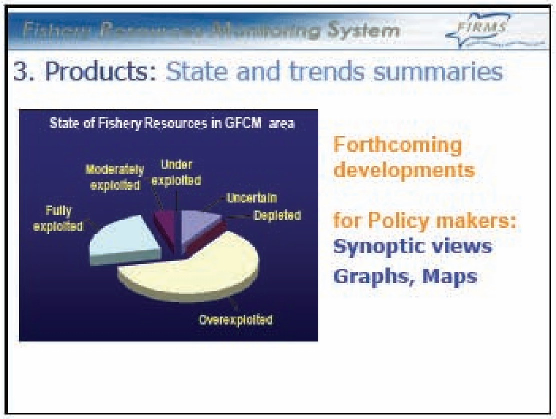
http://firms.fao.org

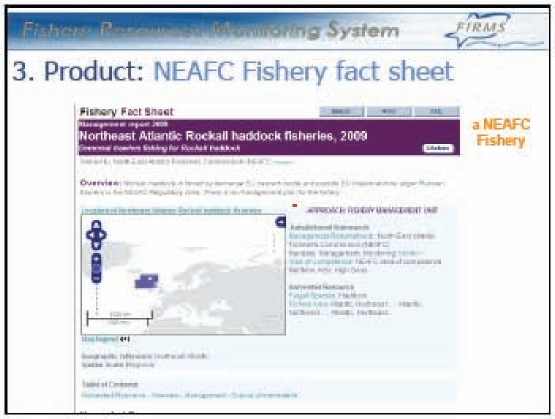

Fishery Resources Monitoring System
FIRMS
3. Products:
Fact sheets
Marine Resource Fact Sheet
Haddock - Rockall, 2008
Marine Resource Fact Sheet
Sardinella - Northwest Africa, 2007


Fishery Resources Monitoring System
FIRMS
3. Products: State and trends summaries
Marine Resource Fact Sheet
Swordfish - North Atlantic , 2008
Biological State and Trend


Fishery Resources Monitoring System
FIRMS
3. Products: State and trends summaries
Search results are based on stock status standard descriptors
1. Abundance level
2. Exploitation rate

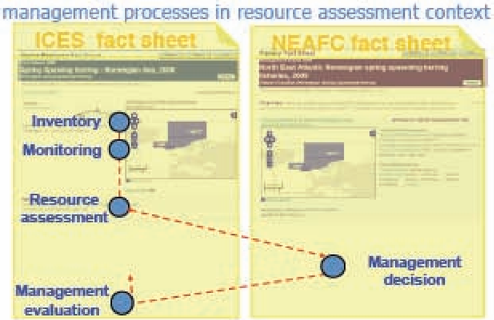

Fishery Resources Monitoring System
FIRMS
3. Products: State and trends summaries
Status and Trend Summaries (extracted from reports)


Fishery Resources Monitoring System
FIRMS
3. Products: State and trends summaries
State of Fishery Resources in GFCM area
Moderately exploited
Under exploited
Uncertain
Depleted
Fully exploited
Overexploited
Forthcoming developments
for Policy makers:
Synoptic views
Graphs, Maps


Fishery Resources Monitoring System
FIRMS
3. Product: NEAFC Fishery fact sheet
Fishery Fact Sheet
Northeast Atlantic Rockall haddock fisheries, 2009
a NEAFC Fishery

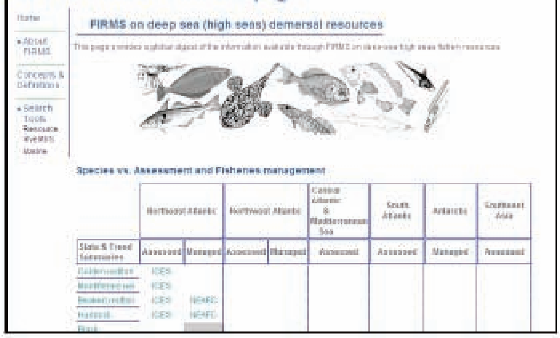
Fishery Resources Monitoring System — FIRMS

Service: synthesis which facilitates interpretation of management processes in resource assessment context



Fishery Resources Monitoring System — FIRMS

3. Products: thematic pages



Fishery Resources Monitoring System — FIRMS

Conclusion: issues and benefits of Partnerships

Issues

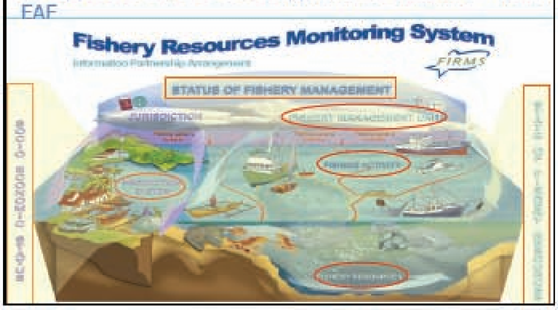
- Can be felt a burden
  - needs strong political support
  - requires a core group of champions
  - need to foster feeling of direct return on investment
  - services to contributors

Benefits

- Enhance visibility – feeling of Community of Practice
  - Influence on the international agenda
- At maturity
  - Partners get more than they contribute

Fishery Resources Monitoring System — FIRMS

Conclusion: FIRMS – provides information backbone in support of Multi-faceted approach to fisheries – fit for EAF



Fishery Resources Monitoring System — FIRMS

Conclusion: FIRMS benefits

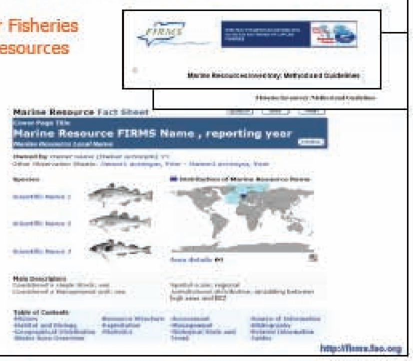
FIRMS information framework provides: methods, structured approaches, standards, tools, i.e. a backbone to develop:

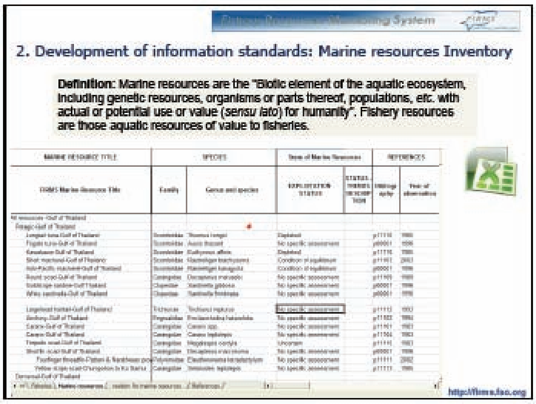
- comprehensive knowledge based on authoritative information at regional level
- support to regional harmonization of Status & Trends information
- enable with monitoring/reporting capacity
- enables more visibility
- and various services to its contributors
- Partners get more than they contribute

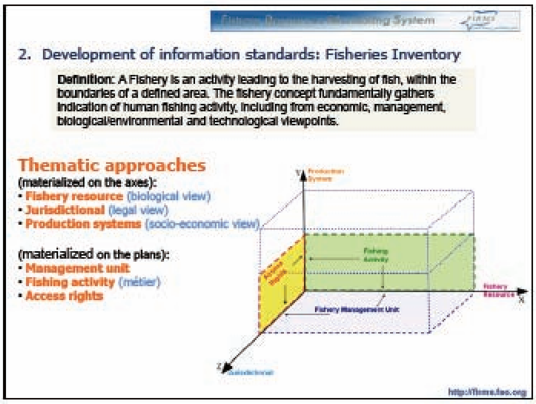
2. Development of information standards

Guidelines for Fisheries and Marine Resources Inventory

FIRMS Data dictionary




2. Development of information standards: Marine resources Inventory
Definition: Marine resources are the "Biotic element of the aquatic ecosystem, including genetic resources, organisms or parts thereof, populations, etc. with actual or potential use or value (sensu lato) for humanity". Fishery resources are those aquatic resources of value to fisheries.
http://firms.fao.org


2. Development of information standards: Fisheries Inventory
Definition: A Fishery is an activity leading to the harvesting of fish, within the boundaries of a defined area. The fishery concept fundamentally gathers indication of human fishing activity, including from economic, management, biological/environmental and technological viewpoints.
Thematic approaches
(materialized on the axes):
• Fishery resource (biological view)
• Jurisdictional (legal view)
• Production systems (socio-economic view)
(materialized on the plans):
• Management unit
• Fishing activity (métier)
• Access rights
Fishery Management Unit
http://firms.fao.org

APPENDIX 6

OUTPUTS OF WORKSHOP WORKING GROUPS AND RELATED DISCUSSION

Outputs from the two breakout groups in day 2 were compared in day 3 to establish where common aspects existed and where there were differences.

Assessment Element	**Group 1 – global/national**	**Group 2 – company/product**	**Common aspects**
1. Goals & objectives	To provide long-term comparisons of performance, establish a system that is capable of guaranteeing and compiling cost-effective, reliable and consistent GHG emission data for fisheries at national level, to be rolled up to global level.	Internal improvement (to increase efficiency, reduce GHG emissions, improve profitability).	Both aimed at reducing emissions Global – where can we find data? Company – how can we provide better data? So, direct link of LCA feeding into national-level reporting. Both aimed at refining estimates Company will require LCA, national/global may not (e.g. could use input/output analysis)
2. Subject of assessment	Combination of more than one option e.g. species and fleets by gear i.e. métier, or species and intensity.	Fully define product to be assessed.	Common aspect: all products are species-based. Difference is level of detail & aggregation.
3. Establishing system boundaries	Cradle to plate in terms of interest, but focus is on productive sector i.e. gate to gate for information requirements. Might or might not report on whole system (using data from other upstream and downstream sources outside of productive sector) depending on whether just reporting hotspots or broader.	Cradle to gate because have to focus on things under the control of the company.	Both recognize life cycle of product Difference in level of detail required for information harvesting, i.e. global/national happier with Tier 1
4. The allocation method	Defer to ISO guidance where appropriate. Some national-level carbon footprint standards/guidelines already, e.g. in Asia.	Various allocation methods. (mass, economic value, other). Cannot leave choice open – either make a choice or define strict criteria in choosing. Methods should be consistent with long-term objective (e.g. GHG emission reductions).	PAS 2050: economic allocation as default, but seafood sector can chose mass allocation if based on consultation and properly justified. Still need to test implications of choices.

5. Deciding on the approach	Initial use of Tier 1, and Tier 2 for hot spots (fuel in capture, feed in aquaculture).	Initial use of Tier 2 with possible move to Tier 3 for hot spots.	Product-level assessments could provide data to inform national/global
6. The emission factors and units	Expression of all gases in CO_2 equivalents.	Include all Kyoto GHG gases.	Agreement between groups. Recognize data deficiencies. Opportunities with existing data sets: could be shared given appropriate platforms and protocols. Can be difficult to understand how numbers in databases are derived. Benchmarking can provide an incentive for data sharing.
7. The style and structure of reporting	Could be simplistic on fuel and feed use.	Companies can make selective claims. So simple clear reporting needed. Reporting standards exist (ISO 14044). To depart from these risks credibility. Company level may not want to report externally.	Both need clear standardized reporting, but of different things. Could be multiple reporting requirements to COFI, IPCC, species forums, civil society, retailers/wholesalers, consumers. Difference that companies LCA reporting, whereas global may be more selective.

APPENDIX 7

POSSIBLE TOPICS FOR WORK PACKAGES AND CASE STUDIES

Following the Workshop, a small number of participants identified a number of existing and potential work areas that could support seafood-related GHG emissions efforts. These included:

- Feed ingredients database and model development. This could be developed as part of a community of practice to share existing data. This could link into the World Bank/FAO livestock feed database already being developed.
- Determining a global figure for GHG emissions in fisheries and aquaculture, using data that can be readily collated and revisited to inform priority setting. This could start with a data gap analysis to explore areas of good quality data and limited data.
- Exploring the impact of fisheries management on GHG emissions. Determining the benefits of technical mitigation measures compared with wider fisheries management measures.
- Operational guidelines to explain important principles of LCAs and how to conduct them properly – "best practice". This could be a seafood addendum to the general LCA handbook produced by the Joint Research Council of the European Union (Member Organization).
- A seafood LCA portal could be established to link LCA researchers, interested agencies, etc. This could provide a gateway to seafood-specific studies, information and outputs from the work proposed above.

This document contains the report of the Expert Workshop on Greenhouse Gas Emissions Strategies and Methods in Seafood held in Rome, Italy, from 23 to 25 January 2012.

ISBN 978-92-5-107351-3 ISSN 2070-6987

9 789251 073513

I3062E/1/10.12