10. Seafood and Aquaculture

7. Challenges and best practices of seafood supply chains LCA

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ABSTRACT

Due to the rapid growth of the seafood sector, it is relevant to study the environmental and ecological impacts associated with current and future seafood supply chains of aquatic products aimed for direct or indirect human consumption, including fish, molluscs, crustaceans and algae. Despite efforts, certain challenges remain in seafood LCA. Based on these concerns, this work suggests best practices (including recent methodological developments and novel methods) addressing challenges for the application of LCA to study seafood supply chains, and promoting more holistic and robust outcomes. A literature review was performed, targeting recent reviews, methodological papers, case studies and guidelines for LCAs of seafood-based supply chains. Best practices were identified based on their capacity to complete, complement and support the interpretation of LCAs, their practical demonstration, and our expert judgement. The adoption of these best practices (which address the inclusion of fisheries management concerns, goal and scope decisions, and data availability and management) guarantees solid LCA studies with adequate data and uncertainty management, inclusion of seafood-specific impact categories, and coherent study design.

Keywords: fisheries, aquaculture, fish processing, fish supply chains, life cycle assessment

1 Introduction

Given the increasing global demand for fish and other aquatic products for human and animal consumption, and the fact that wild caught fisheries —supplying inputs for the food and feed industries— have stagnated over the past 15 years (FAO 2014), it is highly relevant to study the environmental and ecological impacts associated with current and future seafood supply chains. These seafood supply chains encompass aquatic products aimed for direct or indirect human consumption, including fish, molluscs, crustaceans and algae. The production of aquatic biomass for non-food uses, such as microalgae as feedstock for biodiesel production, could also be considered as part of these supply chains, because they share some common production processes and thus exert similar pressures on the environment. Topics addressed by seafood supply chain research include harvesting practices, processing, life cycle assessment (LCA), eco-efficiency, waste management, distribution and consumption, total energy costs, and conservation of resources and biodiversity (Ayer et al. 2009).

An outstanding number of studies have, to date, applied LCA to seafood production systems, many of which have applied novel impact categories and tools designed to account for the ecological impacts of removing biomass from ecosystems, disrupting benthic ecosystems, etc. Despite these efforts, certain challenges remain in seafood LCA. Based on these concerns, this work presents best practices (including recent methodological developments and novel methods) addressing challenges for the application of LCA to study seafood supply chains, and promoting more holistic and robust outcomes.

2 Methods

A documentary review was performed, targeting recent reviews (Avadí and Fréon 2013; Henriksson et al. 2012; Vázquez-Rowe et al. 2012), methodological papers (Avadí and Fréon 2015; Ayer et al. 2007; Patrik Henriksson et al. 2015; Vázquez-Rowe et al. 2010; Ziegler et al. 2015), case studies (Almeida et al. 2015; Avadí et al. 2015; Henriksson et al. 2014) and guidelines (BSI 2012; EPD 2014; Hognes 2014) for LCAs of seafood-based supply chains. From these, suggestions are given for best practices and more homogenised methods for LCA of seafood systems. Best practices were identified based on criteria such as a) their capacity to complete, complement and support the interpretation of life cycle inventory analysis and life cycle impact assessment results; b) their demonstration in literature beyond methodological proposal; c) our expert judgement based on an extensive contribution to the field by the co-authors. For instance, preferred fisheries-specific indicators complement conventional LCA by addressing ecological impacts and are easy to calculate (e.g. they rely on easily obtainable data), while preferred uncertainty management approaches have been demonstrated in fisheries and aquaculture case studies, and contribute to more robust interpretation of results.

3 Results

Across the reviewed studies, there was a strong focus on salmonids aquaculture in Europe and North America. Most studies that evaluated Asian aquaculture looked at *Pangasius* in Vietnam, a commodity mainly exported to the EU and the US. Carp farming in China, however, has been sparely explored despite being the largest source of farmed fish. As for supporting data, many studies relied upon generic processes for feed resources from LCI databases. This was deemed concerning in some cases since the major LCI database, ecoinvent, mainly covers European agricultural production. Especially concerning was the use of fishmeal from the consequential LCAFood database (http://www.lcafood.dk/), since this process is incompatible with attributional LCA data and only describes fishmeal from sandeel in Denmark, a marginal source of fishmeal on global markets. LCA studies on fisheries have largely focused on industrial fleets targeting small and large pelagics, cephalopods and demersal fish.

Additional challenges identified, the following are of great relevance to improve the utility of LCA in the management of this industry: a) inclusion of fisheries management concerns and related impact categories (e.g. discards, by-catch, seafloor damage, biotic resource use, biomass removal impacts on the ecosystem and species); b) general LCA challenges in the specific context of seafood supply chains, such as the selection of functional units, the delimitation of system boundaries (e.g. inclusion of capital goods, end-of-life scenarios), cut-off criteria, allocation strategy, and selection of impact categories; c) data availability and data management; and d) the relation between LCA and seafood certifications. Seafood LCA guidelines were found to have either failed to include all relevant concerns or are yet to be widely applied by the industry, as noticeable from the documentary review (i.e. a consolidated set of practices is not widely applied by practitioners). Best practices were identified to address each challenge (**Error! Reference source not found.**).

Table 1 Challenges and identified best practices for seafood LCAs

Challenges		Best practices
Inclusion of fisheries management concerns	Capture data	Account for landings, discards, by-catch and on-board process losses (Vázquez-Rowe et al. 2012)
	Seafloor damage	Account for at least distance trawled per functional unit (Nilsson and Ziegler 2007)
	Biomass removal impacts	Prefer less data-intensive indicators (e.g. Langlois et al. 2014)
	Biotic resource use (BRU) [a]	Calculate BRU per functional unit, including all wild caught and agriculture-derived inputs to processes assessed (applies also to aquaculture and seafood processing)
	Management-related indicators	Include indicators derived from and informing fisheries management (e.g. Shin et al. 2010)
Methodological LCA challenges in the seafood context	Selection of functional units [a]	• Fisheries: volume of whole landed fish • Aquaculture: volume of whole live fish at farm-gate • Seafood processing: volume of final product
	Delimitation of system boundaries [a]	• Include capital goods (infrastructure, fishing vessels) • Include end-of-life in terms of material recycling and land use change • Model fate of by-products (e.g. fish processing residues, process water, excess heat) considering any raw materials they substitute in their receiving treatment/valorisation process (e.g. fish residues may partially substitute fresh whole fish in the fishmeal industry)
	Cut-off criteria	Include *ad-minima* inventories (Fréon et al. 2014; Henriksson et al. 2012; Vázquez-Rowe et al. 2012)
	Allocation strategy	Contrast mass-, economic- and gross energy content-based allocation, but use each consistently throughout the LCI; alternatively, treat it as choice uncertainty
	Selection of impact categories	• Select *ad-minima* lists of impact categories (Avadí and Fréon 2013; EC 2013; Henriksson et al. 2012; Vázquez-Rowe et al. 2012) • Include seafood-specific impact categories (BRU, biomass removal, etc.)
	Direct emissions	Aquaculture: nutrient budget modelling by means of mass balances (including weight gain, feed, faeces and not consumed feed, mortalities) to estimate direct emissions (Aubin et al. 2006)

Data availability and data management	Data gaps	• Reconstruction of missing data (e.g. fuel use) data from economic data (Fréon et al. 2014) • Approximate missing values within a dataset by multiple linear regression (Fréon et al. 2014)
	Uncertainty management	• Data uncertainty: Horizontal averaging of unit process data including estimates for uncertainty (Henriksson et al. 2013). For comparative purposes, perform dependent sampling and pair-wise comparisons (Henriksson et al. 2015a, 2015b) • Data and choice uncertainty: Statistical or pseudo-statistical methods for joint treatment (Andrianandraina et al. 2015; Mendoza et al. 2015)
Relation between LCA and seafood certifications		Use full-fledged LCAs to provide environmental indicators for and complement seafood certifications (Jonell et al. 2013)

[a] Anchoveta Supply Chains project (http://anchoveta-sc.wikispaces.com)

4 Discussion

Much inventory data relevant to seafood LCAs have been collected. However, a great deal of it has unfortunately gone unreported and there is an overrepresentation of intensive systems in Western countries. Future efforts should therefore aim at collecting data on a more diverse set of countries and systems, and report these properly. Fishmeal and fish oil production also need to be better describe in literature as they often stand out as environmental hot-spots (see Fréon et al. (2016), in this conference, for a detailed study on the Peruvian fishmeal industry).

A large variety of indicators have been proposed by different research groups to cover seafood specific environmental impacts. The most relevant ones, useful to comparatively assess the status of exploited marine ecosystems, were compiled by the IndiSeas project (Shin and Shannon 2009). These indicators complement the environmental impact indicators informed by LCA. Moreover, additional key indicators pertinent to exploited marine ecosystems and fisheries have been proposed and used by environmental assessment practitioners, including those presented in **Error! Reference source not found.**. Alternatives to these indicators, such as the fish-in fish-out ratio (Jackson 2009; Tacon et al. 2011) as an alternative to BRU, or the Lost Potential Yield (Emanuelsson et al. 2014) as an alternative to the impacts on the Biotic Natural Resource (Langlois et al. 2014), were not retained in our list due to additional complexity, refinement specific to certain supply chains but in our view not general enough, and reliance on not easily accessible data. Other indicators were excluded because they are indices based on more common indicators, such as the energy return on investment, which is the ratio of the energy contained in a seafood product and the industrial energy required for its production (e.g. gross energy or protein energy content per cumulative energy demand) (Tyedmers 2000; Vázquez-Rowe et al. 2014).

Key methodological, choice and study design challenges in LCA include the selection of functional units, delimitation of system boundaries, cut-off criteria, allocation strategies, selection of impact categories and estimation of direct emissions. Our retained best practices are mainly based on our own experience applying LCA to fisheries, marine and freshwater aquaculture, and seafood processing. We believe the suggested approaches allow delivering more robust and objective results. In the case of allocation, for instance, the use of contrasting allocation keys prevents criticism of the results based on contrasting opinions and preferences by the research community (given that the ISO 14040 standard is subject of dissimilar and even contradictory interpretations).

Data and specially uncertainty management address critical elements determining the results of LCA studies. The quality of the life cycle inventories and an adequate propagation and incorporation of uncertainty into impact assessment results contribute to the robustness of the latter, and facilitate their interpretation. The approaches retained are relatively easy to implement and, in the case of the highlighted uncertainty management methods, they successfully address two of the main sources of uncertainty in LCA, namely data and choices. Addressing the uncertainty due to missing, inaccurate or imprecise characterisation factors is beyond the scope of these recommendations, yet we recommend using the latest and more complete impact assessment methods, models and characterisation sets available, and to clearly identify uncharacterised substances (e.g. antifouling molecules).

Impact assessment results from different studies should not be compared, because they may rely on different assumptions and methodological choices. Key inventory items such as fuel, water and chemicals use, on the other hand, can and should be contrasted per equivalent functional units for different studies, because interpretation of LCI outcomes also contributes with results and elements of interpretation on the studied system.

5 Conclusions

The adoption of these best practices for seafood LCAs promotes solid LCA studies with adequate data and uncertainty management, inclusion of seafood-specific impact categories, and coherent study design (elements of goal and scope). The wide adoption of best practices will thus contribute to improve the soundness of future LCA studies on seafood and other aquatic supply chains, including fish, algae, crustaceans and molluscs for direct or indirect human consumption.

Further methodological developments and consensus on how to address these challenges should ultimately contribute to make LCA a useful tool as a decision support tool for managers to visualize a wider scope of environmental indicators.

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120. Advancement of the marine biotic resource use metric in seafood LCAs: a case study of Norwegian salmon feed

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