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A framework and review for using life cycle assessment to inform eco-labeling of wild caught fisheries

Jesse Senko

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Introduction:

Life Cycle Assessment (LCA) was originally developed for evaluating manufactured goods, and typically requires that all flows considered incorporate a functional unit (e.g. raw materials, energy, emissions, processing, waste, etc.) (Kruse et al. 2009), although some would argue other origins. LCA is increasingly being applied to a number of food production systems, including seafood (Kruse et al. 2009). Today, at least 50% of people reside within 200 km of a coast (Hinrichsen 1996) and approximately 15% to 20% of animal protein consumed by humans consists of seafood (Delgado et al. 2003). This is particularly concerning as recent research has identified significant declines in fish stocks from global industrial fisheries (Pauly et al. 2003; Ourers & Worm 2003; Worm et al. 2009) and considerable impacts on non-target animals and habitats (Lewison et al. 2004). Additionally, as human populations continue to rise, fishing efforts (amount of gear deployed) are also increasing in coastal areas (Stewart et al. 2010).

To date, peer reviewed LCAs have been developed in a limited number of wild caught fisheries. These include Norwegian cod fisheries (Ellingson and Aanondsen 2006), Spanish tuna fisheries (Hospido and Tyedmers 2005), Danish fish products (Thrane 2006), and Swedish cod products (Ziegler et al. 2003). Nevertheless, there have been no studies that review wild caught seafood LCAs in the context of developing a framework for incorporating LCA into sustainable seafood eco-labeling guides.

Over the past decade there has been a rapid increase in sustainable seafood eco-labeling, but a lack of standardized methods and disparate information leads to consumer confusion and frustration. Currently, no sustainable seafood scheme utilizes LCA approaches. Instead, they all focus on proximate, ecologically oriented considerations. These proximate ecological impacts stem directly from the extractive or productive stages, but ignore the large-scale biophysical impacts that stem from fisheries (e.g. global warming, resource depletion, etc.) (Pelletier and Tyedmers 2008). These impacts include material inputs, fuels, transport and processing of landings, and discharge of waste. The lack of a LCA framework in sustainable seafood awareness campaigns suggests that consumers may be misled about what is truly “sustainable” because these campaigns are only focusing on ecological criteria (Pelletier and Tyedmers 2008).

We chose to focus this review solely on wild caught fisheries because it is a wild production system, unlike agriculture and aquaculture, which implies that the sustainability should be evaluated (Zeigler et al. 2003). Essentially, wild caught fishing is the last major food production service that relies entirely on harvesting wild animals (Hospido and Tyedmers 2005). In addition, current sustainable seafood eco-labeling schemes already incorporate life cycle considerations in their aquaculture ranking assessments, whereas only ecological indicators are included in wild caught ranking schemes (Pelletier and Tyedmers 2008).

Thus, our objectives are to: (1) review the LCA literature to determine the dominant environmental impact categories in wild-caught fisheries in order to evaluate which phases are causing the greatest impacts; and (2) determine how these impacts can best be mitigated and develop a framework that seeks to incorporates LCA into sustainable seafood guides so that consumers can make better-informed decisions. This framework will include developing meaningful LCA impact categories for sustainable seafood guides. Despite their importance, we considered social factors beyond the scope of this paper.

Life Cycle Impact Assessment For Wild Caught Seafood

In LCA studies, the Life Cycle Impact Assessment (LCIA) phase deals with the scale of environmental or social costs related to specific life cycle activities (Pennington et al. 2004) by using impact categories (phases depicting environment issues of concern) and their corresponding category indicators (e.g. resources, emissions, substances, etc.) to quantitatively represent the results of the Life Cycle Inventory (LCI) (Guinee et al. 2001). Our review indicates that wild caught seafood LCAs use traditional environmental impact categories, but also some non-traditional noteworthy categories. Three of the four studies we reviewed employed global warming, acidification, and eutrophication as impact categories (Table 1). Following this, all studies identified the fishery and transports as life cycle groupings (Table 2). However, some non-traditional impact categories emerged. For example, anti-fouling paint was mentioned in two studies, and may deserve more attention due to the release of biocides that can affect entire marine ecosystems. We also found similarities in impact categories and life cycle groupings, highlighting the need for a more comprehensive analysis of the data. For example, Ziegler et al. (2003) reported the indicator “eco-toxicity” based on pollution from anti-fouling paint and grouped it as “industry”, whereas Hospido and Tyedmers (2005) used “marine toxicology potential” and grouped it as “anti-fouling paint.” (See Tables 1 and 2).

Environmental Hotspots in wild caught seafood LCAs:

One of the most important aspects of LCA is the identification of environmental “hotspots”, activities that contribute disproportionately to the total environmental impact of the system (Hospido and Tyedmers 2005). In all wild caught seafood LCA studies we assessed, the fishery was the dominant environmental hotspot, with fuel consumption being the dominant hotspot within the fishery (Table 2).

Thrane (2006) reported significant differences in fuel requirements for fisheries targeting the same species in the same area (Danish flatfish). For example, by switching from beam trawl to Danish seine fuel input per kg of caught flatfish can be reduced, at least in theory, by a factor of 15. Further, if all flatfish were caught by Danish seine the Danish fishery could save 30,000 m^3 fuel per year, and Danish seine requires 10 times less energy per landing value of flatfish versus beam trawls (Thrane 2006). In Danish cod fisheries, significant fuel reductions can be made by switching from trawls to either longlines or gillnets. Similar reductions can be achieved in mackerel and herring fisheries by switching from pelagic trawls to purse seines (Thrane 2004b).

Fuel Efficient Fisheries as a Compliment to Ecological Sustainability?

Any measures that reduce energy use, especially fuel consumption, will improve the overall environmental impact on the product (Ziegler et al. 2003). But is it possible that fuel-efficient fisheries are also more ecologically sustainable? We believe that, at least in theory, this could be the case for most fisheries. For example, larger discards (including bycatch) result in larger fuel requirements because more fuel is allocated to the retained catch when a large percentage is tossed back (Thrane 2006). For habitat impacts, the friction of gear such as bottom trawls that damages habitat, also likely results in higher fuel costs (Thrane 2006), and beam and bottom trawls are typically the most energy intensive fishing methods (Ziegler et al. 2003). Additionally, as many fish stocks decline, fishers are increasingly traveling farther to maintain catch rates, thus becoming more energy intensive (Tyedmers et al. 2005). Fishing abundant stocks (with a high CPUE) is also important in decreasing fuel consumption, since targeting stocks with a low CPUE will result in higher environmental impacts per catch (Ziegler et al. 2003). For example, high fuel fisheries typically also result in greater damage to the seafloor (Thrane 2004a). At least two studies suggest that energy consumption increases as a function of vessel size (Tyedmers 2001; Thrane 2004a), most likely because larger vessels use more machinery, have greater engine power, and may exploit farther fish resources.

Conclusions, Recommendations, and Future Research Needs:

Our review suggests that the use of some impact categories will be more easily achievable than others when incorporating these results into meaningful eco-label categories. For example, the use of fossil fuels will contribute to global warming regardless of where the emissions occur, but the impacts stemming from other categories (e.g. acidification, eutrophication, eco-toxicity) are inherently more difficult to discern (Pelletier et al. 2007). In order to develop a framework for incorporating LCA into sustainable seafood eco labels, it is important to identify the appropriate impact categories that could be used. This will depend largely on two factors: the quality of data for the impact in question and the ability to link the impact to a realistic functional unit (Pelletier et al. 2007).

Of the papers we reviewed, the fishery was the most dominant environmental stage for most seafood products that have undergone a rigorous LCA. However, other stages of the production phase also contribute considerable impacts, all of which are not being addressed by current eco-labeling schemes. Thus, it appears that there is great potential for eco-labeling guides to include fuel efficiency as a proxy for biophysical impacts. We believe that sustainable seafood guides can and should incorporate biophysical environmental impacts. A good starting point would be fuel use, which we believe aligns well with ecological sustainability and would not compromise ecological indicators.

Several studies suggest that, despite increasing technologies that make engines more fuel efficient, fishing does not show an improvement in energy efficiency (Tyedmers 2001; Huse et al. 2003). Thus, rather than focus on new engines, we recommend targeting emissions controls and fuel efficient fishing practices to mitigate impacts from fuel use/production in the fishery stage. Additionally, we recommend targeting ecologically sustainable species, as these stocks are more likely to be abundant and have fewer bycatch/discards. Thrane et al. (2009) recommends the use of fuel credits per kg of landed fish, or the use of fuel quotas where a vessel or a number of vessels can use a set amount of fuel in a given time period. In this case, energy efficient fisheries could, at least in theory, sell their remaining quotas. This could provide incentives for fishers to use more fuel-efficient gear and fishing techniques (Thrane et al. 2009). Future research should quantitatively assess trendlines between fuel efficiency and ecological indicators such as stock abundance, fishing impacts to habitat, and bycatch. Future research should develop methods to evaluate tradeoffs between stakeholder groups and sustainability science (Kruse et al. 2009).

Our suggestions for improvement do not imply that current eco-labels are misleading or ineffective. Rather, we strive for improvements that more broadly encompass "sustainable" fisheries. At the least, we aim to promote a discussion of if and to what extent life cycle components should be considered in eco-labeling schemes. Finally, it is important to include categories in eco labels that can be adequately verified, so as to not jeopardize the credibility of the ranking scheme (Thrane et al. 2009).

Areas of Future Research

Specifically, we aim to conduct the following future research over summer 2012:

1. *Compare and contrast the current wild caught seafood LCAs versus sustainability "rankings" from the two most popular US based sustainable seafood eco-labeling guides (i.e. Blue Ocean Institute and Marine Stewardship Council).*
2. Compare fishing methods from the above mentioned seafood guides.
2. *Develop a list of challenges in deploying LCA in sustainable seafood initiatives with recommendations on how the industry can start overcoming them.*
3. *Develop a more robust framework for incorporating LCA impact categories for sustainable seafood guides (this will most likely be "fuel efficiency" but may also include eco-toxicity from anti-fouling paint and/or processing phases).*
4. *Compare "ocean" stage impacts vs. "non-ocean" stage impacts*

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Table 1. Impact Categories (IC) of the four major studies reviewed; X indicates study used IC

Reference	Impact Category (IC)																	
	GWP	EP	AP	POFP	POCP	ODP	AEP	MTP	HTP	FF	AC/ET	ET	CC	RI	C	ETWC	ETWA	ETSC
Zeigler et al. (2003)	X	X	X		X		X											
Hospido and Tyedmers (2005)	X	X	X	X		X		X	X									
Ellingsen and Aanondsen (2006)										X	X	X	X	X	X			
Thrane (2006)	X	X	X		X	X										X	X	X

GWP=Global Warming Potential; EP=Eutrophication Potential; AP=Acidification Potential POCP=Photochemical Ozone Creation Potential; AEP=Aquatic Ecotoxicology Potential; POFP=Photo-oxidant Formation Potential; ODP=Ozone Depletion Potential; MTP=Marine Toxicology Potential; HTP=Human Toxicology Potential; FF=Fossil Fuels; AC/ET=Acidification/Eutrophication; ET=Ecotoxicology; CC=Climate Change; RI=Resp. Inorganics; C=Carcinogens; ETWC=Ecological Toxicity Water Chronic; ETWA=Ecological Toxicity Water Acute; ETSC=Ecological Toxicity Soil Chronic

Table 2. Life Cycle Groupings of the four major studies reviewed; X indicates study used IC. (The four rows follow the references from table 1).

Life Cycle Groupings (LCG)											
Fishery	Transports	Sewage	Consumer	Retailer	Wholesaler	Storage	Packaging/Processing	Industry	Anti-fouling paint	Vessel Construction	Auction
X	X	X	X	X	X	X	X	**X**			
X*	X								**X**	X	
X	X										
X	X		X	X	X		**X**				X

X indicates study used LCG
Dominant LCC (in at least one impact category) in bold
*Fishery measured in diesel use/production

Table 3. Comparative analysis of fuel efficiency for fishing methods analyzed using Life Cycle Assessment. Data here expands on the four studies we analyzed in Tables 1 and 2.

Fishery (target species)	Functional Unit	Fishing method	Fuel use (emissions)	Reference
Flatfish		Beam Trawl	~2.7 liters diesel/kg caught	Thrane (2006)
Flatfish		Bottom Trawl	~1 liters diesel/kg caught	Thrane (2006)
Flatfish		Danish Seine	~0.1 liters diesel/kg caught	Thrane (2006)
Swedish Cod in Baltic Sea	Frozen Swedish Cod block (400 g)	Gillnet	Lower emissions than trawl	Ziegler (2007)
Swedish Cod in Baltic Sea	Frozen Swedish Cod block (400 g)	Trawl	Higher emissions than gillnet	Ziegler (2007)
Norway lobster	Boiled Lobster	Creel (pot)	Lower emissions than trawl	Ziegler (2007)
Swedish Cod in Baltic Sea	Frozen Swedish Cod block (400 g)	Trawl	~4,000 CO2 equivalents/FU	Ziegler et al. (2003)
Swedish Cod in Baltic Sea	Frozen Swedish Cod block (400 g)	Gillnet	~1,000 CO2 equivalents/FU	Ziegler et al. (2003)
Swedish Cod in Baltic Sea	Frozen Swedish Cod block (400 g)	Mixed fishing (gillnet and trawl)	~2,700 CO2 equivalents/FU	Ziegler et al. (2003)
Pickled herring	Unclear	Trawl and seine	Trawling required 50% more energy than seining	Ritter (1997)
Finnish herring	Unclear	Pelagic trawl and gillnetting	Higher fuel consumption for gillnetting	Lillsunde (2001)
Groundfish and pelagic fish	Kg landed mixed fish		Net or trap = 0.2 to 0.4 liters diesel fuel/kg mixed fish; trawl = 0.8 to 1.4 liters of diesel fuel/kg mixed fish	Endel (1980); Bak (1994); Hassel et al. (2001) *as cited by* Thrane (2004a)
Shrimp, prawn, flatfish	Kg landed mixed fish	Trawl	1 liter diesel fuel/kg landed fish	Thrane (2004a)
Cod, herring	Kg landed mixed fish	Seine	0.36 liter diesel fuel/kg landed cod; 0.18 liter diesel fuel/kg landed herring	Thrane (2004a)
Mussel, mackerel	Kg landed mixed fish	Seine	0.06 liter diesel fuel/kg landed mackerel; 0.012 liter diesel fuel/kg landed mussel	Thrane (2004a)
Norway lobster, European plaice, Atlantic cod	Kg landed mixed fish	Trawl	0.27 to 0.53 L diesel/kg mixed fish	Thrane (2004a)
Norway lobster, European plaice, Atlantic cod	Kg landed mixed fish	Danish seine, Gillnet	Danish seine and gillnet = ~0.02 L diesel/kg mixed fish	Thrane (2004a)
Norway lobster	Kg landed mixed fish	Trawl	~3-4 L diesel/kg lobster	Thrane (2004a)
Flatfish	Kg landed mixed fish	Trawl	~2.5-4 L diesel/kg flatfish fish	Thrane (2004a)