Hotspots in a Cold Chain: A Life Cycle Assessment of Loki Fish
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Abstract

Wild Alaskan salmon is certified "sustainable" even when shipped market by air, the most fuel-intensive form of food transport. Life cycle assessment (LCA) reveals the shortcomings of existing criteria of seafood sustainability, and suggests avenues for improvement. This study used LCA to analyze the salmon supply chain of a Seattle-based company, Loki Fish. It found that the company's recent switch to shipping salmon by ferry rather than air, while aimed at saving money, also greatly reduced environmental impacts. Greater consumer acceptance of frozen seafood would make this shift feasible on a wider scale. The study also highlights the value of incorporating qualitative analysis of social, economic and cultural factors into assessments of sustainable food supply chains.

Introduction

Rethinking sustainable seafood

In recent years, seafood awareness campaigns have sought to steer the market towards more sustainable options. Typically they focus on the most immediate threats to the world's fisheries, namely overfishing and habitat destruction. These threats are well documented and serious. Indeed, many species abundant only a generation ago now face imminent collapse (Jackson et al. 2001; Worm et al. 2009; Pauly et al. 2003). The pocket seafood guides published by organizations such as the Monterey Bay Aquarium tell consumers exactly what they should do about these endangered species: not eat them. Also in the "avoid" category are the aquaculture products that harm fisheries through pollution, genetic contamination, or the depletion of the fish and other marine resources used as feedstock (www.montereybayaquarium.org).

As alternatives, most guides and eco-labels recommend what the Monterey Bay Aquarium calls "ocean friendly seafood": i.e., varieties that are neither overfished nor raised or harvested in an ecologically damaging manner. In this category fall species ranging from humble croakers and catfish to Alaska's prized king salmon.

The problem with the sustainability criteria behind such guidelines is that they tend to neglect everything beyond localized ecological impacts (Pelletier and Tyedmers 2008). They warn against farmed fish fed on other fish, for example, but endorse certain farmed varieties raised on land-based feed—including feed from industries that are arguably more environmentally damaging overall, due to their contributions to global warming. This is just one of many inconsistencies revealed by a growing number of life cycle assessments (LCAs) of fisheries and seafood products (Ayer et al. 2009). These studies demonstrate that existing seafood sustainability criteria are not just overly local in their focus but also ultimately shortsighted, because global climate change counts among the threats to many fisheries (Ficke et al. 2007; Perry et al. 2005).

Life cycle assessment has the potential to reshape both scientific and popular understandings of seafood sustainability. *Potential* is the operative term, however. Published data is scarce, and methodological consensus lacking (Pelletier et al. 2007). In addition, LCA by itself is not yet well equipped to assess the diversified practices typical of smaller fishing operations, nor the social and economic benefits they generate. This is an important consideration for future sustainability policies or certification systems reliant on LCA methods. But already the LCA dictum "count what matters" has shown why any assessment of fish sustainability needs to count more than fish. How seafood gets from ocean to kitchen—and in what form—also matters.

LCA takes on the fetish of fresh

Fish lovers who never dine without consulting their Seafood Watch pocket guides also never forget to ask, is it fresh? It's a good question, for in few foods does tastiness depend more directly on freshness (Freidberg 2009). Due both to its own physiology and that of the bacteria it hosts, raw fish tends to age faster and in a more unappetizing fashion than most other animal-based foods, even in a refrigerator. Thus to arrive truly fresh on a diner's plate, it must be caught locally, transported rapidly, or kept alive en route to the kitchen. In many markets, of course, the local catch is no longer an option, if it ever was. So live lobsters and other shellfish routinely fly great distances, as do live groupers and other species valued in the East Asian market. In the West, meanwhile, salmon caught in certified-sustainable Alaskan fisheries are rushed to the airports of Cordova and Ketchikan, where they fly to Seattle and then onwards to San Francisco, Chicago and New York (see also Petersen and Nielsen 2004). Along the way, their modest "finprint" inflates rapidly, for airfreight is by far the most resource-intensive way to move food (Sim et al. 2007; Garnett 2003).

This case against flying fish made it onto the *New York Times'* opinion page in December 2009. Written by a trio of LCA practitioners, "Catch of the Freezer" urged consumers to stop assuming that fresh is always best (Scholz et al. 2009). Frozen seafood is not only much better than in the past, thanks to improved freezing and storage methods; it can also travel by boat and rail, both much greener forms of transport than airfreight.

The *Times* op-ed drew on the findings of an ongoing multi-sited global salmon LCA research project (ecotrust.org/lca). Unfortunately (especially for this paper) the findings themselves have not yet been published. The LCA literature on seafood, for all its studies on Danish cod and Norwegian aquaculture, thus still lacks data on both wild salmon fisheries and on seafood catch-to-market transport more generally (Thrane 2006; Pelletier and Tyedmers 2007).[1] Nonetheless, the *Times* op-ed suggests that the impacts of flying otherwise "sustainable" seafood may soon receive more attention. It also provides an opportunity to examine the particular case of a small Alaskan salmon operation that has recently switched from air to marine shipping.

Methodology

Goal and Scope

This paper has two goals. First, it aims to identify the “hotspots” in the cradle-to-gate life cycle of the Alaskan and Washington state salmon caught and sold by Loki Fish, a Seattle-based family-run fishing business. Geographically, the salmon supply chain reaches from the Clarence Strait in Southeastern Alaska to Seattle, a major market for the region’s salmon as well as an entrêpot for shipments to other destinations. Second, the paper aims to contribute to the discussion on how to adapt LCA methodology to primary foodstuffs, especially those produced by small-scale operators. Of particular concern is the potential burden of LCA’s data demands, and the suitability of existing life cycle inventories (LCIs) and impact categories to assessments of non-industrial food production processes (Edwards-Jones et al. 2009).

System description and boundaries

The owner of Loki Fish, Pete Knutson, is not a typical fisherman in that he doubles as an anthropology professor and environmental activist. However the scale of his business—two 40-foot gillnetter boats that each land about 40 tons of fish a season—is not entirely unusual in Alaskan waters. The state’s salmon fishery ranks among the world’s best managed (Hilborn et al. 2003). Both the relative abundance and the “green” image of Alaskan salmon have helped to sustain small fishing operations, especially those engaged in direct marketing. Loki Fish, for example, sells fish off-boat in Seattle’s Fisherman’s terminal, at farmers’ markets, to restaurants, and online. Its products include fresh and frozen whole salmon, vacuum-packed salmon fillets, and a variety of smoked and canned salmon preparations (lokifish.com).

This study examines only the product and transport stages of the salmon life cycle. Other LCAs of food products have identified significant environmental impacts in the “use” stages, including transport from the market, cooking, and disposal (Carlsson-Kanyama et al. 2003;

Edwards-Jones and Plassmann 2009; Van Hauwermeiren et al. 2007; Wallgren 2006; Heller and Keoleian 2003). With highly perishable foods such as fish, waste from spoilage also deserves consideration. Apart from practical constraints, however, this study's focus on production and transport was shaped by the findings of other seafood LCAs.

Most such LCAs identify fishing itself as the hotspot, primarily due to its fuel-intensity. Secondary impacts include the marine eco-toxicity of the antifouling paints applied to vessel hulls, and the harm to marine ecosystems caused by excessive by-catch and, depending on the fishing method, seafloor or reef damage. While not trivial, these impacts are not yet well captured by the existing life cycle impact categories (LCIAs) (Pelletier et al. 2007). Nor are the resource demands of fish hatcheries (Tyedmers 2000). This assessment includes antifouling paint but not by-catch or seafloor effects, neither of which pose major problems in salmon gillnetting. It also excludes boat and gear construction, which other LCAs have recommended (Ziegler et al. 2003).

To date, transport has emerged as a hotspot in seafood LCAs only when the fishing vessels are themselves traveling to distant fisheries. Long-distance voyages such as those undertaken by the Spanish tuna fleet—from the Mediterranean to the Pacific and Indian Oceans—reflect both strong demand and diminishing regional supplies (Hospido and Tyedmers 2005). In the United States, the near-collapse of West Coast fisheries has driven many fishing boats on seasonal migrations to Alaska. Here again Loki Fish is not atypical, except that Pete Knutson and his son Jonah follow up the Alaska summer season with fall fishing in Puget Sound, where pink and chum salmon populations are relatively healthy.

This study examines the cradle-to-gate life cycle of both seasons. For the Alaska season, the fuel used during roundtrip Seattle-Ketchikan voyage (700 gallons per boat) is combined with the fuel used during fishing (1000 gallons per boat) for a total of 1700 gallons used to catch approximately 80,000 pounds of dressed salmon per season (or .18 l/kg). For the journey to market two routes are examined: by air in a 737 from Ketchikan to Seattle, and by ferry from Ketchikan to Bellingham.

Until recently Loki Fish, like many small high-value operators, flew most of its fish to market. Rising fuel costs and unreliable flights, however, led to a shift in strategy. Now the Knutsons store their dressed fish onboard in 29 degree refrigerated seawater (RSW), delivering it to shore every couple of days. There it is packed in ice in reusable insulated totes (also excluded from the assessment after initial estimates showed no detectable impacts relative to transport) and driven in a 6-ton refrigerated box truck 145 km to the ferry, which takes two days to reach Bellingham. There a portion of the catch is frozen and stored by the Bellingham Cold Storage Company, and the rest taken by a refrigerated van to Seattle (another 145 km) either for direct sale or further processing (Figure 1).

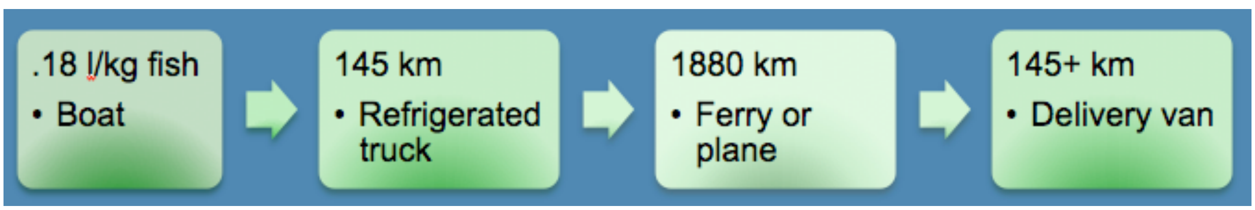

Figure 1: Cradle-to-gate unit processes in Loki Fish Alaskan salmon life cycle

Because of the proximity of the Clarence Strait to Seattle (relative to other Alaskan fisheries), the Knutsons can use marine transport and still deliver their in-season salmon fresh to market. This is not feasible in more remote regions, where niche marketers of fresh seafood depend on Alaska Airlines' quick but costly cargo service. The alternative, as suggested by Scholz et al.'s *New York Times* op-ed, is to blast-freeze the salmon onboard or ashore and then ship it (Ess 2004). Although this process may have more negative environmental impacts than freezing the salmon in Bellingham (where hydropower rather than diesel provides the energy) Scholz et al. imply that it would still not compare to flying.

Functional Unit, Life Cycle Inventory, and Impact Assessment Methods

The functional unit in this study is one kilogram of dressed salmon. One kilo is a conventional unit in seafood LCAs, and suitable when consumer use is excluded. The life cycle inventory (LCI) was assembled and analyzed with SimaPro 7.1. All the unit processes come from Ecoinvent except for "Salmon," which was adapted from the Danish LCA Food database ("Cod, ex harbor" was used as a proxy by taking out the by-catch and adjusting fuel use). The unit "Salmon" includes the fishing diesel fuel and one gallon per year of antifouling paint (an ordinary paint together with copper oxide was used to approximate this input).[2]

Among the modes of transport, Ecoinvent offered an unambiguous unit process only for airfreight (a short-to-medium haul jet such as Alaska Airlines' 737). For the refrigerated box truck, Ecoinvent offered a choice of three 3.5 to 7 ton lorries with different (but unfortunately not clearly documented) levels of fuel performance. The same is true for Ecoinvent's selection of delivery vans. None of the databases have a "ferry" unit process, so an inland vessel (probably too small) and a barge (maybe too big) served as proxies. This assessment also considered the ice used during road and ferry transport, though it only appeared significant in the assessment of the Puget Sound inventory.

The life cycle impact assessment (LCIA) relied on SimaPro's Impacts 2002 method. It began with a simple comparison of the flight versus ferry option. This was followed by assessments of fishing versus road versus ferry transport, for both the Alaska and Puget Sound seasons. Lastly, interview material allowed for a qualitative assessment of ecological, social and economic considerations not suited (at least not yet) for a software-generated LCIA.

Results

Assessment 1: Air versus Sea

As expected, this comparison shows a sharp contrast between Loki Fish's old and new routes to market, even when using the more energy intensive proxy for a ferry (a barge).

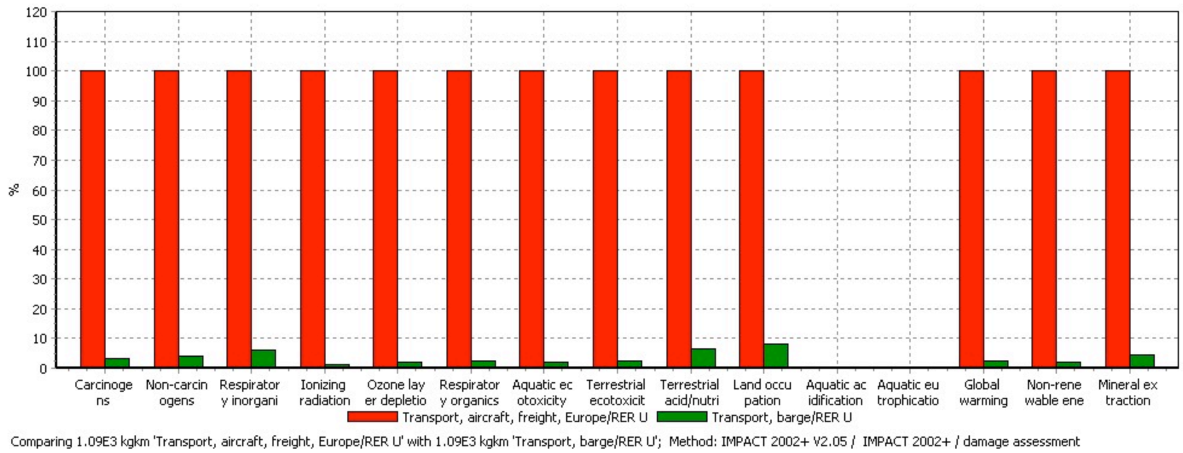

Figure 2: Transport of 1 kg salmon 1088 km by 737 versus ferry: damage assessment

Figure 3 especially shows the dramatic difference in climate change and fossil fuel use impacts. It is worth noting, however, that this LCIA probably underestimates some of the environmental burdens of marine transport. An assessment of the barge/ferry (Figure 4) shows no contribution to aquatic ecotoxicity, which is unlikely (Brooks and Waldock 2009).

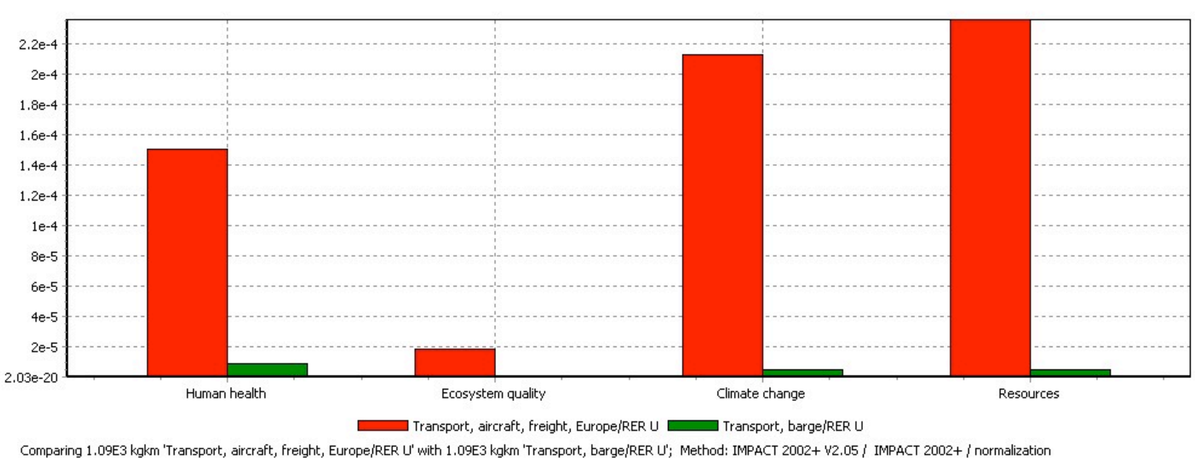

Figure 3: Transport of 1 kg salmon 1088 km by 737 versus ferry: normalization

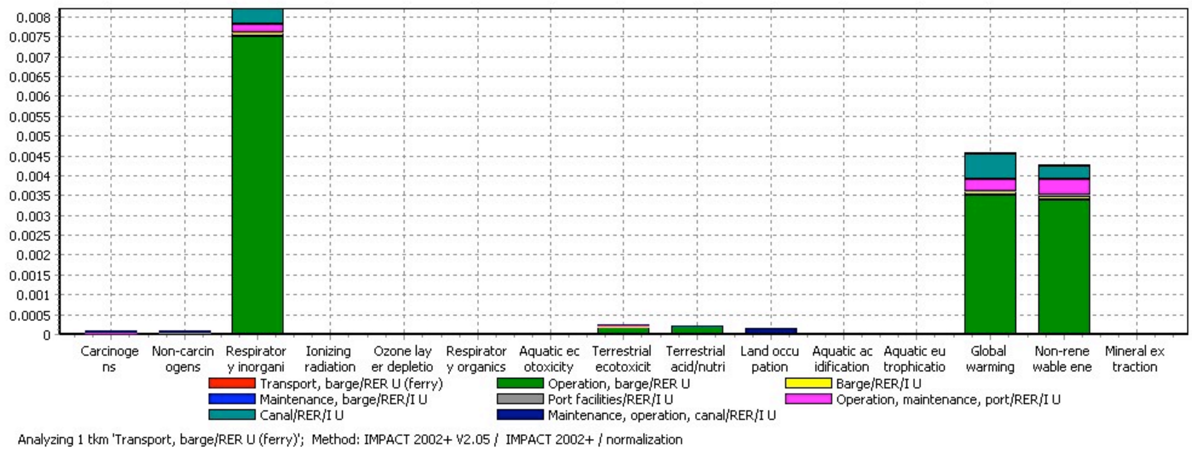

Figure 4: Normalized impacts of ferry (barge) transport

Assessment II: Fishing, road and marine transport

In this assessment, the choice of Ecoinvent unit process turned out to have decisive effects on the overall results. In figure 5, the 145 km journey from shore to ferry terminal clearly dominates. This is conceivable; Loki Fish's truck is refrigerated and gets only about 11 miles to the gallon (4.67 km/l).

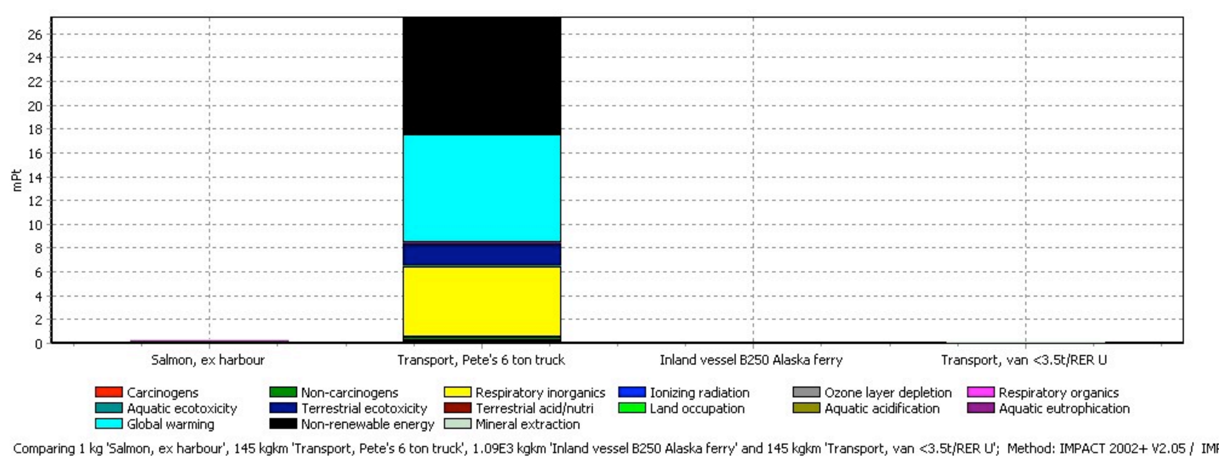

Figure 5: Fishing and transport, "lorry 3.5-7.5t, Euro5/RER U" as proxy for truck

However, when another presumably more fuel-efficient European lorry is used as a proxy, fishing emerges as the hotspot, due to the fuel use and copper-based antifouling paint (Figures 6 and 7).

This result, based on an admittedly very rough approximation of copper inputs, aligns with other seafood LCA findings (Hospido and Tyedmers 2005; Thrane 2006).

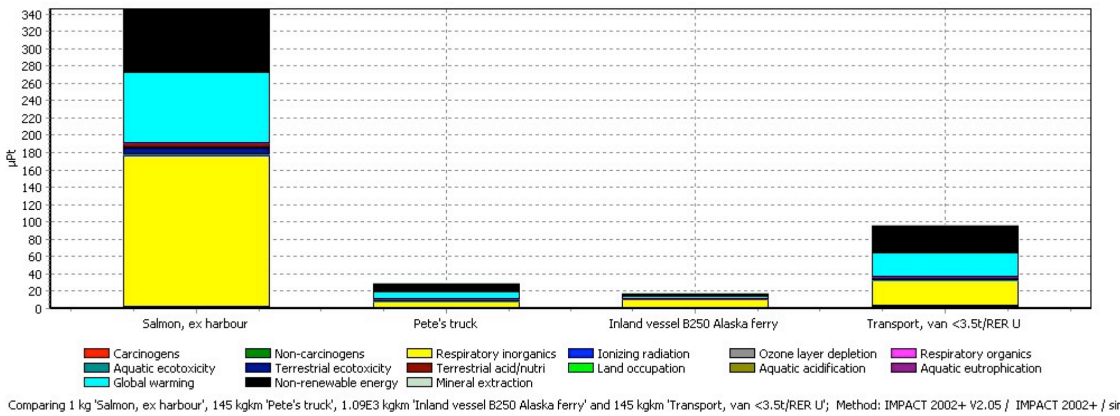

Figure 6: Fishing and transport, "lorry 3.5-7.5t, Euro4/RER U" as proxy for truck

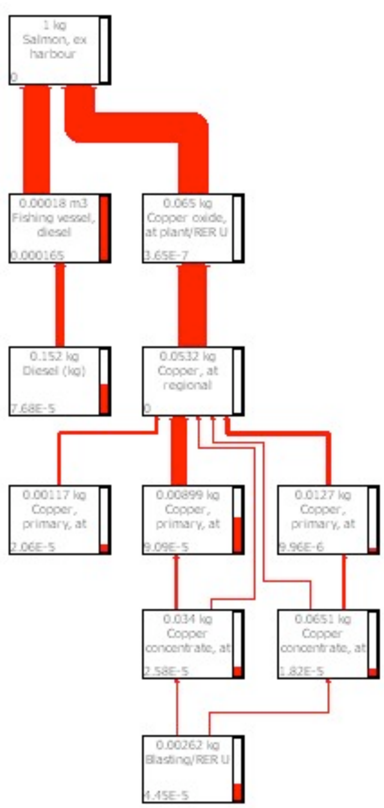

Figure 7: Fishing, Alaska (Method: IMPACT 2002+)

For the Puget Sound fishing season, the results are less ambiguous, assuming that the delivery van selected in Ecoinvent accurately represents the delivery van used to transport the catch from port

(Fisherman's Terminal) to various Seattle outlets. Using a truck instead of a van (Figure 9) changes the picture entirely.

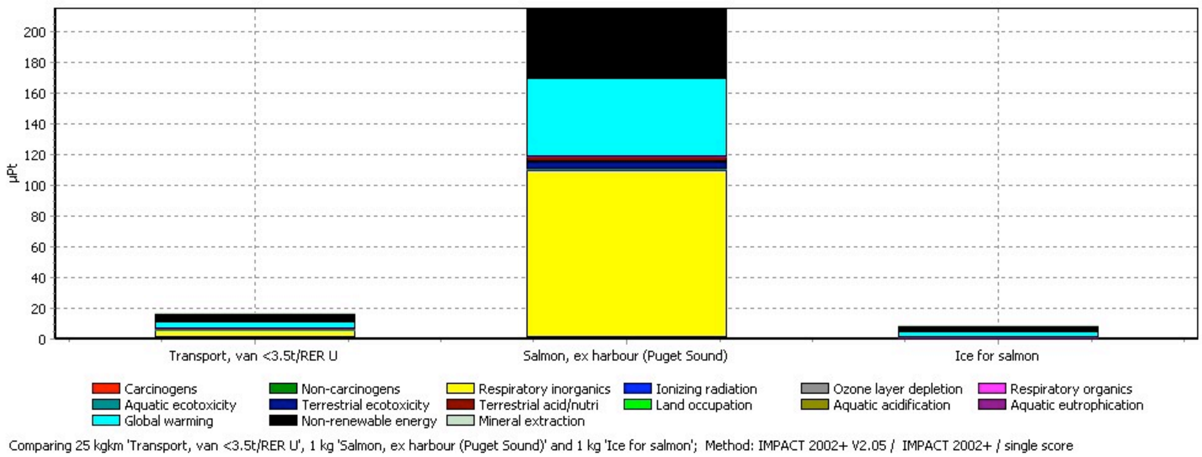

Figure 8: Fishing and transport, Puget Sound fishery (van + 25 km port to market)

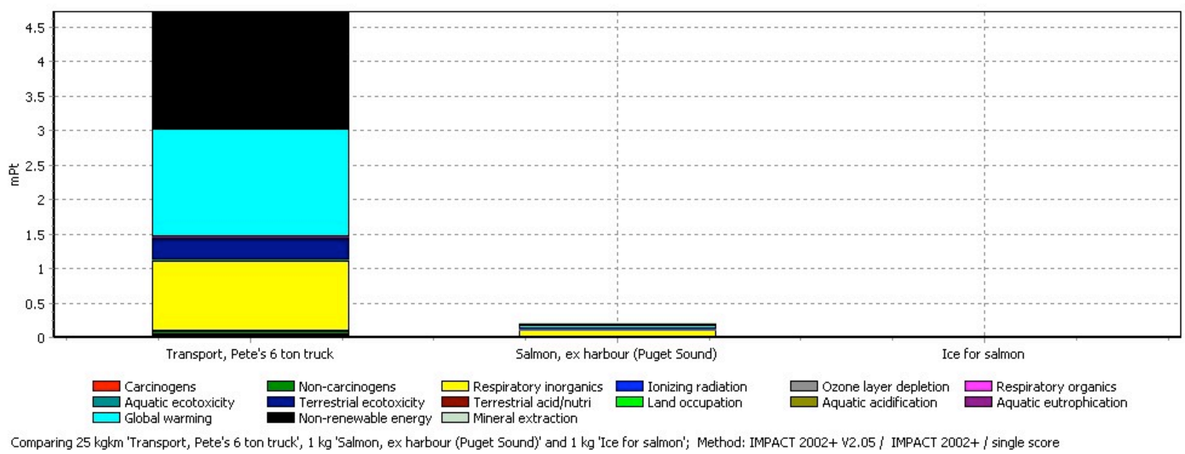

Figure 9: Fishing and transport, Puget Sound fishery (truck + 25 km port to market)

This variation illustrates the extent of uncertainty introduced by proxy data (Norris 2002). However it should not distract from the overall low fuel intensity of Loki Fish's supply chains. Indeed, the choice of lorry has so much effect on the calculated results only because the system's other impacts are relatively minor. Compared to the energy performance of fisheries surveyed in Tydemer (2004) Loki Fish's consumption of 180 liters diesel per metric ton of dressed salmon is extraordinarily low.

Energy Performance of Industrial Fisheries for Direct Human Consumption

Main fishery targets	Gear	Time frame	Location of fishery	Fuel use intensity (liters/tonne)	Edible protein EROI
Demersal fisheries					
Redfish spp.	Trawl	Late 1990s	North Atlantic	420[a]	0.11
Cod/flatfish spp.	Danish seine	Late 1990s	North Atlantic	440[a]	0.10
Cod/haddock	Longline	Late 1990s	North Atlantic	490[a]	0.091
Cod/saithe	Trawl	Late 1990s	North Atlantic	530[a]	0.084
Alaskan pollock	Trawl	Early 1980s	North Pacific	600[b]	0.052
Flatfish spp.	Trawl	Early 1980s	NW Pacific	750[b]	0.066
Croakers	Trawl	Early 1980s	NW Pacific	1500[b]	0.029
Flatfish spp.	Trawl	Late 1990s	NE Atlantic	2300[a]	0.019
Pelagic fisheries					
Herring/mackerel	Purse seine	Late 1990s	NE Atlantic	100[a]	0.56
Herring	Purse seine	Early 1990s	NE Pacific	140[c]	0.36
Herring/saithe	Danish Seine	Late 1990s	NE Atlantic	140[a]	0.35
Salmon spp.	Purse seine	1990s	NE Pacific	360[c]	0.15
Salmon spp.	Trap	Early 1980s	NW Pacific	780[b]	0.072
Salmon spp.	Gillnet	1990s	NE Pacific	810[c]	0.068
Salmon spp.	Troll	1990s	NE Pacific	830[c]	0.067
Herring	Purse seine	Early 1980s	NW Pacific	1000[b]	0.051
Skipjack/tuna	Pole and line	Early 1980s	Pacific	1400[b]	0.053
Skipjack/tuna	Purse seine	Early 1980s	Pacific	1500[b]	0.049
Swordfish/tuna	Longline	Late 1990s	NW Atlantic	1740[a]	0.042
Salmon spp.	Gillnet	Early 1980s	NW Pacific	1800[b]	0.031
Swordfish/tuna	Longline	Early 1990s	Central Pacific	2200[d]	0.027
Tuna/billfish	Longline	Early 1980s	Pacific	3400[b]	0.022

Figure 9: Fishery energy efficiency in liters fuel/tonne catch (Tyedmers 2004)

Recall that this figure includes the fuel consumed during the roundtrip Seattle-Ketchikan voyage. At 160 liters diesel per metric ton, the salmon caught in Puget Sound is even more fuel-efficient. The overall difference between the two supply chains is less than might be expected due to the higher daily fuel usage in travel to and from the Puget Sound fishing grounds (Figure 10).

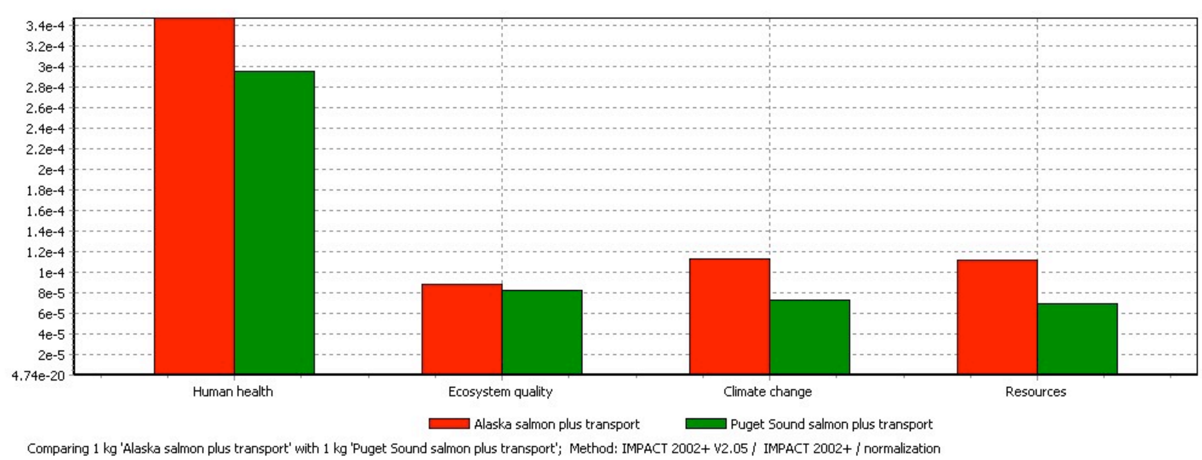

Figure 10: Fishing plus transport, Alaska versus Puget Sound

Qualitative considerations and conclusion

By switching from air to marine shipping, Loki Fish greatly reduced the environmental impact of transporting its salmon to Seattle. This comes as no surprise; other studies have found airfreight accounting for about 90% of the global warming potential of fresh foodstuffs such as Kenyan green beans (Sim et al. 2007). As Figure 9 suggests, the next logical target for improvement might be gear type. A number of seafood LCAs find purse seining far more fuel-efficient than trawling, as well as less destructive to the seafloor (Thrane 2004; Ziegler et al. 2003; Tyedmers et al. 2005). Gillnetting, the method used by Loki Fish, generally ranks somewhat less favorably than seining when assessed simply in terms of fuel consumed per mass of fish or edible protein landed. But purse seines tend to trap more by-catch than gillnets and also to bruise or even crush their target catch, rendering it unsuitable for sale as whole fish or fillets. While this loss in value matters little to industrial scale fish processors, it is unaffordable to direct marketers such as Loki Fish (Knutson 2009).

The question of what constitutes efficiency in fishing—or for that matter, any kind of food production—leads inevitably to questions of scale and value. All are normative, and therefore not easily resolved through purely quantitative assessments. That said, qualitative interview material does indicate areas where social indicators could be fruitfully incorporated into LCA (Norris 2006). For example, catching Alaskan salmon in two small boats and then selling it at Seattle farmers' markets is almost certainly *not* the most fuel-efficient way to deliver seafood calories to consumers. But the "social efficiencies" of direct marketing are potentially considerable (Knutson 2009). Loki Fish typically employs at least 10 people, including family members. If job creation and quality were incorporated into LCAs (as some researchers are already attempting; see (Hunkeler 2006; Grieflhammer et al. 2006; Andrews et al. 2009), assessments of the efficiency and sustainability of different food supply chains might look quite different.

Another consideration, also not easily quantified, is the value of the knowledge transmitted within food supply chains, both between sellers and buyers and sometimes between generations. This knowledge can itself have ecological benefit. For example, Scholz et al's *New York Times* piece points out that one obstacle to more sustainable seafood sourcing is consumers' wariness of frozen fish. In the Seattle area, however, Loki Fish and other small fishing enterprises have taken advantage of their direct and regular contact with buyers (including restaurants) to educate them about the virtues of fast-frozen wild catch (Freidberg 2009). Now some of the city's most acclaimed restaurants feature it.[3] Loki Fish also encourages customers to try smaller salmon species such as pink and chum, which reproduce more prolifically and feed at lower trophic levels than the high-status king or sockeye. This type of consumer education may prove at least as effective at changing market behavior than the most carefully designed and certified eco-labels.

As for intergenerational communication: it matters insofar as it helps to sustain skills and knowledge that are both culturally valued and have the potential to advance sustainability more broadly. The cultural value attached to skillful fishing—which is as much about quality as quantity—hardly needs explanation anywhere that it contributes importantly to regional foodways. At the same time, studies of the "skipper effect" suggest that such skills also have ecological value. Simply put, skippers who know where to find the fish can spend less fuel doing so (Ruttan and Tyedmers 2007; Bjarnason and Thorlindsson 1993). Loki Fish is one example of a fishing enterprise that is passing thirty-plus years of knowledge from one generation to the next. Its success in doing so owes partly to the fact that direct marketing Alaskan salmon remains, at least in Seattle, an attractive and viable livelihood—a fact that in turn owes to the strong supply of and demand for the fish itself.

This point leads to what is perhaps the least controversial finding of seafood LCAs: namely that when there are plenty of fish in the sea, it takes less energy to catch them. Healthy fisheries, in other words, are better not just for local ecosystems and economies, but also for the global environment (Driscoll and Tyedmers 2009; Pimentel et al. 1996; Ziegler et al. 2003). Life cycle assessment thus bolsters the arguments for effective fisheries management and habitat protection. In addition—and as this study has reaffirmed—it shows why criteria of seafood sustainability need to take account of ecological processes and human practices well beyond the water.

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[1] One partial exception is Peter Tyedemer's PhD thesis, but it relies on an ecological footprint rather than an LCA methodology. (Tyedmers 2000)
[2] Of the two boats used by Loki Fish, the fiberglass one is painted every three years, and the wooden one annually. Both use two gallons for each painting. An estimate of 600g of copper per liter of paint was used, based on the literature.
[3] Tilth, ranked by the *New York Times* as one of the 10 best restaurants of 2008, lists "Pete Knutson's sous-vide Sockeye salmon" on its December 2009 menu (tilthrestaurant.com).

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