Impacts of the Peruvian anchoveta supply chains: from wild fish in the water to protein on the plate

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The Peruvian anchoveta fishery is the largest national fleet worldwide targeting a single species, with catches averaging six million tons over the last four years (PRODUCE, 2009). Fish are targeted by both an industrial fleet, whose landings are directed nearly exclusively at fishmeal and fish oil production, and by an artisanal fleet (GRT <32 t), whose catches are, in principle, mostly used for direct human consumption (canned, frozen, fresh or smoked). In practice, however, a great deal of anecdotal evidence indicates that most of the artisanal fleet's catch in recent years is also destined for fishmeal production. As a result, supply chains for direct human consumption (DHC) appear to only receive <1% of total anchoveta landings (Fig. 1). Although DHC of anchoveta has apparently increased over the last 10 years, the continued low overall rate of DHC constitutes a paradox in a country where severe malnutrition continues to affect a substantial portion of the population. Furthermore unemployment is high in Peru (8% in 2008, possibly more in practice due to under-reporting), especially for unqualified or poorly qualified people that could benefit from changes in the present exploitation and transformation of the anchoveta supply chains (Fig. 1). Although the present situation seems to be economically sustainable, socio-economic aspects need to be considered more fully to understand this paradox (e.g. choice of the consumer according to gustative preferences and economical resources; better rent provided by the fishmeal supply chain boosted by the aquaculture demand, etc.).

The Peruvian fishmeal and fish oil production is aimed at producing primarily animal feedstuffs (about 30% of the world production; IFFO, 2008). Despite the relative conversion efficiency of many culture systems (e.g. poultry, fish, etc.) cycling anchoveta meal and oil through other species is not as effective a means of providing highly nutritious animal protein to humans than the DHC of anchoveta. In addition, previous research suggests that substantial energy inputs are required throughout the meal/oil mediated supply chain when inputs to fish harvesting, reduction, transport etc. are accounted for (Pelletier, 2008; Pelletier *et al.*, 2009). Importantly, due to extremely high catch rates, the anchoveta fishery (and resulting meal and oil produced) is one of the most efficient per ton of landed fish in terms of energy use and associated environmental impacts (e.g. greenhouse gas emissions, acidifying emissions etc.). To what extent this advantage compensates for the length of the indirect human consumption supply chain is an open question. Furthermore, without a proper quantification of the numerous sources of environmental impacts, one must

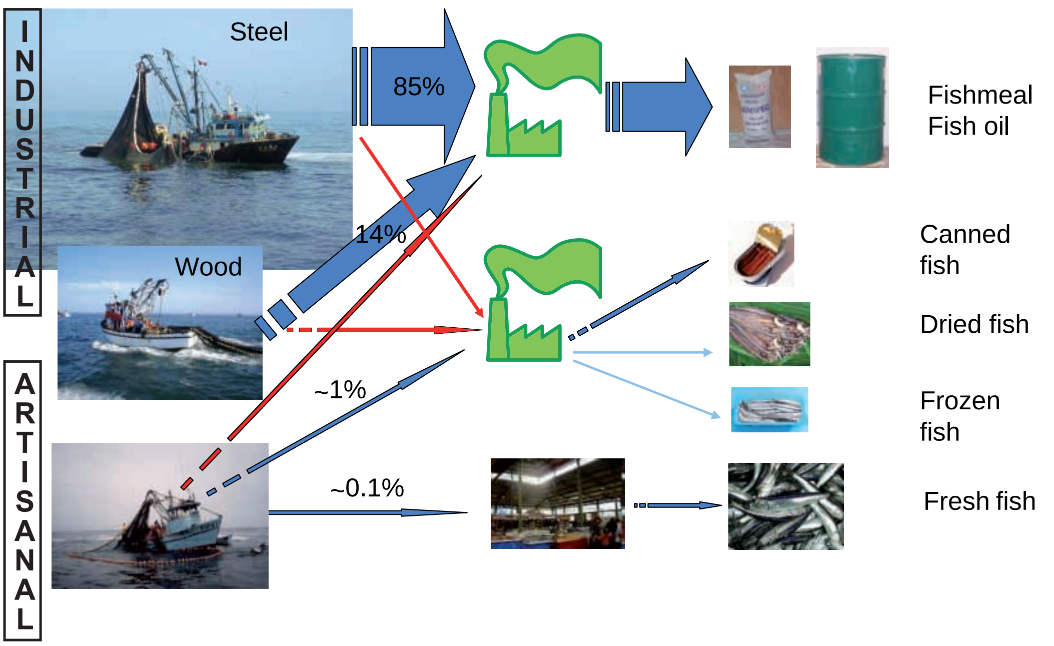

Figure 1. Scheme of the Peruvian anchoveta supply chains. Red arrows represent low (<1%) and not quantified flows.

be cautious before pointing to supposedly bad practices. For instance a detailed study of the Indonesian farmed tilapia supply chain that includes all inputs to production (including anchoveta meal and oil), processing and transport of fish in refrigerated cargo to Rotterdam or Chicago indicates that, due to economy of scale, the major impact within the whole chain was not associated with this long cargo transport but from the production of the tilapia fillets themselves (Pelletier and Tyedmers, in press).

Aquaculture versus fishing

This issue of efficiency of supply chains for direct or indirect human consumption is further complicated if one considers the present changes in animal farming and feeds. Animal proteins are not used any more to feed bovine and their use in swine and poultry production has decreased markedly over the last decade. In contrast, the use of both fishmeal and oil has increased markedly in aquaculture feeds (Tacon and Metian, 2008). The proportion of fishmeal (up to 63%) and fish oil (up to 26%) in some aquafeeds is typically much higher than in poultry and livestock feed (2–3%) and the production of aquaculture is growing fast (Naylor *et al.*, 2000, 2009). As a result, most (~70%) of the world (and Peruvian) production of fishmeal and fish oil is now used for aquaculture feed, mainly in Asia (Tacon and Metian, 2009). Nonetheless, the proportion of animal proteins and lipids (mainly fishmeal and fish oil) used in animal feeds has decreased substantially in recent years as feed formulations improve and many aquafeed formulators strive to reduce overall dependence on marine-sourced inputs. For instance, 10 years ago the equivalent of 5 kg of live weight fish (typically anchovy) was necessary to produce 1 kg of a carnivorous fish species like salmon, whereas nowadays the value is closer to 4 kg and even lower when fast-growing tropical carnivorous species are used (Yuto Aguilar *et al.*, 2007; Mora-Sanchez *et al.*, 2009). The overall "fish-in to fish-out" (FI/FO) ratio for fed species was reduced from 1.05 in 1995 to 0.65 in 2007 (Naylor *et al.*, 2009), and expected "progress" in genetics, physiology and feeding practices will likely continue to reduce this ratio into the future. Furthermore, a recent trend is to feed herbivorous (typically carp) and omnivorous fish species with fishmeal and fish oil. In all these cases the decrease in FI/FO ratios is obtained by greater use of alternative protein sources like soya meal, that also have an environmental impact linked to agricultural practices and related emissions (e.g. mechanical traction, production of fertilizers and pesticides, deforestation).

There are many more elements that contribute to the debate between aquaculture and DHC of wild fish (e.g. effluent discharge, habitat modification, use of wild seed to stock aquaculture ponds, unintended introduction in the wild of non-endogenous organisms, discharge of nutrients, dispersion of chemicals, concentration of pathogens, acceptance by the consumer of some forage fish species for DHC, use of fishmeal for pets, etc.; see review of Naylor *et al.*, 2000). One of them is the fact that in the wild, the equivalent of FI/FO ratio for carnivorous fish species is always higher than in fish farming, due in part to the higher metabolic energy demands associated with the foraging behaviour of wild fish in contrast with the industrial energy inputs to supply feed to farmed fish. Assuming a conventional value of a 10% conversion rate between trophic levels (Lindeman, 1942; but see controversy in Burns, 1989), producing 1 kg of wild predatory fish requires 10 kg of wild prey compared with 2–5 kg to produce 1 kg of farmed fish. This kind of comparison, while at first seemingly reasonable and straight forward, has its weaknesses. It includes the presumption that prey species and all species destined for reduction are trophically equivalent. Moreover, energy flows in marine ecosystems do not occur within a linear food-chain but within a complex food web. Exploiting higher trophic level fish in the wild allows, in principle, increased productivity of forage species that may in turn be more easily exploited (but within this forage fish community an unexpected decrease of productivity of some species can occur due to increased competition). In contrast, exploiting only one or other trophic level of the ecosystem could favour undesirable regime shifts. More importantly, the growing aquaculture industry cannot indefinitely continue to rely on finite stocks of wild-caught fish, as many are already considered fully exploited, over-exploited or collapsed (FAO, 2009). However, fisheries are not expected to be able to fulfil increasing demand for fish resulting from the demographic expansion of the human population. The gap could be fulfilled by relying on energy-efficient aquaculture production. Rather than pitting aquaculture against fisheries, we consider that both activities urgently need further research for integrated management and sustainable development.

Artisanal versus semi-industrial or industrial fishery

Since Thomson's work in 1980 (Thomson, 1980), several authors have compared artisanal and industrial fisheries using rough global estimates of number of employees, capital cost per fisher, fuel consumed and discards (Sumaila *et al.,* 2001; Pauly, 2006; Therkildsen, 2007; BNP, 2009). Although the methodology of these estimations varies and is sometimes not described, they often reveal previously unappreciated benefits of artisanal fisheries in terms of employment, food security and poverty alleviation, all points that deserve more detailed study. Small boat fisheries are also alleged to make better use of energy (Pauly, 2006; BNP, 2009). However, these statements appear to be supported by limited data. In some cases, including a preliminary study of the Peruvian anchoveta fishery (Fréon *et al.*, in prep.), small scale fisheries may be less energetically efficient than their large-scale, more industrialised counterparts (Sumaila *et al.*, 2001; Therkildsen, 2007). However in some instances, other factors such as differences in fishing gear and fishing grounds targeted, may confound the role of vessel scale.

An innovative research project

All these issues indicate that a proper integrated, quantitative and comparative study of food supply chains founded on anchoveta is needed. Indeed a fishery is one of the nodes of a larger network that includes up and downstream processes or activities such as fluxes of energy and biomass in marine ecosystems, boat and gear construction, fuel provision, fish processing, marketing and transport, aquaculture uses and impacts. Often impacts of these other activities are easily overlooked. Fossil fuel use and associated greenhouse gas emissions, which are important aspects of the environmental and economic sustainability of a fishery (Driscoll and Tyedmers, in press) are important examples. Some studies have previously been performed to determine the life cycle environmental impacts of fisheries (e.g. Hospido and Tyedmers, 2005) or aquaculture (e.g. Aubin *et al.*, 2009; Ayer and Tyedmers, 2009; Pelletier *et al.,* 2009) in other countries, while in Peru studies have concentrated on socio-economical aspects (Aguero, 1987; Csirke and Gumy, 1996) or ecological ones through the use of trophic models for example (Tam *et al.*, 2008; Taylor *et al.*,

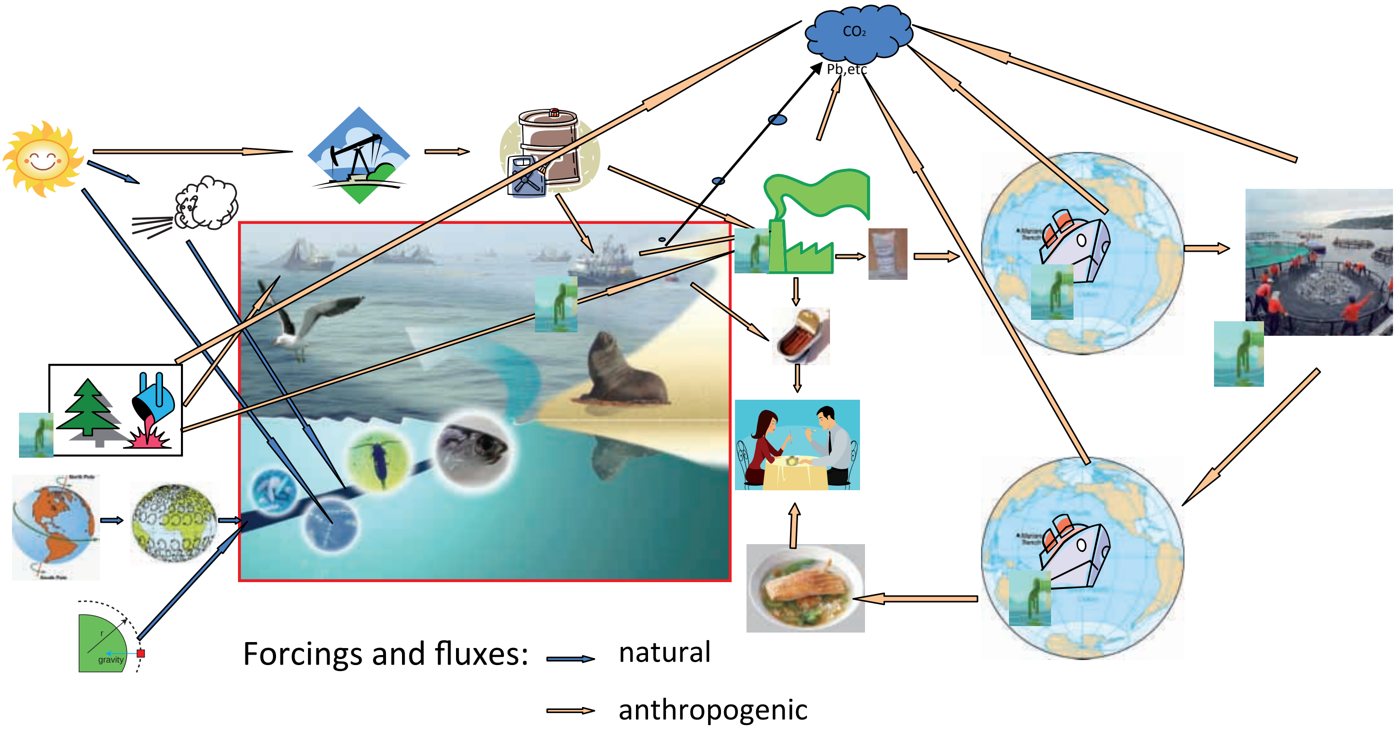

Figure 2. Simplified diagram of the functioning and environmental impact of the Peruvian anchoveta supply chain. The large composite image with a red frame in the diagram represents the Peruvian Marine ecosystem whereas items surrounding it in the far left and upper parts of the diagram represent natural forcing (sunlight, wind, Coriolis and gravity forces) and "exosomatic" input such as construction materials (wood, mineral) and domesticated energies (fuels). Items on the left hand side of the diagram represent transformation of anchoveta for direct or indirect human consumption, for instance through carnivorous fish cultivated in Asia.

2008). However, little is known about the environmental effects of the entire life cycle of anchovy production including the different impacts resulting from industrial and artisanal fleet activities and from indirect and direct human consumption alternatives. Given the important role that anchoveta meal and oil play in a wide range of aquaculture and terrestrial livestock production systems, current models of these systems rely upon poorly resolved data regarding the anchoveta fishery and reduction process.

A new research project on environmental and socio-economical impacts of the Peruvian anchoveta supply chains was launched at the end of 2009 by IRD (French Institute of Research for Development) and IMARPE (Instituto del Mar del Peru), within the framework of the International laboratory DISCOH (Dynamics of the Humboldt Current system) and with the input of external experts in various fields. The aim of the study is to quantify and compare the environmental and socio-economical impacts of the Peruvian anchoveta supply chains for direct and indirect human consumption, from end to end (Fig. 2). The first step will be a comparison of impacts resulting from the extraction phase according to the type of boat (small-scale, semi-industrial wooden boat, and industrial steel boat fleets) and, within each of these three categories, according to boat size (ranging from 2 to 600 t of holding capacity, with large overlap between boat types; Fig. 3). Life cycle assessments of the extraction phase will be performed, along with analyses of employment (direct and indirect) and economical rent in order to provide decision makers with a broader and multidimensional understanding of this complex sector. A similar study will be undertaken for the transformation phase (fishmeal and fish oil production, canned fish, frozen fish, fresh fish and cured fish) both locally in Peru and abroad (for example in Asia). The project is challenging due to its scope along with technical and scientific issues such as the unification of energy units according to their sources and diversity of the conversion processes from ecosystems to human driven systems: conventional eco-energetics around biomass from the ecosystem will be completed by calculations of exosomatic energy available for human societies (considered through the exergy concept), resulting mainly from the use of fossil fuels (Georgescu-Roegen, 1971; Margalef, 1980; Ayres and Weaver, 1998). Here we will try to reconcile recent approaches such as the New Ecology (Jørgensen *et al.*, 2007), Industrial Ecology and Industrial Metabolism (Socolow *et al.*, 1994, Ayres and Ayres, 1996) and Generalized Ecology (Frontier *et al.*, 2008). We will also try to reconcile economical and environmental issues, making use of the concepts of ecological economics or eco-economy (Costanza *et al.*, 1999; Brown, 2001; Cutler *et al.*, 2002) and economics of industrial ecology (van den Berg and Janssen, 2004).

With increasing awareness of the contributions made by food systems to environmental challenges (Millenium Ecosystem Assessment, 2005; Garnett, 2008) and socio-economic changes (BNP, 2009), it is increasingly apparent that any comprehensive sustainability assessment must encompass the whole production and consumption chain through an integrated concept of provisioning chain. This will help to identify sustainable fishery systems that better align with policies aimed at addressing climate change (Driscoll and Tyedmers, in press) and social welfare (Pelletier *et al.*, 2007). This type of analysis is especially important at this juncture, where over-exploitation and collapse of several fish stocks (FAO, 2007), increasing fuel prices, concerns over greenhouse emission contributions to climate change and ocean acidification and related issues have combined to increase consumer concern regarding how and where their food is produced (Deere, 1999; Jacquet and Pauly, 2007). To date, these issues have been partially addressed in fisheries that comply

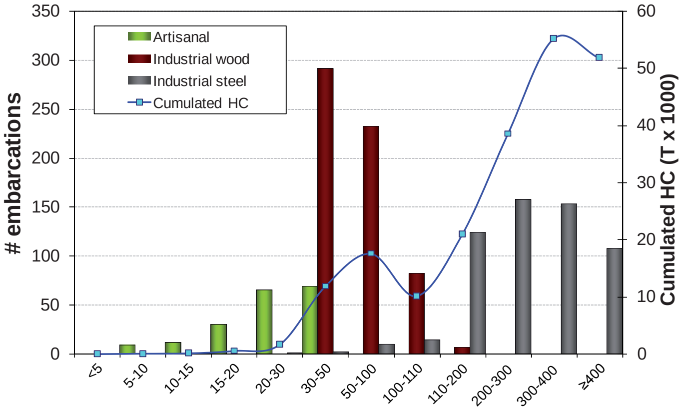

Figure 3. The three Peruvian purse-seiner fleets exploiting anchoveta. Vertical bars represent the number of embarcations according to categories of holding capacity (HC; horizontal axis) and the solid line the represent the cumulated HC within each HC category. Note that only approximately a quarter of the artisanal purse-seiner fleet (here presented) is mainly devoted to anchoveta catches.

with the FAO Code of Conduct for responsible fisheries, however much needs to be done. The increasing interest for certification of fisheries for their environmental and management performance and related ecolabelling shows that it can represent an alternative approach, through pressure on the market by consumers, in ecosystem protection and more broadly the environment at global scale. This new approach reflects the failure of traditional fisheries management in some fisheries as it is an alternative approach to protect ecosystems. This project should help in the definition of criteria and good practices for certification of pelagic fisheries and supply chains in order to promote incentives for a more environmental friendly exploitation of natural resources.

Methodology

Life Cycle Assessment (LCA) is a tool which provides a useful framework to identify potential contributions to a wide range of global scale environmental concerns that result from various production systems. It will be used to inventory the physical inputs, production materials, energy requirements along with the resulting emissions (to air, land, fresh water and oceans) associated with each stage of each production chain: from anchovy capture through production, transport, use and disposal. The functional unit will be 100 g of animal protein of anchoveta or derivative product on the plate of a consumer according to his/her location on earth (Peru or other countries) and according to the type of protein: anchoveta (fresh, frozen, canned, dried and smoked), cultivated fish, chicken or pork (rated according to the quantity of anchoveta fishmeal and fish oil used as source of protein in their feeds). The process will be facilitated by the use of the SimaPro software package by Pre Consultants that allows various indices of environmental impacts to be derived. Material Flow Analysis and conventional micro-economics approaches will be used to complement LCA and study rents and employment (but not environmental costs). The Umberto software will facilitate this approach.

Large amounts of data needed to conduct a LCA will be derived from field observations, contacts in industry and academia, peer and non-peer reviewed literature (especially for foreign aquaculture, swine and poultry farming), governmental statistics and chemical analyses when necessary. Detailed questionnaires will also be distributed to fishers, industry workers, transporters and consumers.

Expected outcomes

This study will help us understand the above-mentioned food security paradox of Peru. It will also provide direction on how to best support people dependent on fisheries as it will assess and compare the socio-economic implications of each stage of the anchovy production system in terms of indirect and direct jobs, and use of the rent and wealth redistribution. Together with other studies of the whole artisanal and industrial fisheries undertaken by IMARPE and IRD, this work will provide indications on the vulnerability of Peruvian fisheries to global changes such as climate change, globalisation of the markets, human population growth, global economical growth and the associated increasing demand for animal proteins.

This study will allow us to compare the environmental impacts generated from each link in each process of the supply chain and indicate potential ways to reduce these impacts per functional unit produced. Quantifying natural resource use, together with the social and environmental factors of the industry represent a novel approach which could lead to improvements of the management and a more environmentally and socio-economic sustainable anchovy industry. It aims at providing stakeholders and policy makers with a basis upon which to jointly decide further research and development perspectives in the sector and generate the necessary information to inform consumers about the aggregated environmental impacts of each anchovy derived product, in addition to socio-economics aspects. The information generated during this study will provide us with necessary data to predict the best possible adjustment of the current structure of the anchovy production systems for the future, while maintaining the most social benefits and in compliance with climate change objectives.

Another concern is overcapacity of most industrial fisheries that are managed using a global quota. This situation prevailed in the anchoveta Peruvian fisheries until 2008 and resulted in 72% fleet overcapacity when expressed as the proportion of unused present capacity, and in a 89% processing overcapacity (Fréon *et al*., 2008). This situation is improving with the implementation of individual quotas in 2009 and the present study, which will deal with historical data, will serve as a reference point to compare historical with present and future practices and investments resulting from this change in management.

Finally, the LCA of the Peruvian anchovy production can serve to identify impact hotspots, aggregated environmental impacts and key leverage points for environmental performance improvements in the anchovy industry (possible examples are the use of alternative energy sources such as Peruvian natural gas, or recuperation of solid content lost in boats and plants). In the end, if the environmental impact of the Peruvian supply chains compares favourably with standard impacts of similar chains in other countries (as expected), this will improve the position of the Peruvian industry to seek ecocertification of one form or another. In that respect, it is necessary to experiment locally with the definition of criteria of sustainability in order to allow the stakeholders to collectively negotiate the constraints related to labels for different supply chains of anchovy. An example of such an approach is provided by the EVAD (Evaluation de l'aquaculture durable) programme (Rey-Valette *et al*., 2008).

This project is open to additional participants, please contact the first author for further details.

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