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REVIEWS

Harvesting for food versus feed: a review of Peruvian fisheries in a global context

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Abstract Peru is the top exporter of fishmeal and fish oil (FMFO) worldwide and is responsible for half and a third of global production, respectively. Landings of "anchoveta" (*Engraulis ringens*) are used nearly exclusively for FMFO production, despite a proactive national food policy aimed at favoring the direct human consumption of this inexpensive species. It may be surprising that in a country where malnutrition and caloric deficit constitute major issues, a low-priced and highly nutritious fish such as anchovy does not have stronger domestic demand as a food fish. Here, we review and assess eight potential politico-socio-economic processes that can explain this situation. The main explanation are dietary habits, the preference for broiler and the higher profit from anchovy sold as feed fish compared to its use as a food fish due to historically high FMFO prices, boosted by an increasing demand for aquaculture in a context of finite forage and trash fish resources. In addition, the recent introduction of an individual quota system has shifted bargaining power from processors to fishers, thereby increasing competition for the raw material. This competition results in an increase in anchovy prices offered by the feed fish industry due to its onshore processing overcapacity, which is detrimental to the food fish industry. In the end, although the dominant use of anchovy for fish feed is largely explained by integrating these market mechanisms and other minor ones, this use raises other issues, such as rent redistribution through public policies, employment, equitability and utility (low social costs), and resource management (threats to ecosystems or global change). Different policy scenarios are proposed in relation to these issues.

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Introduction

An old and unresolved debate is raging around the best use of primary production by agriculture to feed humanity. Crops can either be consumed directly as food or converted to animal proteins for use as feed stuff. However, farmed animals are associated with low food conversion efficiency because many kilos of feed are required to produce 1 kilo of animal meat (e.g., Leitch and Godden 1941; Brown 1997; Bradford 1999; Smil 2002). This debate is becoming even more current because of global population growth and corresponding food security issues, such as climate change and distributional issues. In developing countries the poorest cannot afford to buy the available, but expensive, food (Alexandratos 1999) or cannot access this food (Sen 1981).

Seafood is increasingly recognized as being an important part of global food security (Smith et al. 2010; Tveteras et al. 2012). Similar to production of agricultural crops, seafood production does not escape the food versus feed debate, since approximately a third of landed fish catches were used for animal feed in recent years (Tacon et al. 2011). Marine feed inputs are mainly derived from the transformation of forage and trash fish into fishmeal and fish oil (FMFO) (Tacon and Metian 2009), while a smaller part is derived from fish trimmings. Controversies exist over what the best use of forage fish is, i.e., for either direct human consumption (DHC or food fish) or indirect human consumption (IHC or feed fish) through the feeding of farmed animals, with the associated loss of yield for human consumption (Welch et al. 2010).

The global demand for marine ingredients for feed has grown so fast in recent years that it has raised concerns about the sustainability of marine fisheries (e.g., Naylor et al. 2000, 2009; Smith et al. 2010). Furthermore, because a large share of forage and trash fish is harvested in developing countries, some authors feel that the production of animal feed diverts scarce food fish away from the poor in favor of high-paying consumers in emerging and developed economies (Kent 1997; Gillet 2008). In contrast, other authors argue that hardly any local demand for direct consumption exists for certain forage fish species. Instead, the transformation of fish to FMFO generates economic benefits for both producers and buyers (i.e., the aquaculture industry; Wijkström 2009). Smith et al. (2010) argue that net seafood exports can still contribute to food security in developing countries by generating income and livelihoods. This argument can also be extended to export-oriented forage fisheries industries (see Discussion).

The question of how to best use scarce fish resources is further complicated by structural changes in the demand for FMFO. Animal proteins are not used to feed bovines anymore, and the proportion of FMFO in poultry and swine feed has decreased drastically over the last decade (Tveteras and Tveteras 2010). In contrast, FMFO usage in aquaculture feeds has grown rapidly since the 1990s for two reasons. First, in some aquafeeds, the proportion of fishmeal (up to 36 %) and fish oil (up to 26 %) is typically much higher than that in poultry and pig feed (2–3 %). Second, global aquaculture production is growing quickly (FAO 2011a). However, this growth in aquaculture production is no longer resulting in an equivalent growth in the use of FMFO due to an increasing use of substitutes, as detailed below.

Food supply chains are becoming increasingly globalized and many of them produce a commodity, hence the term "global commodity chain'' (GCC) proposed by Gereffi (1994). Gereffi classified GCCs into two broad categories according to their governance structure: "producer-driven chains" and "buyer-driven chains". The former category is found in sectors where production is capital- and technology-intensive, such as automobiles and computers. In contrast, the latter category appears in activities that are more labor-intensive, including most agricultural commodity chains (Ponte 2002). In the case of long-established and complex food chains, such as seafood, clear patterns of governance are less easy to establish than in the case of fresh products from the agricultural sector (Wilkinson 2006). Whether fish supply chains for global commodities such as FMFO are "producer-driven" or "buyer-driven" has implications for price formation at the micro-economic level of the food fish market. This distinction also has strong implications at the macro-economic level because Peru has a "commodity-dependent economy" (CDE) through the FMFO markets, according to the definition provided by Farfan (2005) ("inserted into global markets through primary products bearing little value relative to final consumption goods").

Outlining the Peruvian case

The dominant Peruvian forage fish, the anchovy (*Engraulis ringens*) or "anchoveta", supports the largest single species fishery in the world. The average annual landings were between five to six million metric tons (t) during the last decade (PRODUCE 2011). Peruvian anchovy is used in several food chains of different lengths and complexity. The shortest supply chain provides fresh anchovy to Peruvian consumers, whereas the longest involves international shipment of anchovy-based FMFO. The Peruvian FMFO exports accounts for about half and a third of world production of fishmeal and oil, respectively (IFFO 2012).

Anchovy meal and oil are used in feeds for aquaculture and livestock production. Most aquaculture and livestock production take place in other developing countries (with the notable exception of Norway). This means that most of the revenue and employment generated from aquaculture goes to the countries that farm fish.

Canned, frozen or cured food products based on Peruvian anchovy represent supply chains of intermediate lengths. Canned and frozen products are primarily destined for local consumption and secondarily destined for exportation. Conversely, cured fish is mostly exported, but this type of DHC product is not dominant in Peru (Online Resource 1; Fig. S1). Fresh anchovy is devoted exclusively to the national market due to its highly perishable nature. In summary, supply chains of short and intermediate lengths are aimed at DHC and mostly occur locally, whereas long supply chains are aimed at IHC and are export oriented.

Peruvian anchovy is targeted by both small- and large-scale industrial vessels. The industrial fishing vessels are subdivided into a semi-industrial fleet of wooden boats and an industrial fleet of steel vessels (Online Resource 1; Fig. S2). By law, industrial landings are almost exclusively used for FMFO production, whereas the small-scale fleet's catches, in principle, should be utilized for DHC (canned, frozen, cured or fresh fish). However, an increasing amount of anecdotal evidence, including observations

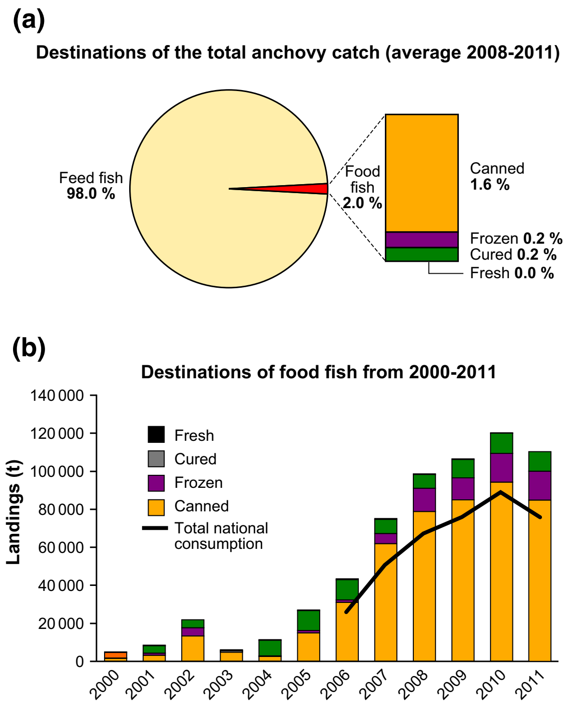

Fig. 1 Anchovy landings in Peru according to use. **a** the share of uses between feed fish and food fish during a typical year (2009) where the contributions of the different food fish sub-categories are as follow when related to the total of their category: canned 79 %, frozen 12 %, cured 9 % and fresh 0.2 %; **b** trends in uses for DHC from 2001 to 2011, with the aggregated national consumption (*source* PRODUCE)

by authors of this work, indicates that over the last decade, a large share of the small-scale fleet's catch has been targeted for fishmeal production. Additionally, a recent decree (Supreme Decree 005-2012) partly authorizes the practice of using the artisanal fleet's catch for fishmeal for the largest small-scale fishing units. As a result, supply chains for DHC appear to receive only ~1 % of the total anchovy landings, which has been approximately 110,000 t in recent years (Fig. 1). Around one third of DHC products are exported (as estimated from a combination of landing, production (PRODUCE 2011) and export data (PromPeru 2011)). It may be surprising that, in a country where malnutrition and caloric deficit constitute major issues, only a tiny fraction of a low-priced and highly nutritious fish such as anchovy is marketed for domestic consumption.

Another surprising characteristic of the anchovy fishery sector in Peru is that small-scale fishers still sell anchovy for DHC despite the similar or formerly even lower prices paid for fresh anchovy aimed at DHC than the prices paid for IHC (Online Resource 1; Fig. S3). Fishers only receive higher prices for DHC anchovy over anchovy for IHC when the former is sold for fresh consumption; however, corresponding landings are anecdotal (Fig. 1). This is unexpected because the costs of production of anchovy delivered for any DHC are normally higher than for IHC. The reason why fishers still land for DHC are twofold: (1) the prohibition against small-scale fishers selling anchovy for IHC is not enforced; and (2) the expected landings per trip of a given vessel equipped for DHC production are smaller than those of the same vessel not equipped, due to the reduction its holding capacity. Today, many small-scale vessels choose to land anchovy for IHC even if this goes against regulations. Anchovy caught within the 5-mile limit, which was regulated for small-scale vessels until 2010, can only be utilized for DHC. One would believe the exclusivity of these fishers in DHC utilization would improve their bargaining position and yield higher economic returns. However, given the observed behavior, this does not appear to be the case.

Although DHC of Peruvian anchovy has increased over the last 10 years, one may question why consumption did not grow sooner or reach higher levels given the problems with employment, poverty and malnutrition. Unemployment is high in Peru, reaching 29 % in 2011 (INEI-PNUD 2013) and affecting mostly the population segments with low educational level (INEI 2013b). Unqualified or poorly qualified people could particularly benefit from a transition to more labor-intensive DHC production of anchovy because most employees are devoted to fish sorting and various handling tasks. In contrast, the fishmeal industry is capital-intensive and therefore has a relatively modest impact on employment. For instance, an average fishmeal plant requires 16 times less employees than a food anchovy plant (values computed from Alvarado's (2009) data from 2001–2007). Similar estimations for anchoveta extraction yield a 1:5 ratio of employees in industrial fisheries as compared to small-scale fisheries.

The average poverty and extreme poverty reached 32 and 8 % of total population in Peru, respectively, over the period 2008–2012 (INEI 2013a). Caloric C deficit is also of great concern, with 28 % over the same period (INEI 2013b). Furthermore, the percentage of children under the age of five that display evidence of chronic dysnutrition is high in Peru, averaging 18 % during the period 2009–2012, while the proportion of anemic children averaged 35 % over the same period (INEI 2013c). At the same time, the prevalence of overweight individuals is also high (10 %), resulting in a "double burden" of malnutrition, as frequently observed in developing countries that are in the transition or post-transition stages (FAO 2011b).

The objective of this paper is to explain the social and economic reasons why such an abundant small pelagic fishery yields relatively little fish for consumption to the local population, as illustrated in Fig. 1. Identifying these reasons will hopefully contribute to the understanding and resolution of similar food chain problems elsewhere. In the "Discussion" section, we debate the competition between anchovy food and feed supply chains, discuss the drivers (producers or buyers) of the FMFO GCC, and finally propose and argue alternative development options related to the balance between the different supply chains.

Identifying the direct causes behind the low consumption of food anchovy

A series of four hypotheses constitute the analytical framework used to identify the causes of the low consumption of food anchovy:

1. The demand for anchovy for human consumption is not sufficiently strong for the fisheries sector to be willing to develop this market further.
2. Governmental regulations and lack of public support hinder transition to marketing of anchovy for DHC.
3. The cost structure favors value chains for indirect over DHC.
4. The strong demand for FMFO undermines incentives to develop markets for DHC.

Demand and supply-side factors that can directly explain the low consumption of food anchovy are shown in Table 1. The second column in the table associates each of these factors with the relevant hypothesis above. The identification of the factors was based on a literature review (including informal publications), interviews and forums consultation such as the OANNES one (http://www.oannes.org.pe.

Table 1 Processes able to explain the low consumption of food anchovy in relation to the price paid for landed anchovy and the supply/demand faced by fishers

Factors	Framework hypothesis	Anchovy price for food or feed use		Demand for or Supply of food anchovy
Direct factors decreasing consumption				
Dietary habits (anchovy disregarded) limit the demand for food anchovy in favor of more expensive fish species	1	−DHC	←	−−D
Broiler dominates the Peruvian protein market and displaces other sources of cheap protein	1	−DHC	←	−D
Higher profit from reduction (FMFO) than canning decreases the supply of food anchovy	4	+++IHC −DHC	→	−−−S
Indirect factors				
Lack of a cold chain and optimal sanitary conditions for fish favor other sources of protein and difficult food fish production	2	−DHC	←	−D or −S
Canning or curing processes raises too high selling price	3	+DHC	→	−D and −S
Increasing global demand of FMFO rises FMFO and feed anchovy prices	4	+++IHC	←	+++ D
Lower catches of Chilean jack mackerel and Peruvian anchovy rises FMFO and feed anchovy prices	4	+IHC	←	−S
New fishery management regime shifts bargaining power from processors to industrial fishers, resulting in an increase in the feed anchovy price	4	++IHC	←	++D

The signs indicate increasing (+) or decreasing (−) changes in prices and demand or supply; the number of signs indicates the intensity of the change; arrows indicate which process is supposedly driving the other

DHC direct human consumption; *IHC* indirect human consumption; *D* demand; *S* supply)

Accessed 15 October 2013) where different stakeholders debate. A large part of reviewed material was difficult to access because it was published in local scientific journals, press releases or Internet pages and was often in Spanish. Therefore, a thorough search of information was performed, using Internet search facilities and consulting various stakeholders, including during dedicated workshops. It is worth noting that the second, fourth, fifth and sixth authors of this work authors have been directly involved with the pelagic fish sector in a variety of roles (decision making at ministerial level, fishing companies' actors and governmental scientist) and therefore have first-hand knowledge of many of these issues.

Dietary habits favor fish species more expensive than anchovy

Traditionally, the Inca and pre-Inca populations ate anchovy fresh or dry and salted (Antúnez de Mayolo 1997). In more recent times, anchovy has been viewed as food for poor people. More than 57 % of Lima's population are aware of the species and anchovy is no longer considered a pet food, as it was in the late 1940 s (FAO 2012).[1] Nevertheless, consumption studies performed in Lima on 600 adults in 2000 indicated that less than 7 % of the people consumed anchovy and that nearly all of them only consumed it infrequently. To change this situation, the Peruvian government initiated a food policy program to promote domestic anchovy consumption in the late 2000 s. The program includes subsidies and the distribution of anchovy surimi and hot-dogs in primary schools by the National Program of Food Assistance (PRONAA; 76 million USD mostly aimed at promoting anchovy consumption

[1] The reasons people declared for not consuming anchovy in 2000 were as follows: 1) it is difficult to obtain (32 %); 2) it is mostly for rich people (19 %); and 3) it is too expensive (19 %); note that the two last reasons obviously refer to only to some sophisticated products such as cured or canned fish packed with additional ingredients. When consumers are asked to describe the cons of anchovy they mention the organoleptic properties (21 %, including the presence of many fine bones that make fish ingestion painful, 12 %); however, in the list of pros, flavor—another organoleptic property—comes first (19 %), followed by nutritional value (17 %) (FAO 2012).

during the period from 2007-2011). Since 2003, the Peruvian Institute of Fishery Technology (ITP) developed new canning techniques and product presentations based on anchovy and "pota" (giant squid *Dosidicus gigas*). In 2007, the government directed some of its ministries and national bodies to allocate at least 8 % of their dietary budgets to the purchase of anchovy and "pota" based products (Supreme Decree n°002-2007). In recent years, "the anchovy week" promotes the preparation and consumption of anchovy in public places and restaurants, and educates consumers on its high nutritional value. These efforts have contributed to increased consumption of anchovy (Fig. 1). importantly, about half of consumed canned anchovy has been subsidized by the PRONAA project. However, another survey of fish consumption in a representative rural area, the Castrovirreyna province (Huancavelica department, central Peru), in 2011 shows that anchovy lags behind other species. The Castrovirreyna study was performed on a sample of 400 adults who indicated that the last time they consumed canned fish in less than 5 % of cases this fish was anchovy, whereas the share of tuna was >82 % (FAO 2011c). The Peruvian government itself appears to have been disappointed with the slow progress made in the consumption of anchovy (and"pota") since it created the National Council for the Promotion of the Resources anchovy and giant squid (Supreme Resolution n°028-2010) in 2010.

As demonstrated, the preference for other fish species than anchovy, whether fresh or canned, is not primarily driven by economic factors. The Peruvian domestic market of fish is largely dominating by fresh fish (>75 %; Online Resource 1; Fig. S4), where fresh anchovy sales are negligible despite being the cheapest on the market (landing price: 0.16 USD; supermarket price: 0.70 USD). Indeed, only another anchovy species (longnose) that is seldom consumed is cheaper than anchovy (Online Resource 1; Fig. S5). Other low-priced fish species commonly consumed fresh, such as drums and sea silverside, are twice as expensive (source IMARPE data 2008).

Likewise, tuna, jack mackerel and chub mackerel dominate the canned fish market despite anchovy being the cheapest alternative (Maximixe 2013). A typical 125 g can of anchovy filets (90 g of flesh) in oil is sold for approximately 1 USD in supermarkets. In contrast, a similar sized can of chub mackerel or jack mackerel is currently sold for 2 USD. Grated anchovy is even cheaper—selling at 0.70 USD for cans of 170 g. Nonetheless, this product is only popular in the interior of the country, representing for instance more than half of canned fish sold in Iquitos, the largest city in the Peruvian Amazon area (Lopez Ríos 2010).

In conclusion, although fresh and canned anchovy represent affordable alternatives compared to other species offered in the same product formats, the consumption of anchovy remains modest. This difference is due to the preference for other similar-priced fish species and even more expensive ones in relation to consumers' dietary habits and, to a lesser extent, for practical reasons detailed in Indirect causes of the high price of transformed anchovy and unavailability of fresh one section.

Broiler dominates the Peruvian protein market and displaces other sources of cheap protein

Chicken has become the most popular animal protein in Peru during the last decades, not least due to price competitiveness. Poultry meat is among the most inexpensive animal proteins and is attractive for the lower and middle social classes, which account for the largest share of the Peruvian population. Chicken is mostly produced from locally available feed ingredients (cereals, FMFO), which contributes to keeping production costs low. In 2009, Peruvians consumed approximately 28 kg of chicken per capita. In Lima, chicken consumption is even higher, with a magnitude of 58 kg per capita (source: APA, Peruvian Poultry Association). In contrast, the domestic consumption of fish was only 22 kg per capita in 2010. With respect to affordability, the average price of chicken breast is cheaper than canned grated anchovy (3.5 vs. 4.1 USD per kg, respectively).

As a result of the above-detailed economic and dietary habit factors, broiler dominates the national meat consumption (>51 %), followed by all fish species (>26 %) (FAO 2011c), of which anchovy represents less than 3 %.

Higher profit from reduction (FMFO) supply chain than canning or curing

It is more profitable for small-scale fishers to fish for IHC than for DHC, although, surprisingly, their unitary production costs are higher in the former case (Online Resource 2; Table S1). These higher costs are due to the numerous manual manipulations of the fish uploaded, fees at private quays and transport by lorry to some small fishmeal plants. Such plants, whose number is increasing, are residual plants that illegally accept anchovy coming from small-scale fishers to process (Miró, in press). The higher production costs are compensated by larger landings per trip (Online Resource 2; Table S2); as a result, fishing for IHC results in substantially (19 %) higher profits than does fishing for DHC.

The profit associated with FMFO production itself must be high because raw fish for IHC landed by independent fishing vessels (approximately 30 % of the production; mostly from the semi-industrial fleet) are paid at 8.5 % of the average FOB[2] price of fishmeal in Hamburg. Using 4.2 as the physical conversion factor from transforming raw fish to fishmeal, the direct production costs represent only ~40 %[3] of the income, likely less when the fish is caught by the company's own vessels. Indeed, profit, excluding the cost of capital, is greater than 50 % for FMFO production, whereas for canned fish, it is about 20 % (Fig. 2); preliminary profit results on cured fish suggest intermediate values between FMFO and canned. Hence, there is a strong incentive for the industry sector to prefer production for indirect rather than direct consumption. The industry sector is not inclined to increase the price of raw materials for DHC, and this gap in prices is aggravated by the fact that raw materials are one of the few production costs that can be reduced substantially.

The overall intent of identifying the direct causes behind the low consumption of food anchovy has highlighted three endpoint factors. Six indirect factors favoring this situation have been identified (Table 1; Fig. 3) and are detailed below.

[2] The average Free On Board (FOB) price is a weighted average of Fair Average Quality (FAQ) and Prime fishmeal according to sales.

[3] The value of 40 % results from 8.5 % × 4.2 × 1.11, with 8.5 % being the proportion of the fishmeal price paid to fishers, 4.2 being the conversion rate of raw fish to fishmeal and 1.11 being the rising factor for total direct production costs (1/.9).

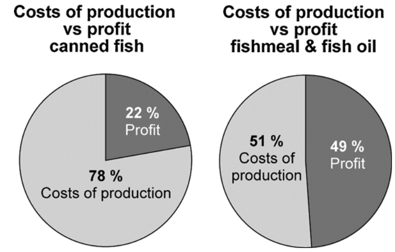

Fig. 2 Comparison of profits (excluding cost of capital) for canned fish and FMFO (*source* 2010 data from one of the biggest (anonymous) fishing companies in Peru)

Indirect causes of the high price of transformed anchovy and unavailability of fresh one

Lack of cold chain and optimal sanitary conditions for fish favor other sources of protein and difficult food fish production

Despite recent investments made by some of the largest Peruvian fishery companies, there are few continuous cold chains for fish in Peru. The sanitary and cold storage deficiencies start with the fishing vessels, as in 2010, only 17 % of small-scale boats were equipped with cold storage facilities. Anchovy is usually stored in bulk in large holds of several cubic meters with some ice added on top. Consequently, only the top of the hold is of acceptable quality for DHC. The lack of proper washing of the storage hulls in the vessels also constitutes a serious issue.

In harbors where small-scale fishing vessels land anchovy, vessels often have to wait in a queue to disembark due to insufficient infrastructures (particularly quays). This leads to a deterioration in anchovy quality—especially because this is a fragile fish species. The fish is then handled several times (in scopes, boxes, and trucks) during landing and transportation before reaching the factory or fish market. The logistical operations of the artisanal fisheries seldom comply with international sanitary standards. It is only when small-scale fishers land directly at the terminals of the large fishing companies that sanitary conditions are adequate. Fortunately, this is the case for most of the production of canned and frozen fish, but not necessarily for cured fish and fresh fish.

Few Peruvian cities provide large-scale cold storage facilities. Moreover, the number and size of refrigerated transports—mainly trucks—is limited. In 2012, public electricity was available in 91 % of all

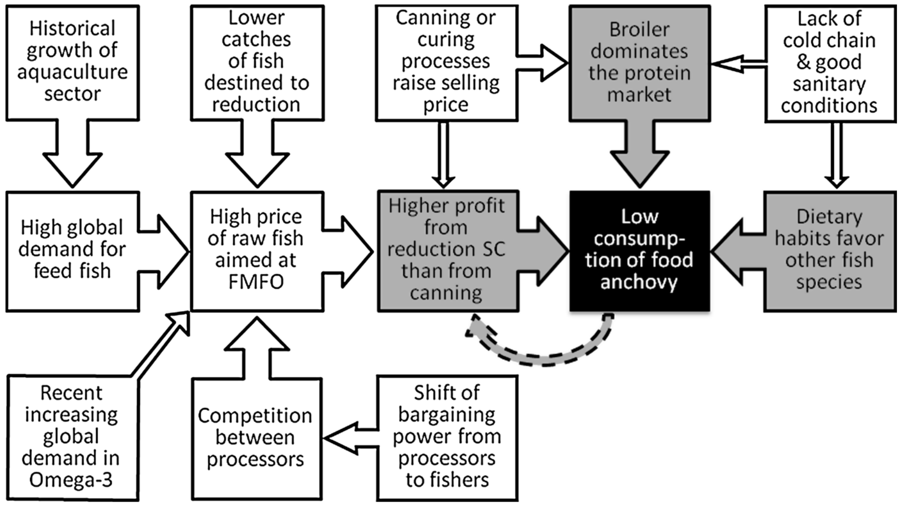

Fig. 3 Simplified diagram of the processes explaining the low demand for food anchovy (*black rectangle*). *Grey rectangles* represent direct factors, and white rectangles represent indirect factors. The *arrow* widths are roughly proportional to the impacts

homes, but only in 69 % of homes located in rural areas (ENEI2013a). Consequently, the low proportion of fresh anchovy consumption can also be explained by deficient handling, logistics and storage of this highly perishable species. Many other fish species are more robust to poor preservation conditions than anchovy due to their lower fat contents, firmer flesh, and larger sizes. As a result, they are often sold in markets without refrigeration and preferred to anchovy. The same applies for fresh chicken meat, which is considerably less perishable than fresh anchovy, thus making it easier to transport and commercialize. In contrast to anchovy, chicken can be stored in households for 2 or 3 days with limited impact on its quality. Moreover, whereas fresh anchovy is only available in a very few fish markets and supermarkets, fresh chicken is available in most food stores, including small groceries without refrigeration facilities.

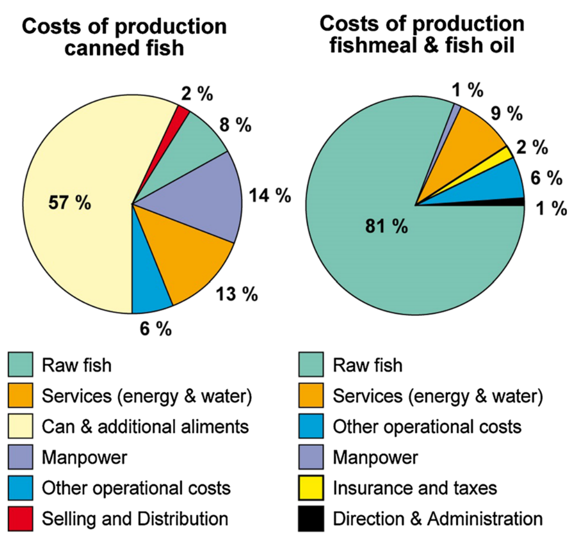

Fig. 4 Comparison of production costs for canned fish and FMFO (source: 2010 data from one of the biggest (anonymous) fishing companies in Peru)

Canning or curing processes raises too high selling price

Analyzing economic data from one of the biggest Peruvian fishing companies (anonymous), it is obvious that direct production costs of canned anchovy are dominated by the can itself and the adjuvant, such as vegetable oils, whereas raw fish contributes less than 10 % to the cost (Fig. 4). In contrast, anchovy accounts for close to 90 % of the direct production costs in fishmeal production. In both cases, capital costs are not included. A similar cost structure analysis of cured fish (unpublished data) produced similar results. In contrast, the low contribution of fuel to fishing and canning processes (Online Resource 3) demonstrates the moderate impact that crude oil price variations (Online Resource 1; Fig. S6) may have on food anchovy products.

Increasing global demand of FMFO rises FMFO and feed anchovy prices

An important factor that can help explain the relative use of anchovy for feed and food in the last two decades is the growth of global aquaculture production and the farming of terrestrial livestock of pigs and poultry (broilers and layers) (Hasan and Halwart 2009). Global population and economic growth have led to increased global demand for animal proteins, including fish (Brown 1997, 2001; Garcia and Rosenberg 2010). Rapid growth and urbanization in developing countries have led to an increase in the presence of modern food retail chains where fish and other sources of animal proteins are sold in a variety of presentations (Reardon et al. 2003; Rana et al. 2009). However, because the supply of food fish from capture fisheries is leveling off, food retail chains have increasingly turned to aquaculture to satisfy the growing demand for fish. According to the FAO (2011a), approximately 31.5 million t (46 %) of global aquaculture production were dependent on the direct use of manufactured feed in 2008. During this year, aquaculture absorbed 74 % of the global fish oil production, whereas the share of the global fishmeal supply used for aquaculture was 61 % (FAO 2011a; Tacon et al. 2011).

The decrease in FMFO supply (Fig. 5a) in relation to the decrease in the amount of raw fish aimed at reduction (detailed below) and the increasingly inelastic demand for terrestrial and aquatic animal feeds resulted in record high prices (Fig. 5b) (Kristofersson and Anderson 2006; Tveteras and Tveteras 2010). The differentiated fishmeal prices and fishmeal production series are negatively correlated at national ($R^2 = 0.39$; $p < 0.005$) and global ($R^2 = 0.33$; $p<0.005$) scales (see Online Resource 3 for details). These results suggest that when the demand for fishmeal (including terrestrial animal feed) is high, the scarcity of raw material partly drives the price of this commodity, suggesting that this GCC is "producer-driven". The lack of a significant relationship with fish oil is most likely due to the lower income derived from this product when processing the raw material compared to the equivalent fishmeal income[4] and to the use of fish oil substitutes in fish feed (see Online Resource 3 for details).

More recently, the large-scale production of omega-3 from refined fish oil increased dramatically (Online Resource 11; Fig. S8) and affected demand for fish oil. As a result, large amplitude fluctuations ($\sim$80 %; Fig. 5b) in the fish oil price were observed from 2007 to 2010. The 2008 peak can be explained, at least partly, by the anticipation of European fish oil producers of a new sanitary regulation on importing fish oil from a third country, which was indeed enforced in April 2009.[5] To avoid a shortage of certified fish oil, European producers stocked up. Because these producers are the largest buyers of fish oil for human consumption, the stocking behavior resulted in a scarcity and a corresponding price increase in 2008.

Lower catches of fish destined for reduction rises FMFO and feed anchovy prices

Global catches of fish destined for reduction decreased from 30 million t in 1994 to 20 million t in 2007 (Tacon et al. 2011). The updated time series shows a further decrease to 15 million t in 2010 (Fig. 6a). This negative trend is mainly due to a decrease in South American production (Fig. 6b). Peruvian and Chilean fisheries provided 60 % of global fishmeal exports and 39 % of global fish oil exports in 2009 (Source: IFFO). In these two countries, the major species contributing to the production of FMFO are anchovy, from both countries, and jack mackerel, mostly from Chile. The total catches of all three stocks have decreased since 1994, but in particular, catches of Chilean jackmackerel have experienced dramatic reductions (Fig. 6b). The decrease in fish catches aimed at FMFO reduction is another important factor behind the record high prices of FMFO during the last decade. Indeed, statistical analysis of differentiated yearly time series of FMFO Peruvian prices and regional raw catches for reduction from 1994 to 2011 shows a significant linear negative relationship ($R^2 = 0.29$; $p < 0.05$) with fishmeal price but no significant relationship with fish oil. When the analysis was repeated using global catches, a similar result was found ($R^2 = 0.19$; $p < 0.005$; see Online Resource 3 for more details). The decrease in raw fish catches and the in part

[4] Fishmeal and fish oil prices per ton are about the same (Online Resource 1; Fig. S6), but the mean annual conversion factor of raw fish into fishmeal is around 4.2:1, whereas for fish oil, it varies from 15:1 to 40:1, according to fish fat content.

[5] The regulation specifies that the non-European country must be listed in accordance with Article 11 of Regulation (EC) 854/2004 for the import of fishery products and that the whole production chain, including fishing vessels and the raw materials, must comply with the EU requirements.

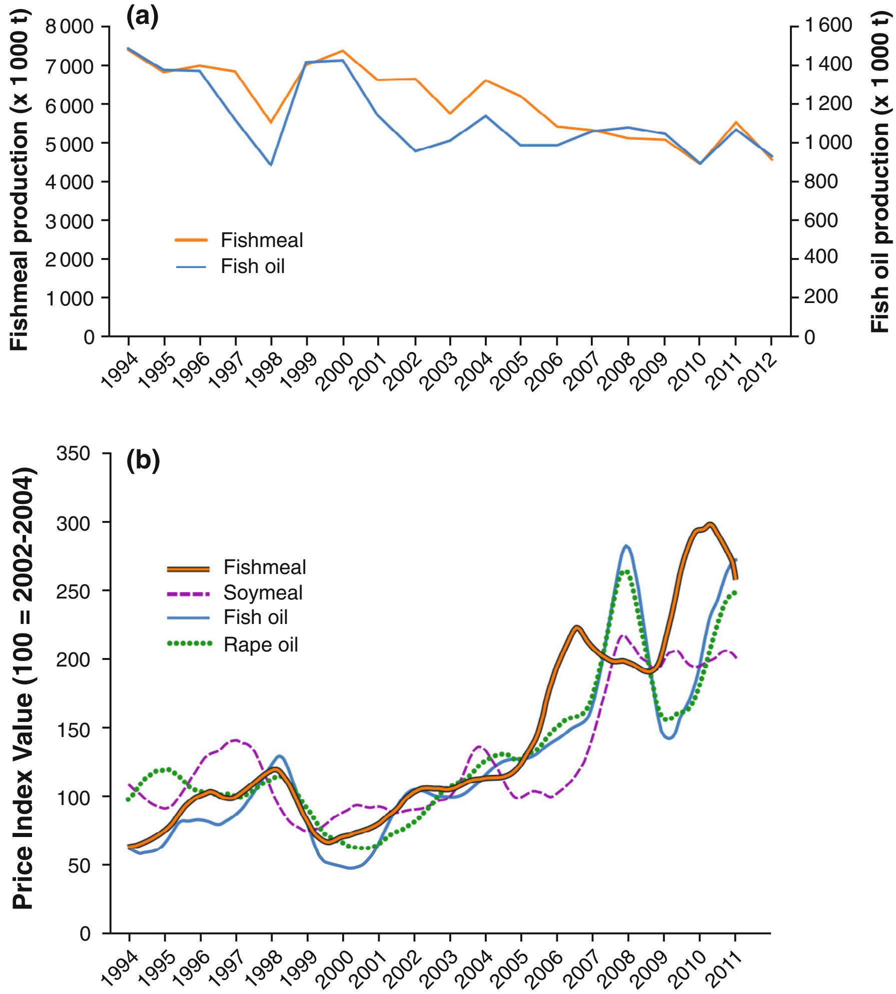

Fig. 5 Production and prices of FMFO and prices of FMFO substitutes: **a** global production of FMFO from 1994 to 2012; **b** 12-month centered moving average (MA) of price indices of fishmeal, soybean meal, fish oil and rapeseed oil from 1990 to 2011. The common price index base (100) was computed from prices during the base period of 2002–2004. The price indices have been further transformed using a 12-month centered MA to remove short-term volatility (*source* production, IFFO; commodity prices, FAO EST—International commodity price database, http://www.fao.org/economic/est/statistical-data/est-cpd/en/. Accessed 15 October 2013)

subsequent increase in fishmeal price contribute to making the IHC-processing sector comparatively more competitive than the DHC sector in terms of purchasing anchovy.

To summarize this indirect factor and the previous one, FMFO prices are boosted by the increasing demand for these two commodities, which face a limited supply but also depend on substitute commodities through complex and varying relationships. Rise in FMFO prices result in rise in feed anchovy prices.

New fishery management regimes shifting bargaining power from processors to industrial fishers

In June 2008, the Peruvian government implemented an individual vessel quota (IVQ) system that took effect in January 2009, ending a long-running fisheries management regime of restricted open access (Legislative Decree n°1084; Aranda 2009). As expected, this system resulted in an increase in the duration of the fishing season, as fishing rights mitigated the “race to fish”.[6] With the introduction of the IVQ system in the main fishing area (north-center region, ∼85 % of national catches), the number of operating vessels was reduced by 9.2 % from 2008 to 2009, and kept decreasing in the following years (Paredes 2012). Nonetheless, the total used holding capacity remained stable, except for a small reduction in 2010 due to a poor fishing season (Fig. 7). The new regulation allows for the transfer of quotas within fishing

[6] Locally nicknamed “Olympic race”.

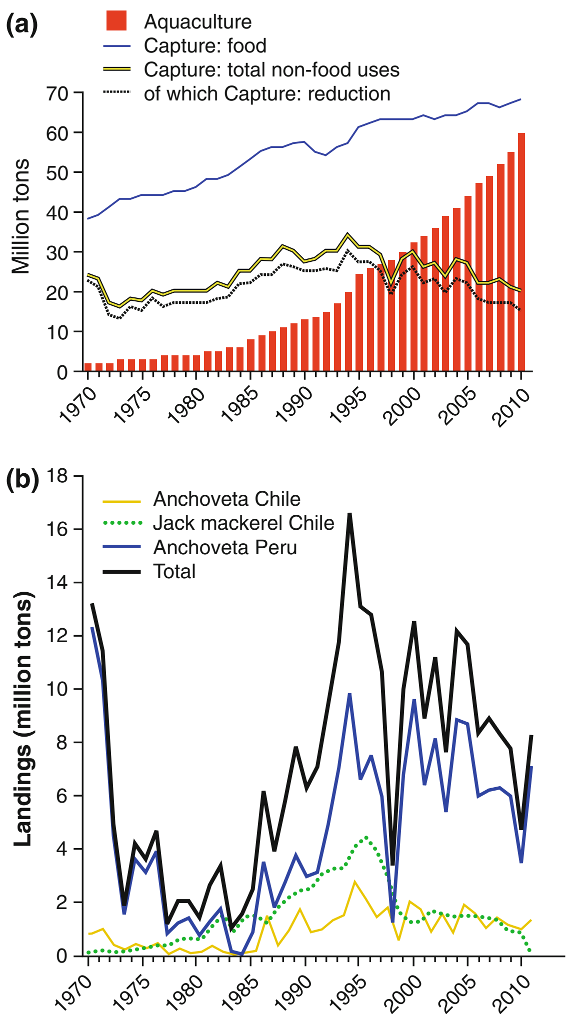

Fig. 6 Capture fisheries and aquaculture production, and the volume of the catch destined for reduction and other non-food uses: **a** World data 1970–2008 (Tacon et al. (2011) updated figure [Stefania Vannuccini, FAO, pers. com.)]; **b** National catches of Chile and Peru contributing largely to the production and exportation of FMFO (source: FAO FishStat http://www.fao.org/fishery/statistics/software/fishstat/en. Accessed 15 October 2013)

companies, but not between them. As a result, companies owning more than one vessel parked temporarily the smallest ones (allowed for two fishing seasons maximum), limiting therefore the reduction in holding capacity. Furthermore, Tveteras et al. (2012) suspect that temporary fishing permits have been granted to boats that do not necessarily qualify for such rights.

The new regulation has made it clear that there was, and still is, an overcapacity of fishmeal plants. Fréon et al. (2008) estimated this overcapacity to be 89 %, based on 240 potential fishing days per year. When the number of fishing days increases, the total allowable fishing quota is spread out over more days, leading to lower capacity utilization at fishmeal processing plants. Thus, with an extended fishing season of 150 days per year, it is difficult to keep the same number of plants (Fig. 7) operating at full capacity without detrimental effects on profitability. In contrast, plants were working close to their maximum capacity when the two annual fishing seasons amounted to less than 50 days per year. As a result, companies must now either temporarily close down some of their plants during the fishing season, or attempt to buy anchovy "at any cost" from the freelance semi-industrial fleet. Consequently, the race to fish is now replaced by a race to buy fish. The shift of bargaining power from the processors to industrial fishers has resulted in the recent increase in the landing price of feed anchovy relative to the FMFO prices.

To summarize, the higher landing price of feed anchovy results from a decrease in daily landings of the industrial fleet, whereas the demand of processing plants remains constant (Paredes 2010).

Discussion

Major processes explaining the low consumption of food anchovy

The low use of anchovy as food fish is mainly due to three factors of similar importance: (1) the preference for more expensive fish in the high and medium social classes; (2) the preference for cheaper broiler proteins for the less fortunate classes; and (3) the higher profit derived from reduction than from canning for fishers and for the industry. It is likely that this last factor is reinforced and sustained by a negative feedback of the low food anchovy demand on the profit expected by the food fish industry (dashed arrow on Fig. 3), which correspond to our first hypothesis on the lack of willingness of the fisheries sector to develop this market further. The two first factors are aggravated by the lack of cold chains and of good sanitary conditions for the production of food anchovy, particularly fresh and frozen anchovy, the only forms of production that could compete in price with broiler. This issue can be related to our second hypothesis inferring that the lack

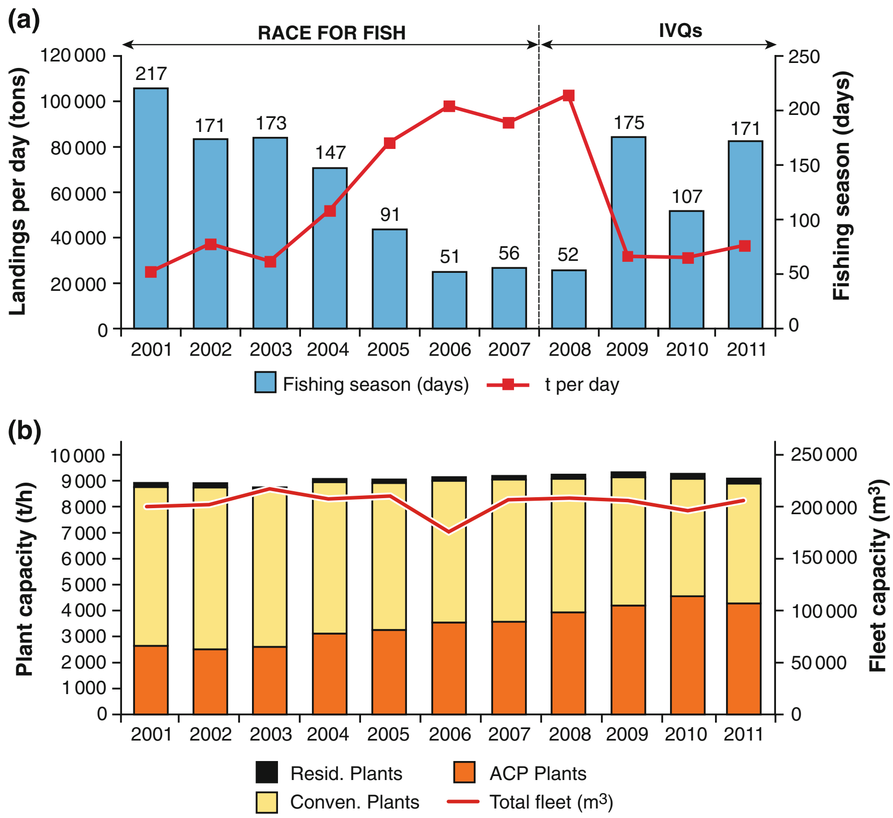

Fig. 7 Recent changes in the Peruvian fishing sector: **a** duration of the anchovy fishing season (days) and the mean catch per day (t.d^{-1}) in the north-center area; **b** fleet and plant capacities (*sources* PRODUCE and IMARPE)

of public support could hinder transition to marketing of anchoveta for DHC. Factors 2) and 3) are aggravated by the raise in protein price resulting from transformation processes such as canning and curing. The main reason is the additional cost of the tinplate can itself in most canning (Fig. 2) and curing processes. This issue support our third hypothesis on the cost structure that would favors value chains for indirect over DHC. To overcome this issue, the Peruvian ITP is promoting anchovy in larger cans to reduce production costs and is deploying technological and promotion efforts in alternative packaging, such as vacuum bags made of plastic material.

All the other indirect factors that participate to the low consumption of food anchovy are associated to the third direct factor (higher profit derived from reduction than from canning) through the higher price of raw fish aimed at FMFO production (Fig. 3). These indirect factors support our fourth hypothesis that strong demand for FMFO undermines incentives to develop markets for DHC. Indeed observed high commodity prices of FMFO are driven by global demand for animal feed (aquaculture and terrestrial animals) within a context of a limited offer that make it more profitable for fishers to deliver to the IHC sector than to the DHC one. The local demand for anchovies for reduction to FMFO is exacerbated by the overcapacity of Peruvian fishmeal plants, leading to stronger competition for the raw material. This has become even clearer with the implementation of an individual quota system that has shifted bargaining power from the processors to fishers (Fig. 3). Due to the fish-resource-ownership introduced by this system, fishing operators and their vessels have become "floating banks". These quota-holding vessels are not prone to leaving the fishery unless quotas can be transferred.

Competition between the food and feed supply chains

We did not consider the competition for the supply of raw materials between the feed and food anchovy fisheries as a factor explaining the low consumption of food anchovy. The competition for the raw material between the two markets could be representative if the anchovy fisheries were well-regulated with a common total allowable catch (TAC). This is presently not the case because there is nearly free access to resources for small-scale fishers (a spatial restriction was implemented only recently) and only a limited local competition. The major limiting factor regarding raw material aimed at food anchovy is the natural variability of the resource *vis-à-vis* its abundance and, to a lesser extent, its availability to fishers. Indeed, the Peruvian anchovy fisheries are characterized by large annual variations in biomass and, ultimately, in landings, at different time scales.

The interannual volatility is dominated by ENSO events, especially El Niño, which can dramatically decrease the production of the two major producing countries (Peru and Chile) and, to a lower extent, La Niña, which favors abundance but often decreases catchability (Bertrand et al. 2004). Strong El Niño events, such as the one in 1997–1998, affect the market substantially (Fig. 7), whereas weak ENSO events, including speculations and rumors, result in limited and short duration reactions (Asche and Tveterås 2004; Asche et al. 2013).

Even in the absence of exploitation, abundance cycles over decades and centuries are more pronounced than interannual variability, as indicated by paleontological studies of anoxic sediments off the coasts of Peru and Chile (Valdés et al. 2008; Gutiérrez et al. 2009). Climate change could amplify this long-term variability, as well as interannual variability, and may interact with exploitation (Fréon et al. 2009). Because the scientific community recently discovered and accepted the concept of long-term cycles of abundance, their impact on the sector is more difficult to appreciate, as they are not predictable processes. Possibly, this acceptance could prevent the more recent anchovy food market from developing in Peru.

Lower landing prices of anchovy for food than feed and small-scale fishers' limited bargaining power

Because small-scale fishers sell their production individually to the fishing companies' operating plants (usually through traders), their individual power of negotiation is obviously very limited because their landings are small and often in poor sanitary condition. The only legal recourse for them is to go fishing or not, according to the price currently offered by the industry and, if they must go, to target anchovy or other pelagic species that are usually less abundant but better paid. Therefore, it is obvious that the low demand for food anchovy from the industry is driving the price, which in turn controls the supply. This is so true that in many cases, the industry supplies fishers with ice and large containers ("dinos") to best preserve the catches aimed at DHC. In other cases, the industry only uses the upper layer of the anchovy store in the vessels' holds for DHC and uses the rest of the catch for IHC.[7] Paradoxically, it is more profitable for the small-scale fishers to see most of their catches considered sanitarily improper for DHC and bought for IHC.

Whether maintaining different management regimes and fleets for DHC and IHC is suitable is questionable (e.g., Iriarte Ahón 2011; Paredes 2012). The present management strategy aims at favoring food anchovy, but it is increasingly distorted and could be counterproductive because it prevents the corresponding transformation sector from having full control of the supply and sanitary conditions. In relation to our second hypothesis related to governmental regulations that may hinder transition to marketing of anchoveta for DHC, the present dual regulation where the industrial fleets are forced to use fish for FMFO can be seen as a weakness. It is likely that allowing the big companies to use their present quota for landing anchovy for either DCH or IHC would be the most efficient way to increase the use of anchovies as food fish. These companies have the financial strength to invest in this kind of marketing, and they already own big plants for processing fish for DHC. If such a strong change in regulation were adopted, it would be necessary to change in parallel the small-scale fishing regulation for an equity reason, allowing this segment to fish also for IHC. Further discussion on this issue is beyond the scope of this work.

Are FMFO producer-driven or buyer-driven global commodity chains?

The evidence provided here on the effect of the increasing demand for feed fish on the prices paid for FMFO advocate for a buyer-driven GCC. Nonetheless, because the natural resource is not an infinite and

[7] Although the regulation of this second type of use has been recently enforced for small-scale fishery landings (Supreme Decrees 002-2010- and 005-2012, PRODUCE).

renewable one, there is obviously a threshold of global FMFO offered, which at present seems to have been reached. Nearly the entire global stock of forage fish is fully exploited, if not overexploited, and the recent ecosystem approach to fisheries recommends decreasing the present levels of exploitation. The use of other raw materials for FMFO production such as trimmings and trash fish is increasing, mostly to the expense of the use of the entire fish, but not at the same rate as demand is increasing. Therefore, the market is also producer-driven or, as it could be better said, marine ecosystem-driven (including limitations due to carrying capacities and variability due to environmental effects), as shown above.

The anchovy consumption market and the linked sardine consumption market are also GCC, although in Peru, most of the consumption is presently domestic. The high share of domestic consumption will not necessarily continue after the dissolution of PRONAA in 2013 and its subsequent transfer to regional entities. During the last few years, the Peruvian producers deployed efforts to take over foreign markets. Because sardine is usually in higher demand than anchovy, with the notable exception of Spain, canned Peruvian anchovy is labeled “Peruvian sardine”, despite the existence of a sardine species in the country (*Sardinops sagax*, currently depleted). Moreover, no less than 34 forms of anchovy were currently produced in 2009–2010 (9 canned, 11 cured and 14 frozen). Despite these efforts, the export market of food anchovy is limited (Online Resource 1; Fig. S1). The reason for this limited export market could be linked to competition with other producing countries, the taste of the product or biases about it, or the fact that the international market for canned small-pelagic fish is mature and does not easily absorb large additional quantities without corresponding price reductions. In contrast to feed anchovy, the food anchovy market seems buyer-driven.

Balance between the different supply chains

Three scenarios of the balance between the different supply chains can be considered as follows: (1) as occurs presently, massively transforming the anchovy production into FMFO and exporting most of these commodities; (2) increasing the DHC:IHC ratio and the production of elaborated food anchovy products, aimed mostly at export markets; or (3) leaving a larger part of the biomass in the ecosystem to rebuild, and then better exploit predatory fish stocks of higher value.

Scenario 1 presents the advantage of it being efficient to capture a large volume of fish using large vessels. In addition, the market is presently healthy, although the future of the demand remains uncertain. Present projections suggest that the continuous decrease in the fish-in/fish-out ratio of aquaculture will be over-compensated for by the continuous growth of this sector (Tacon et al. 2011). In the meantime, one could feel that in an open economy, such as the Peruvian one, it is natural to leave the markets driving the balance between the different supply chains according to profits. This would mean leaving fishers selling according to best profits and consumers choosing their sources of proteins or energy according to their taste and incomes. Nonetheless, the major drawback of this scenario is that it provides little employment nationally and a low national redistribution of rent. According to Paredes and Gutierrez (2008) and to Paredes (2012), fees are limited to 4.8 % of the production (5.6 % if fees on fuel are considered; Chilean fees are four times higher) and this amount cannot be changed until 2018 (Legislative Decree. No. 1084). Furthermore, the VAT is refunded to companies on their exported production (and for fish exported canned, frozen and cured, the industry benefits from the drawback system). Finally, this scenario is likely to be less sustainable in regard to environmental impacts (fossil energy, biotic and abiotic resource depletion, contamination; work in progress, as described by Fréon et al. (2010)). Note that an increasing part of FMFO is used for national aquaculture activities and, to a lesser extent, livestock. Although this is a small part, it must be encouraged because it generates a high employment rate and local added value. This consideration also applies to the recent construction of an omega-3 plant.

Scenario 2 seems to have a limited perspective on the short term, as explained earlier, but this perspective is expected to improve thanks to continuous global population and economic growth in many populated countries. Indeed, the world population is expected to grow from the present seven billion people to approximately nine billion by 2050 (UN-DESA 2009). According to Garcia and Rosenberg (2010), the growing need for nutritious and healthy food will increase the demand for fisheries' products from marine sources, whose productivity is already highly stressed by excessive fishing pressure, growing organic pollution, toxic contamination, coastal degradation and climate change. This scenario, even with a reasonable share of 10–15 % of the anchovy production potential, would definitely substantially increase employment and rent distribution. It requires a high investment from the fishing sector, both for the adaptation of fishing units and for the creation of large transformation plants, as well as offensive marketing; it also requires a solid government policy, and it will take many years to meet both requirements. Conversely, if the demand for Peruvian canned anchovy exportation became dominant, the risk would be an increase in prices in the domestic market, as has already occurred for fishmeal. Indeed, seafood is presently heavily traded internationally, exposing non-traded seafood to price competition from imports and exports (Tveteras et al. 2012).

Scenario 3 is in line with the consensual approaches of Ecosystem-Based Management (EAF; FAO2003), preservation of ecosystem services (Peterson and Lubchenco 1997) and the idea that fisheries have progressively eliminated piscivore species, mostly leaving either forage fish, such as anchovy, or in worse cases jellyfish (Jackson et al. 2001; Richardson et al. 2009). Furthermore, the moderate exploitation of forage fish is recommended to allow the population survival of the unexploited, but ecologically important, top-predators, such as marine birds and mammals (Cury et al. 2011). There are, nonetheless, uncertainties regarding the economic benefits of this scenario. Will the economic gains related to the exploitation of predators (e.g., fisheries, tourism) compensate for the losses related to smaller anchovy landings? Will the decrease in these landings substantially boost the price of FMFO? Will the relaxation of anchovy fishing mortality reveal that this stock was overexploited, and can it, after rebuilding, sustain both high fishing levels and top-predator abundances? In any case, because most Peruvian predators of anchovy are already fully or overexploited, several years will be required to allow the stocks to rebuild, which will lead to a difficult transition period for the industry. Furthermore, markets (domestic and internationa) for the corresponding more valued, but more expensive, products must be found. Our group is presently exploring some of these issues, including a combination of the compatible scenarios (2) and (3) to limit the economic losses of the latter scenario.

Conclusion

The facts collected here about the structure of the feed and food supply chains of Peruvian anchovy represent empirical material that can be used to illustrate typical market-driven systems. The present situation can be explained using conventional economic concepts. Although the low consumption of food anchovy is largely explained by market mechanisms, it raises other issues such as energy or human alimentation performance (eco-energetics), rent redistribution through public policies (political economy), employment, equitability and utility (low social costs), and resource management (threats on ecosystems, global change, ecosystem services). The success or failure of other scenarios of exploitation of the Peruvian marine ecosystem will largely depend on governance decisions. Understanding the reasons for the low consumption of food anchovy is a first step in demonstrating that governments have opportunities to influence the markets when they fail in building prosperity at an optimal cost for the community, considering the following (Daly and Farley 2011):

- a liberal economy is not always helpful in the optimization of resource productivity and the exploitation of common goods,
- governments have legitimacy to influence markets regarding macro-economic targets, social performance and responsibility criteria, although there is often a negative relationship between the degree of market interventions and market efficiency,
- the new paradigms of sustainability and societal responsibility will demand new accounting frameworks (still largely undefined, but ideally assessing sustainability performance) to discuss the new policy scenarios and performances, both within the country and along the supply chains, for provisioning world population,
- developing countries are presently in a new financial context of increasing speculations and energy/raw material prices, shocks and currency wars. Consequently, they will have to estimate the

macro-economic advantages (GNP contributions of different sectors, energy costs, state budget, social policy costs, food security) in playing the game of international markets and rent optimization, and/or the game of devoting part of the common resources to local markets (local currencies, employment and multiplicative effects).

Building alternative scenarios to the present situation of low productivity of anchovy exploitation in Peru requires going over the restrictive micro-economic analysis and neo-classical theories. Sustainability [environmental, ecological and social (humans)] and societal responsibility (insurability and fair trade) are new dimensions for public policy making. The challenge is to propose new criteria of resource productivity and prosperity (Meier and Stiglitz 2001). Governments of developing countries have the challenging opportunity and financial means to facilitate the creation of attractive domestic markets, thereby limiting their dependency on international markets for some strategic living resources, and to find new exportation strategies for accessing high-paying international markets.

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