Assessing Management Strategies for the Artisanal Sector of the Peruvian Anchoveta Fishery

Submitted in partial satisfaction of the degree requirements for the Master in Environmental Science and Management at the Bren School of Environmental Science & Management

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The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. It is a three quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Steve Gaines, Faculty Advisor
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List of Abbreviations and Acronyms

CERPER – *Certificaciones del Perú*, Peruvian Certifying Agency

CLD – Causal Loop Diagram

CPUE – Catch Per Unit Effort

DHC – Direct Human Consumption

DIGSECOVI – *Dirección de Seguimiento Contol y Vigilancia de PRODCUE*, Enforcement Program

EEZ – Exclusive Economic Zone

HACCP – Hazard analysis and critical control point

HCRZ – Human Consumption Reserve Zone

HCS – Humboldt Current System

IHC – Indirect Human Consumption

IMARPE - *Instituto del Mar del Perú,* Marine Institute of Peru

IQ – Individual Quota

ITP – Instituto Tecnológico de la Producción

ITQ – Individual Transferable Quota

IVQ – Individual Vessel Quota

LS – Low-scale

MT – Metric tons

NPV – Net Present Value

OA – Open access

PRODUCE – *Portal del Ministerio de la Producción*, Ministry of Production

ROP – *Reglamentos de Ordenamiento Pesquero*, Fisheries Management Regulations for DHC fleets

SISESAT – *Sistema de Seguimiento Satelital*, Satellite Tracking System

TAC – Total Allowable Catch

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Map of Study Area

Figure 1: This project focuses on the northern/central anchoveta stock off the Peruvian coast (Map credit: University of Texas at Austin).

Abstract

The Peruvian anchoveta fishery is the largest single species fishery in the world. The Peruvian fishing fleet is separated into two sectors: industrial and artisanal. One hundred percent of the industrial fleet's catch is processed into fishmeal, and most is exported for use in the growing global aquaculture and livestock industries. In contrast, the government requires the artisanal sector to sell its entire catch for human consumption in an effort to lower domestic malnutrition rates and increase jobs. Despite this restriction, the potential for economic gains and poor enforcement incentivize fishers to illegally sell most of their catch to fishmeal plants and misreport landings. This, combined with both fleet overcapacity and an unregulated growth of fishmeal plant businesses, creates a fishing pressure that threatens the biomass and therefore the socioeconomic value of the fishery. In response to these challenges, this project developed a bio-economic model to assess the tradeoffs between the current restricted open access system and alternative management scenarios. Results suggest that increases in both the biomass and certain economic indicators can be achieved by managing the artisanal sector under a total allowable catch (TAC). The results also suggest that both the industrial and artisanal sectors can increase profits while decreasing yields as harvest efficiencies improve with a larger biomass, which translates to ecosystem benefits throughout the Peruvian Humboldt Current System. We recommend the implementation of a national TAC that increases target escapement, and that the artisanal sector receives a proportion that is consistent with national goals for distributing economic benefits between both sectors.

Executive Summary

The Peruvian anchoveta fishery is the largest single species marine fishery in the world. The fishery and its associated industries contribute significantly to Peru's economy, as well as the economies of numerous nations that use processed anchoveta for food and other industrial purposes. Sustainable management of the fishery is not only important for ensuring the continued ecological productivity of the Humboldt Current System, but also the social welfare of thousands of individuals and families living in Peru's coastal communities. The motivation for this project arises from an interest in sustaining the biological stock of anchoveta in a way that maximizes the social and economic benefits to stakeholders within the fishery.

The Peruvian fishing fleet for anchoveta is separated into three sectors: industrial, low-scale, and artisanal. The industrial fleet is by far the largest, and its harvest constitutes 99% of Peru's fishing activities. Industrial fishing is tightly regulated under an Individual Vessel Quota (IVQ) system, and the sector has been internationally recognized for its successful management of marine resources. The total industrial quota is set by IMARPE, Peru's specialized marine resource agency, which uses the best scientific data available to estimate the total allowable catch (TAC) per fishing season. IMARPE biannually calculates the total biomass of anchoveta, and designates 4-6 million tons as "critical biomass." This critical biomass, also known as target escapement, is off-limits to industrial fishing in order to ensure adequate spawning and recruitment of anchoveta for future fishing seasons and to provide ecological benefits to the Humboldt Current System. The TAC designated for the industrial fleet is calculated over this target escapement. One hundred percent of the industrial fleet's catch is processed into fishmeal, the majority of which is exported for use in the growing global aquaculture and livestock industries. Export markets for fishmeal, existing mainly in China and other Asian countries, are lucrative and expected to increase in value.

Contrastingly, both the artisanal and low-scale fleets (collectively referred to as the direct human consumption [DHC] fleet) are managed under a restricted open access (OA) regime, and are not subject to restrictive harvest quotas. Therefore the entire harvest from these fleets comes from the "critical biomass" that restricts the TAC of the industrial fleet. In addition, the artisanal and low-scale fleets are legally required to sell their entire catch to DHC processing plants. The artisanal fleet is managed by regional governments, which have been found to implement enforcement inconsistently and therefore allow varying rates of illegal fishing activity to occur. The low-scale fleet is managed by the national government; while it has more capacity to enforce the low-scale fleet than its regional counterparts, uncertainty exists in regards to the number of active low-scale vessels and their harvest rates, complicating its ability to effectively monitor and enforce fishing activities.

One of the most influential drivers for illegal activity among the DHC fleet is the lucrative fishmeal black-market. The mandate requiring the fleet to direct catches to DHC processing plants was created in an effort to lower domestic malnutrition rates and increase employment in coastal regions. However, high fishmeal prices on international markets combined with weak enforcement incentivize fishers to illegally sell most of their catch to fishmeal plants and misreport landings.

The lack of a fishing limit (TAC) for the DHC fleet combined with rampant illegal activity creates an unchecked fishing pressure that threatens the sustainability of the anchoveta stock. Though industrial vessels overwhelmingly constitute the bulk of anchoveta extraction activities, an analysis reveals that the DHC fleet's fishing activity is potentially significant in terms of harvest levels and biological effects on the anchoveta stock. This study suggests that the DHC fleet's unrestricted and at times illegal fishing activity, combined with an overcapacity of vessels and the unregulated growth of residual fishmeal plant businesses, may generate enough fishing pressure to threaten the biomass of the entire anchoveta stock. The lack of monitoring and control of this fleet increases the level of uncertainty in regards to the true health of the anchoveta stock. Unregulated catch from biomass that is supposedly set aside for maintaining a healthy spawning stock compromises the accuracy of official stock assessments that are used to set the industrial fleet's TAC, which can exacerbate the problem. However, specific management systems, if implemented correctly, can increase stock biomass, increase profits to both fleets, and in some cases address incentives that lead to illegal fishing activity.

To address these issues, we developed an integrated bio-economic model to quantitatively assess the tradeoffs between the current restricted OA system and alternative management scenarios. The biological component of the model estimates the behavior of the anchoveta biomass under a range of fishing pressures and varying El Niño conditions. The resulting stock estimates determined by the biological model are then used as inputs in the economic model to estimate the monetary implications of different fishing and management practices.

The results suggest that increases in both fish biomass and fishery profit can be achieved by managing the DHC fleet under a TAC that raises the target escapement of anchoveta in the water. Even though 4-6 million tons of average target escapement is large, the model shows additional economic and biological benefits can be realized when this escapement reaches 6-7 million tons. As escapement grows and the anchoveta stock becomes more productive, the catch per unit of effort (CPUE) increases and the costs of fishing are reduced. Despite slightly lower returns on the absolute tonnage of fish landed, the fishing industry makes up for the loss in landings with a substantial reduction in fuel use and other operational costs. Both the industrial and DHC fleets can benefit economically as a result of this management option, although the DHC fleet benefits less when its catch is limited to fish for direct human consumption.

Due primarily to the high price of fishmeal on international markets, maximum profit for the DHC fleet is obtained when it is allowed to sell its catch legally to fishmeal plants, which offer a higher price per ton than plants processing fish for direct human consumption. Allowing the DHC fleet to devote part of its catch to fishmeal would relieve the *de facto* economic burden placed on them as a result of the DHC mandate. Importantly, the DHC processing sector was partially developed to improve the welfare of Peru's working class and poor population segments, and removing the DHC mandate without taking further action might have negative social effects. Prudent policy alterations, ensuring an adequate supply of anchoveta for direct human consumption can be balanced with obtaining satisfactory profits for both the direct human consumption and industrial sectors.

Project Significance

The Peruvian anchoveta fishery is the largest single species fishery in the world (Bakun & Weeks 2008), and its effective management is important for both the Peruvian economy and the global aquaculture industry. The majority of the anchoveta catch in Peru is directed towards fishmeal and fish oil production, which are economically important exports. Demand for fishmeal has continued to grow as aquaculture farming has increased in the last 10 years in an effort to meet increasing global demands for salmon, crustaceans, and other marine and freshwater fish. The aquaculture industry is expected to grow, primarily in China and other Asian countries (IFFO 2009).

The project client, The Nature Conservancy (TNC), was seeking to understand the problems of the fishery and how they might be solved so as to recommend proper management to the Peruvian government. The Bren School offers a unique and interdisciplinary approach to solving natural resource problems and developing sustainable solutions.

Project Objectives

The objectives of this project are to evaluate the current regulatory system for the artisanal and low-scale fleets of the anchoveta fishery, and develop and assess alternative regulatory strategies for this sector. Both qualitative and quantitative approaches were used to examine the biological, economic, and social implications of the current scenario and potential alternative regulatory scenarios. Ultimately, the goal of this project is to identify ways in which current legislation and management could be altered and how alternative regulatory strategies can be implemented in order to (1) ensure the sustainability of the anchoveta biomass, (2) improve the economic value of the fishery, and (3) protect the jobs and livelihoods that rely upon this resource.

Specifically, qualitative and quantitative analyses were performed to achieve the following objectives:

Qualitative Analyses:

- Characterize both the industrial and DHC sectors of the anchoveta fishery, including fleet capacity, landings, processing capacity, and production
- Identify potential threats to the biological, economic, and social aspects of the fishery and drivers of these threats
- Develop a causal loop diagram to explore key linkages and leverage points that drive fishery dynamics, and to identify potential points of intervention
- Explore and assess regulatory and management alternatives for the DHC fleet
- Perform a conceptual evaluation of current legislation and management pertaining to the artisanal sector of the fishery, particularly the DHC mandate

Quantitative Analyses:

- Develop a bio-economic model to quantitatively assess the tradeoffs between four management scenarios:
    - **Artisanal Restricted Open Access**: The current management scenario
    - **Artisanal Variable TAC:** A variable TAC allocated to the artisanal fleet each season as a proportion of a National TAC designated for the entire fishery
    - **Artisanal Fixed TAC #1:** A constant TAC assigned to the artisanal fleet that reduces the TAC allotted to the industrial fleet and maintains the set target escapement
    - **Artisanal Fixed TAC #2:** A constant TAC is assigned to the artisanal fleet that does not affect the TAC allotted to the industrial fleet and reduces the set target escapement

Overall Analysis:

- Use results from our qualitative and quantitative analyses to develop management recommendations for the DHC fishing sector that can allow for improvement to the biological, economic, and social aspects of the fishery

Background

Environmental and Fishery Dynamics

The coastal waters of Peru are among the most productive in the world due to intense upwelling that is driven by the Humboldt Current System. These biologically rich waters support vast schools of anchoveta (*Engraulis ringens*) that not only perform a vital role in the marine ecosystem, but have also supported the livelihoods of Peruvian fishers for decades (Clark 1976). The resiliency of the anchoveta to intense fishing pressure and environmental phenomena such as El Niño has allowed the species to thrive even under the most difficult conditions. The seeming abundance of the species, however, has hindered precautionary management, putting the long-term stability of the populations at risk. Recently, stock levels have been dangerously low, despite decades of largely natural fluctuating population levels (IMARPE, 2012). The Peruvian anchoveta is divided into two main stocks, the north-central stock and the southern stock. The southern stock is shared with Chile, and it is not as large or as valuable. Therefore this project will only address the north-central stock.

Peru has approximately 3,100 kilometers of coastline (Durand & Seminario 2009) with waters rich in oxygen and nutrients as the result of intense upwelling from the Humboldt Current. The oceanographic conditions that support the vast and abundant biodiversity of the area include steady winds that blow equator-ward along the coastline (Bakun & Weeks 2008). These "trade winds" drive the strong coastal upwelling that recycles oxygen and nutrients throughout the water column. The Humboldt Current routinely produces more than 20 times as much fish as other upwelling systems (such as the Canary or Benguela systems).

The anchoveta have a very fast growth rate and time to maturity (~1 year), and a short lifespan (~4 years; Bertrand *et al.* 2008). These characteristics allow the anchoveta to have a high resistance to fishing pressure and to respond quickly to environmental variability such as El Niño phenomena. Anchoveta populations vary spatially and temporally and are particularly affected by the occurrence of frequent El Niño events in the region. Fish recruitment, or the fish that survive to become the next harvestable population, has been shown to be an important factor affecting anchoveta biomass in Peru (*Ibid*). The spawning months for the north-central stock are from November-January and May-July (Pauly & Tsukayama 1987 *quoted in* Durand & Seminario 2009).

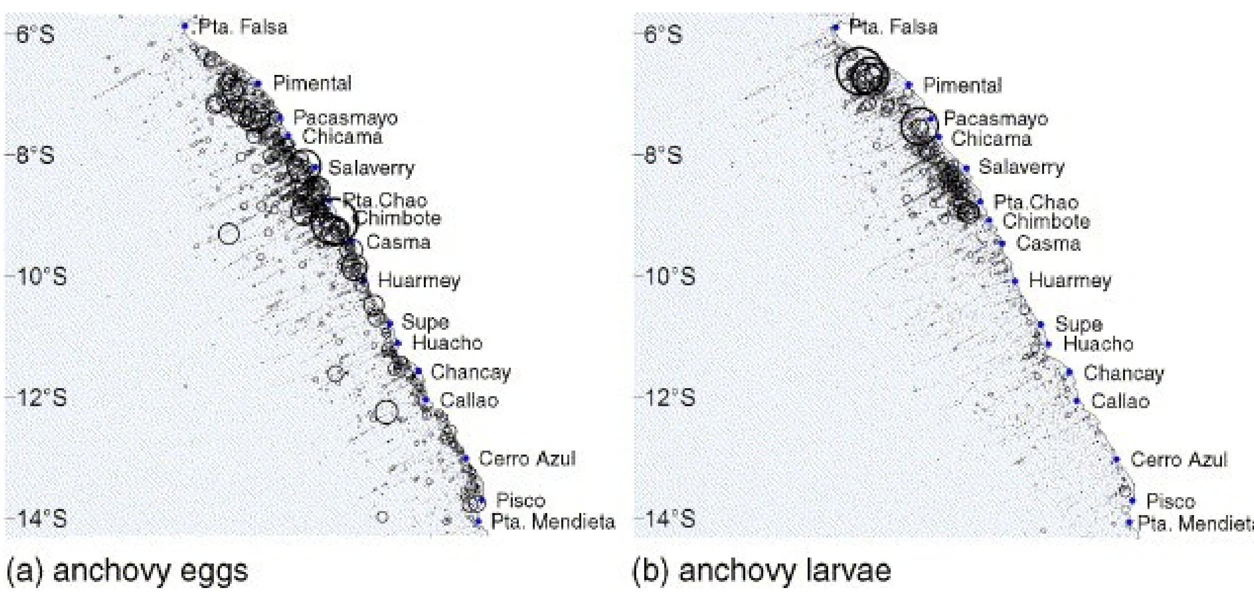

Figure 2: Composite distribution maps for (a) eggs and (b) larvae of anchovy collected during surveys conducted by IMARPE from 1970 to 2003. The dots indicate anchovy spawning areas, and

the circles represent main spawning regions. Circle radii sizes are proportional to egg and larval abundance (Lett, *et al*. 2007)

Anchoveta that are smaller than 12 cm in length are considered to be juveniles, and the harvest of these fish is limited to 10% of landings by all fleets (Durand & Seminario 2009). In order to prevent the harvest of juveniles, fishers are required to use nets with a minimum mesh size of 13 mm, and a large percentage of industrial landings are monitored to ensure that the 10% maximum allowance is not surpassed. Anchoveta live approximately 3-4 years, but are usually captured right when they reach sexual maturity at 1-2 years of age and with a length of 11-12 cm. This holds implications for the future reproductive potential of the north-central stock. Since a majority of the population is captured before it reaches sexual maturity, the overall size of the population decreases with time. The main spawning areas are located between Chicama and Chimbote, and Callao and Pisco (Figure 2). The largest spawning stock is observed from December to April, which coincides with a closed fishing season for the industrial fleet, but not the low-scale or artisanal fleets.

El Niño is a climate event that increases the temperature of the sea surface water in the Southeast Pacific when the upwelling of cold nutrient rich water is suppressed (Tveteras *et al.* 2011)**.** El Niño events drastically affect stock distribution: stocks generally move southward, closer to the coast and into deeper waters (Durand & Seminario 2009). Anchoveta populations vary greatly over space and time, with the most noticeable and dramatic changes occurring on a multi-decadal, basin wide scale (Bertrand *et al.* 2008) associated with El Niño conditions. Landings during these periods are drastically reduced, and can lead to closures of the anchoveta fishery. Despite the devastating effects of an El Niño event on Peru's social and economic livelihood, however, it is hypothesized that these events may be elemental to the productive success of the anchoveta, as they are highly adapted to the inherent variability of the Peruvian ecosystem (Bakun & Weeks 2008). The anchoveta's ability to thrive depends on the stock's capacity to rebound from these events. This recovery is highly dependent upon the adjustment of fishery regulations during and following El Niño events, where lowered quotas are imperative for stock recovery. El Niño events nearly always result in dramatic reductions in anchoveta biomass, but recovery following the event has not always followed the same pattern. Variability in the rate of recovery is hypothesized to be due, at least in part, to the management regime. Increasingly precautionary regulations since the 1980s have resulted in a more consistently rapid recovery of the anchoveta stock (Bertrand *et al.* 2004).

History of Governance and Fisheries Regulations in Peru

Political Will

The anchoveta fishery collapsed most precipitously immediately following the enactment of the first General Fisheries Law. This irony supports the notion that Peruvian fisheries laws historically have not been reactions to biological needs or even social upheaval, but instead are a reflection of political changes and "expressed general attitudes towards the exploitation of natural resources that mirrored the political ideologies of the governments of the day" (Schreiber 2011). Each distinct and newly elected Peruvian government drafted its own fisheries laws, but did not do so in response to the needs of the fishery. Rather, much of the laws focused on delineating access boundaries and defining the role of foreign investment (*Ibid*).

Implementation of General Fisheries Laws

The legal instruments developed for the fishery in the first two decades of the Peruvian anchoveta fishery from the 1950s to the early 1970s were characterized by fragmented and reactive decision-making (Glantz 1979; Hammergren 1981; Aguilar 2000) and unresponsiveness to fisheries management recommendations provided by IMARPE after its creation in 1964. Instead of strengthening sustainability, the regulations focused mainly on taxing exports of fishmeal to collect revenue for the state. In 1968, a revolutionary military government came to power in Peru and established the Ministry of Fisheries and passed the first General Fisheries Act. The Act's primary purpose was to delineate and strengthen government control of the private fishing sector (Hammergren 1981), and to expropriate and nationalize entire industries, which followed larger nation-wide political goals of the left-wing military dictatorship. Even with the passing of the first General Fisheries Act (Decree Law 18810), natural resource management considerations were overshadowed by political interest in state control of profit-making industries (Schreiber 2011).

After the fishery collapsed in 1972, unfavorable environmental conditions persisted until 1984, bringing low annual harvests. During this time, no major fisheries acts were written or enacted (Schreiber 2011). Following the election of a new populist social democratic government led by Alan Garcia, the second Peruvian Fisheries Act of 1987(Law 24790) was passed, focusing on "rational" (sustainable) exploitation of resources, social welfare, and cooperation between the re-emerging private sector and government (Aguilar 2000). Especially reflective of the Garcia government's social trajectory were new mandates for the Fisheries Ministry to direct diversification and yield enhancement for direct human consumption products by supporting artisanal fishery and processing industries. Overall, the time span from 1984 to 1992 can be characterized as a controlled-growth period of increased public- to-private cooperation (Schreiber 2011).

In 1990, right wing neo-liberal economic policies surged and the fishing and processing industries experienced changes that come with the application free-market principles, specifically new investment by foreign capital. In 1992 the third Peruvian Fisheries Act (Decree Law 25977) was approved. The law further emphasized inter-agency coordination and regulation of artisanal fisheries, but also added sections stipulating how economic efficiency could be optimized with biological diversity and conservation goals. Although the pro-capitalistic policies of the time increased foreign investment and ultimately led to the current period of sustainable catches, an authoritarian regime rife with human rights violations and corruption (BBC 2002) generated distrust by Peruvians in regard to political matters, with consequences for civic engagement by Peruvian citizens.

Corruption

The 1990s can be described as one of Peru's most corrupt decades, and the era is considered a template for the rise of "electoral authoritarianism" in Peru (Carrion 2006). During this time, Transparency International ranked Peru's government 7th on its list of most corrupt countries world-wide (Global Corruption Report 2004). The systemic nature of 1990s-era corruption differed from most corruption activities in that money flowed in the opposite direction – instead of the private sector paying the public sector for contracts and favors, factions within the Peruvian government would pay media outlets directly with the express intent of controlling what would appear each evening on the national news. Although the level of corruption in Peru overall has decreased, the government is still structured in a way in which politicians are susceptible to special interest groups, which has led to poor fishery management and threats to the long-term sustainability of the fishery.

Insufficient Civic Engagement

Although the rise in corruption in the 1990s was certainly not the sole cause of Peru's institutional weaknesses, it has been estimated that the Peruvian economy lost US$ 8 billion in this decade (Montgomery & Feltch 2006). Transparency International claims that the past corruption has increased societal vigilance against such behavior, while others argue that it set a precedent for years to come (Carrio 2006). The World Bank's Institutional Governance Review on Peru states that the country's historic trend of "*hipercentralismo"* (extreme centralization) has led to a lack of sufficient checks and balances and given too much power to the office of the President, allowing short-term narrow interests to supersede long-term public interest. An unstable regulatory environment inadequately supports economic growth, leading to recurrent policy volatility and a recycling of poor governance trends. The delayed introduction of universal suffrage, weak political parties, and inadequately informed voters also contribute to Peru's lack of civic engagement and lengthen the nation's on-going struggle for a secured public interest.

Malnutrition in Peru

Causes of malnutrition in Peru are direct, including food insecurity and poverty, and indirect such as lack of access to markets, transportation, and education; inadequate water and sanitation; cultural practices; and weak governance (Aquiar *et al.* 2007). Generally, children are at a higher risk of malnutrition, particularly if raised in households that do not have access to, or knowledge of, proper nutritional diets. Malnutrition at an early age leads to reduced physical and mental development during childhood, which may lead to more severe consequences as an adult (WFP 2012). Nutrition and food-intake of Peruvians is sensitive to food supply and price increases of commodities in imports (Aquiar *et al.* 2007). Therefore, impoverished areas are less able to afford healthy and nutritious food.

Health benefits are a 'luxury' concern, addressed once basic needs such as food, shelter, and clothing are secured. Often poor, rural areas do not have this luxury, suggesting that accessibility and affordability of nutritional products such as anchoveta are essential for increasing their consumption in these underdeveloped areas. There are numerous programs funded by the Peruvian government, international donor agencies, and non-governmental agencies that aim to address this issue, and a number of regional presidents signed the “Lima Declaration” against malnutrition in 2007 (Aquiar *et al.* 2007). However, these programs have been less successful than anticipated because of poor political management. Malnutrition prevention programs are often plagued by misuse of funds, unresponsiveness to local needs, and lack of inter-sectoral cooperation among ministries and organizations to address the root causes of malnutrition.

The Anchoveta Fishery

Industrial Fishery

The industrial fishing fleet emerged in the early 1950s with the introduction of anchoveta-based fishmeal production. Prior to the rise of the fishmeal industry, artisanal and small-scale coastal fisheries dominated the catch. It was not until the mid-1960´s that the industry experienced rapid development, a period known as “the anchoveta boom” (Castillo & Mendo 1987). Peruvian fishmeal is a major contributor to Asian aquaculture activities, directly linking the aquaculture industry’s growth to Peru’s marine resources (Asche & Tveterås 2004; Nordahl 2011).

The industrial anchoveta sector is comprised of two fleets: the industrial or steel fleet (434 vessels), and the wooden fleet (662 vessels; Figure 2). While fewer in vessel number, the steel fleet is larger in terms of storage volume. With a total hull capacity of over 140,657 m^3, this is approximately three times the wooden fleet’s capacity of 41,320M^3 (PRODUCE; Figure 3). Each steel vessel typically ranges from 100 to 800 metric tons (MT) of hull capacity, whereas the wooden vessels hull capacities range from 32.5 to 100 MT. In Peru, the steel and wooden fleets are usually referred to collectively as the “industrial” fleet, although they are differentiated by specific fisheries policies (in this report the “industrial” fleet refers to both steel and wooden ships unless otherwise noted).

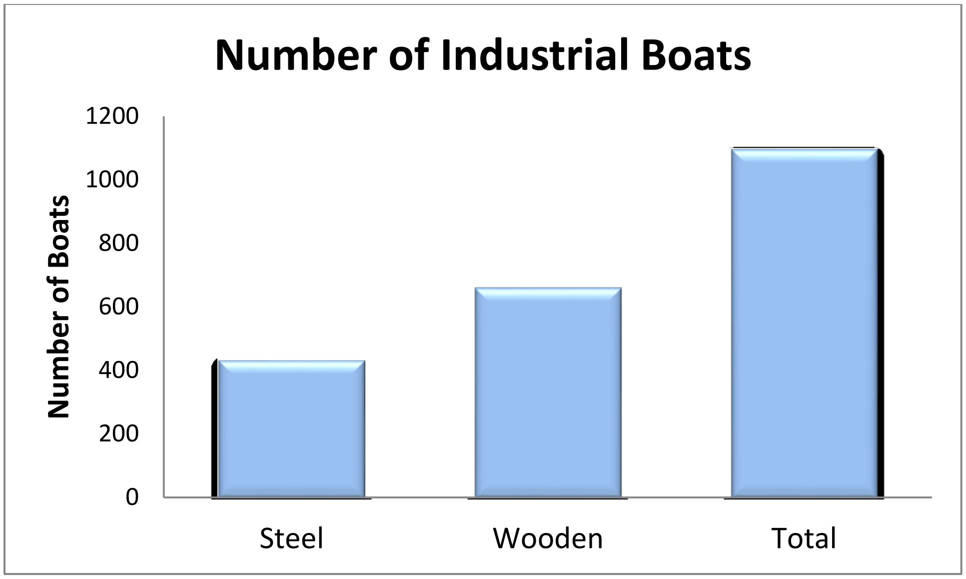

Figure 3: The total size of the steel and wooden industrial fleet is over 1000 vessels as of 2012

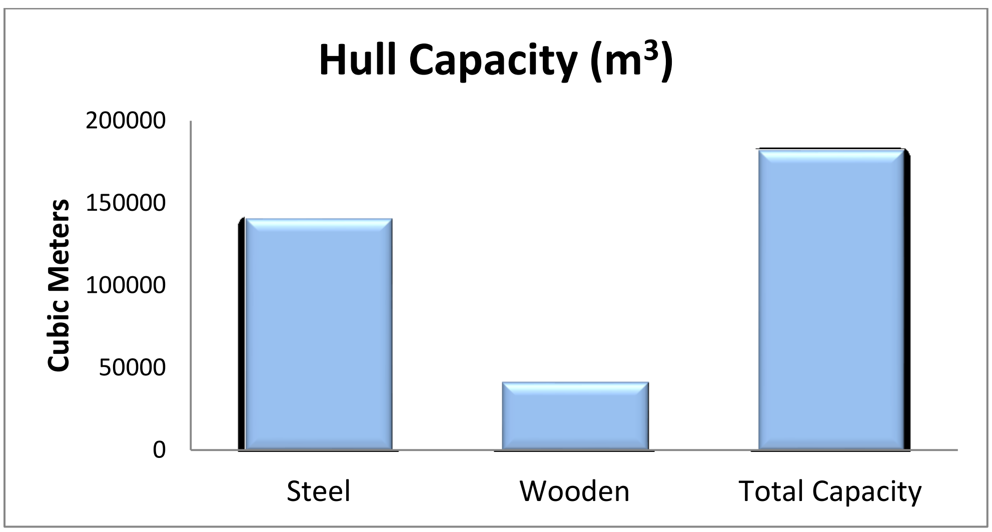

Figure 4: Despite being fewer in number, the steel fleet comprises the bulk of industrial hull capacity

The industrial fleet, like fishing fleets in other Latin American countries, is grossly overcapitalized (Ibarra *et al.* 2000), in terms of number of vessels, total hull capacity, and potential fishing effort. In Peru, a typical steel ship will have a hull capacity of 250 m^3 and is equipped with purse seine nets and sophisticated sonar technology that efficiently targets moving schools of anchoveta. A study conducted by Paredes revealed that the industrial fleet possesses three times its optimal hull capacity (Paredes 2012), which contributes to economic inefficiencies. In 2006, Hatziolos and de Haan estimated that the steel fleet used just 31% of its total fishing capacity and the wooden fleet 25%, which translates into 69% and 75% of overcapacity, respectively. According to fleet data from PRODUCE, the industrial fleet has a standing capacity of 181,977 m^3.

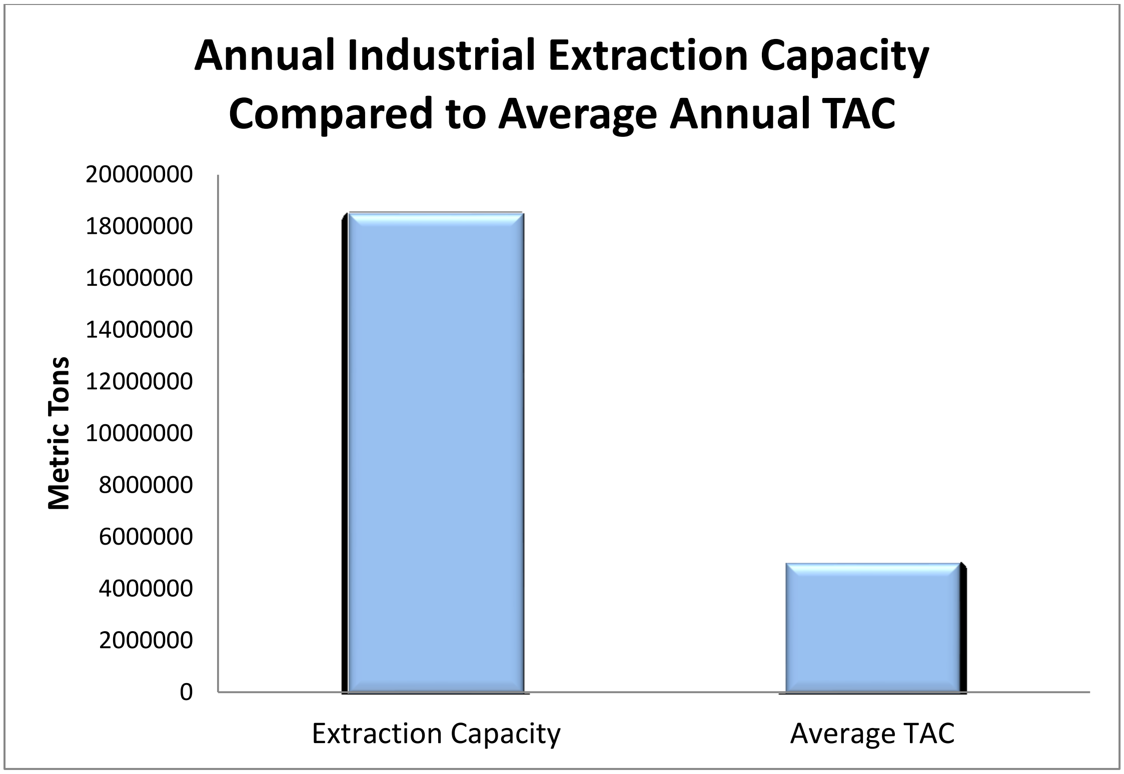

Figure 5: The industrial fleet has a combined hull capacity 3.7 times greater than the average anchoveta TAC

During the first 13 years of the fishmeal industry development in the 1950s, the anchoveta fishery was under no overarching managing body and it was not until the creation of IMARPE in 1964, the Fisheries Ministry in 1969, and the collapse of the fishery in 1972, that the Peruvian government began to actively manage the fishery (Castillo & Mendo 1987). Regulation of fishing effort and processing facilities by permit allocation, the establishment of a minimum catchable size of 12 cm, and the implementation of no-take periods during the spawning seasons to allow for recovery of the stocks were the first management strategies implemented in the fishery (Castillo & Mendo 1987; Pauly 1987).

However, the high economic value incentivized fishermen to circumvent the new regulations by fishing illegally and selling catches on a growing black market (Agüero 1987). A study by Castillo and Mendo (1987) found widespread underreporting throughout the production chain of the industrial anchoveta fishery from 1950 to 1985. Illegal fishing includes "black fishing" (fishing without a permit), discarding of juveniles and bycatch, misreporting of landings through the use of clandestine pumping tubes and modified fish weighing scales that deliberately underestimate catch weight, and illegal trading between fishermen and the fishmeal industry. Twenty percent of the total anchoveta landings in that period went unreported (*Ibid*). The 1990s brought management improvements in the industrial sector, and greater cooperation between the ministries and the private sector (Ibarra *et al.* 2000), setting the stage for the introduction of an innovative management scheme in 2009.

Management and Regulations (2009 to Present)

The industrial fishery is currently managed under a total allowable catch (TAC) and an individual vessel quota (IVQ) system. The TAC is determined by IMARPE and the fisheries vice-ministry. The inclusion of an IVQ system in this management approach aims to ensure the sustainability of the fishery by reducing pressure from the "race to fish." The IVQ system was first implemented in 2009 and within two years the length of the fishing seasons increased significantly. The total number of effective fishing days increased from fewer than 50 to more than 180 days per year (IMARPE; PRODUCE; Tveteras *et al.* 2011). The number of active fishing ships simultaneously decreased from 1200 to no more than 1000 in 2011 (Figure 5). These combined factors reduced the overcapacity of the industrial fleet from 4.6 times the average TAC in 2006 to 3.0 in 2011 (Tveteras *et al.* 2011).

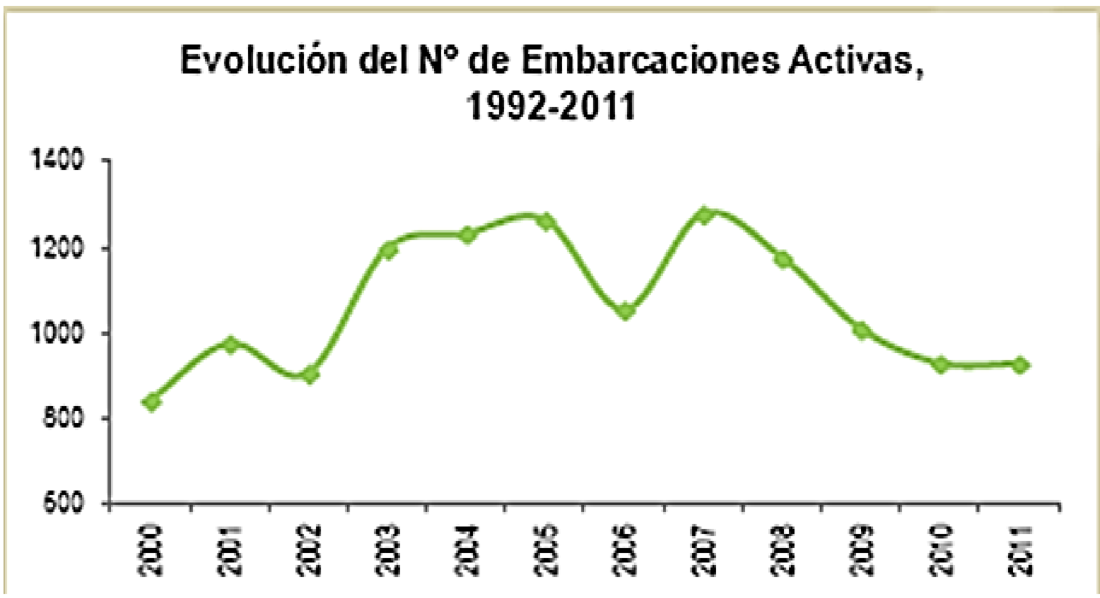

Figure 6: Active industrial fishing boats from 2000-2012 (Tveteras *et al.* 2011)

In the industrial IVQ system, transferability of quotas was limited in order to avoid the social implications of a concentration of rights among a small group of fishers. However, some consolidation of quotas did take place in the years following the introduction of the IVQ system. As of 2012, 70% of industrial quota shares belong to just seven companies, all of which owned fleets of industrial vessels prior to 2009 (Figure 6).

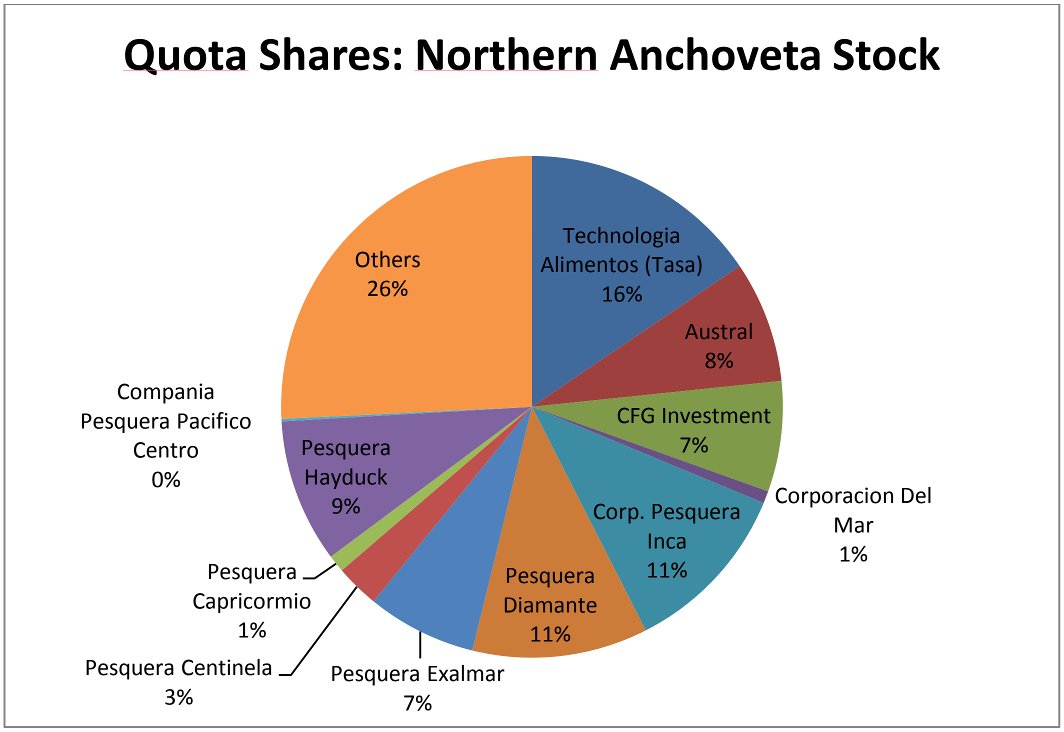

Figure 7: Industrial fishery quota allocation for the northern anchoveta stock (PRODUCE)

Entry to the industrial sector of the anchoveta fishery is closed, and new vessels can only replace decommissioned vessels with the same hull capacity. The industrial fleet as a whole is subject to catch quotas, restricted fishing seasons, gear-type regulations, and controlled fishing effort (Sánchez & Gallo 2009). All boats are tracked using satellite GPS systems and landings are monitored with sampling to verify fish size and catch composition for bycatch. The *Sistema de Seguimiento Satelital* (SISESAT) office, a branch of the Peruvian DIGSECOVI agency, which is a sub-agency of PRODUCE, monitors the activity of industrial and low-scale boats via the satellite tracking system. The industrial fleet is prohibited from fishing within the first ten nautical miles (nm) from the coast, which are reserved for the artisanal and low-scale fleets (DS-005-2012-PRODUCE). These management practices have led to more sustainable harvests as well as protective strategies that reduce the likelihood of overfishing and allow for the recovery of the anchoveta populations during catastrophic El Niño weather events. The IVQ management system has resulted in economic gains in the fishery and guaranteed supply by quota ownership, which has provided processing facilities the incentive to invest in technological upgrades resulting in the production of higher quality fishmeal and therefore higher profit margins (Tveteras *et al.* 2011). Another trend taking place at an increasing rate since the adoption of the IVQ system and value-added products is the increase in products for direct human consumption.

The anchoveta spawning season ends around October each year, and the industrial fishing season usually begins in this month. Although some spawning occurs from August-March, peak spawning periods are typically August-September and February-March, and these months are closed to fishing for the industrial sector. These seasonal closures represent one of the management strategies IMARPE uses to ensure adequate recruitment and annual biomass. Since 1995, the anchoveta fishery has maintained stable landings and was heralded as one of the most sustainable fisheries worldwide after implementation of the IVQ system for industrial vessels (Schreiber 2011). The end to the industrial "race for fish" in Peru increased economic efficiency and increased profits. With stable profits, companies had the financial ability to invest in product differentiation within the processing industry. This added jobs to the canning sector, which has positive social implications for job-scarce regions along Peru's coast (Tveteras *et al.* 2011).

Direct Human Consumption Fleet and Fishing

Quality Requirements for Anchoveta Destined for DHC

Direct Human Consumption (DHC) anchoveta products can only be processed from high quality fish that meet certain health and sanitary requirements. The main products of the DHC anchoveta are frozen and canned, and there exists a small industry for cured fish (Durand & Seminario 2009). Because the processing of these products is directed for human consumption, the DHC plants must adopt a hazard analysis and critical control point (HACCP) systems to ensure satisfactory quality for export (*Ibid*). Anchoveta are a small and fatty species, and often deteriorate under mechanical pressure during processing. Anchoveta intended for DHC cannot sustain the intense mechanical pressure used to process other species such as mackerel. For this reason, anchoveta require hand-processing and need careful treatment during the capture and preservation phase. Studies have shown that small and medium vessels are most suitable for harvesting fish intended for DHC, most likely because of the less mechanized fishing gear used by these vessels. To ensure good quality fish for DHC, the following requirements must be met: minimize the time between capture and processing, use vessels that are specifically equipped with preservation systems for small pelagic species, maintain cold storage throughout the supply chain of the fish, use appropriate landing systems so as not to impact the quality and physical integrity of the catch, and avoid bacterial contamination through the application of sanitary measures (Durand & Seminario 2009).

Present Management and Regulations of the DHC fleet

In August 2012, a new management regime replaced the former legislation for the direct human consumption anchoveta fishery, with the main objective of re-organizing the artisanal and low-scale fleets and controlling the fishing effort. The former regime considered only one artisanal fleet, comprised of boats with a maximum hull capacity of 32.5 m^3 and a maximum length of 15 m. This fleet was permitted to fish only for human consumption, allowing for 10% of discards. An artisanal exclusive zone from the coast to the first 5 nm was reserved for their activities. The coastal regional governments were in charge of enforcing this fleet´s activity, allocating permits, and controlling fishing effort. Boats were only allowed to land their catch in the region where they received their permits. Permitted only to supply raw material to the DHC processing sector, those in the artisanal fleet were obligated to sign contracts with processing facilities.

The current DHC fleet is still mandated to fish for DHC and is comprised of 926 vessels. While there is nearly the same number of boats in the DHC sector as in the industrial sector, its total hull capacity makes up only a small portion of the fishery – the artisanal fleet's total capacity is 8588.98 MT, representing 4% of the total hull capacity of the entire anchoveta fishery. The new regulation not only divided the DHC fleet into two classes, but it also changed many of the regulations that these vessels are subject to.

Low-scale Vessels and Management

Boats are considered low-scale (LS) if they have a capacity between 10 and 32.5 m^3 and are no more than 15 m in length. According to PRODUCE´s database, there are 371 LS vessels (Figure 7), accounting for 4658.96 m^3 of hull capacity (Figure 8), which represents 2.17% of the total hull capacity of the entire anchoveta fishery.

This fleet is permitted to fish between the first 5 and 10 nm and is required to sell 100% of its catch to DHC processing plants (allowing for 10% as discards). The low-scale fleet is to be managed and controlled by the central government, and is now required to carry a satellite monitoring system (SISESAT) and pay for additional fishing permits as stipulated by the new regulation. DHC plants can derive up to 40% of raw material received from low-scale vessels to residual fishmeal plants, considering that not all the fish complies with the size and quality necessary for DHC products.

Artisanal Vessels and Management

To be considered artisanal, a boat must have a hull capacity less than or equal to 10 m^3. According to PRODUCE's database, there are 556 artisanal vessels (Figure 7), which account for 3939.02 m^3 of hull capacity (Figure 8), representing 1.83 % of the total hull capacity of the entire anchoveta fishery.

These fishermen are given access to the first 5 nm, and 100% of the catch from artisanal boats supplied to the DHC plants must be processed into DHC products. The new law provides a vague description of surveillance and enforcement for this fleet, stating that the artisanal sector will be managed by regional governments as opposed to the central government. Under the new regulation, the artisanal fleet is still only allowed to land their catch in the region where they received their permits.

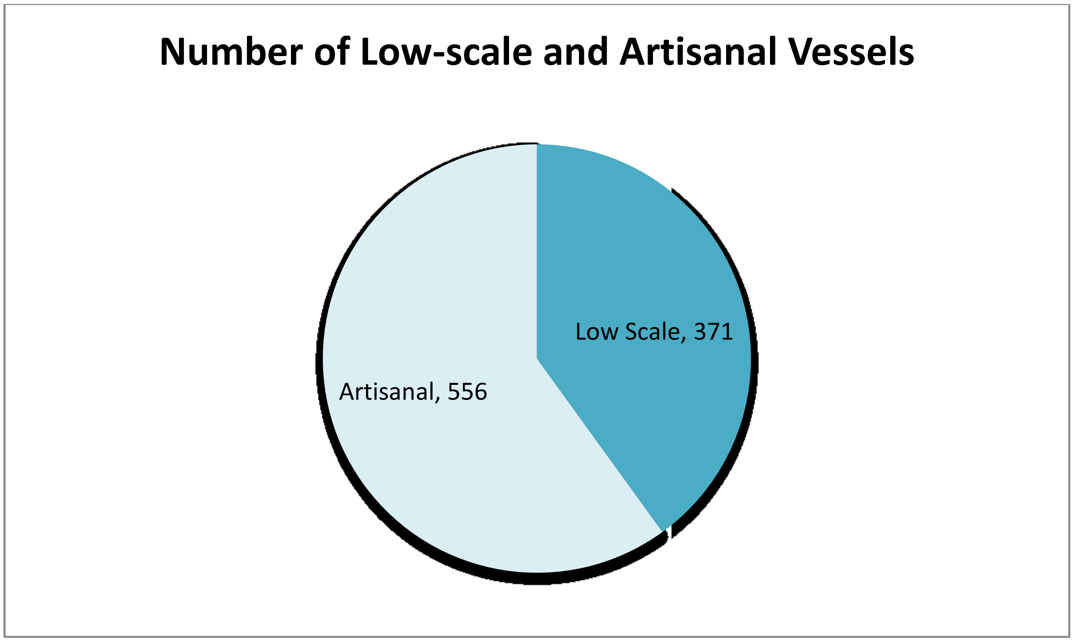

Figure 8: The DHC fleet is comprised of low-scale and artisanal vessels, which are defined by their hull capacities

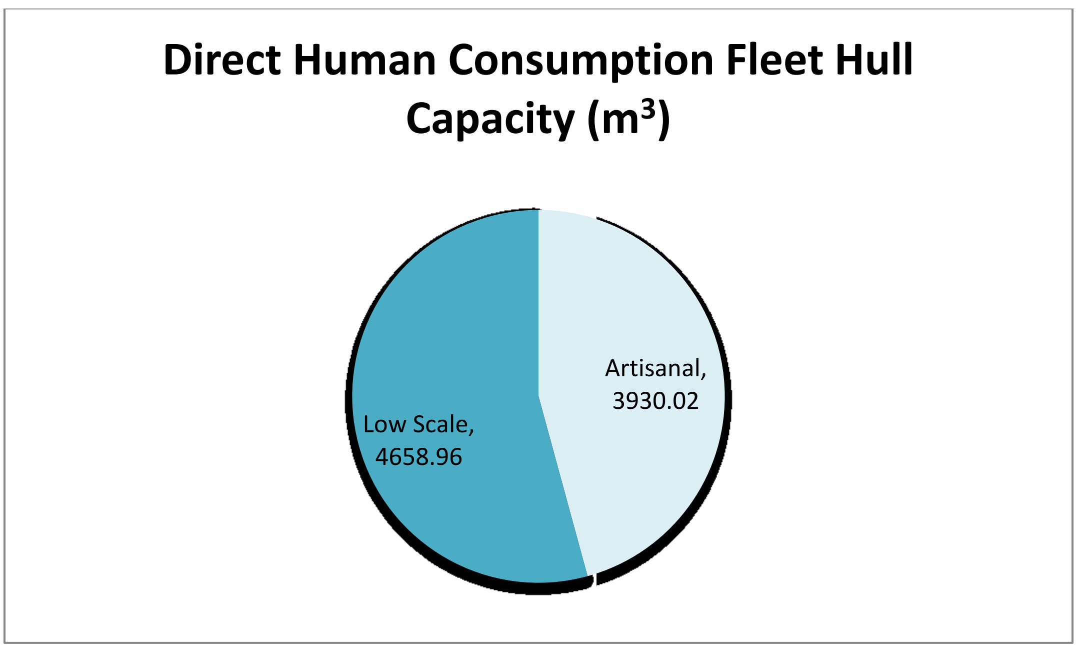

Figure 9: Although artisanal vessels outnumber the low-scale fleet, the low-scale's hull capacity is greater

Fishmeal and DHC Processing Sectors

Fishmeal and DHC Plants

The Peruvian fishing industry has an estimated yearly processing capacity of almost 25 million tons of raw fish. Fishmeal plants account for more than 95% of the total processing capacity, and canning plants account for nearly 5%. Plants that produce cured anchoveta products make up a small fraction of total production (Table 1).

	Traditional Units		Normalized Units	
Sector	**Units**	**Total Capacity**	**Units**	**Total Capacity**
Fishmeal	**MT/hour**	9,332.67	**MT/Year***	23,689,320
Canning	**Boxes/Shift**	183,373	**MT/Year****	1,258,133
Cured	**MT/month**	1764	**MT/Year**	21,168

*100 fishing days were considered for the fishmeal industry and 200 for canning
**60 boxes/MT was considered as the production ratio; 2 shifts per day; 200 days per year

Table 1: Total processing capacities by sector (IMARPE)

Industrial Fishmeal Plants

Fishmeal processing facilities are distributed along the entire coast from Piura in the north to Ilo in the South. Production of fishmeal can be divided into two sectors: fishmeal plants and residual plants. The industrial fishmeal plants have more than 97% of the total processing capacity and uses whole fish as inputs for production. The raw material used by industrial plants represents 99 - 97% of the total anchoveta landings. Processing capacity has been reduced since the IVQ system was implemented, with limited allocation of permits for new plants (Tveteras *et al.* 2011). Residual plants represent 3% of the total fishmeal plant capacity with an estimated potential production of nearly 2 million MT per year. The number of plants and plant capacities have been steadily rising over the last three years, while simultaneously improving processing efficiencies. Residual plants are now able to produce high quality fishmeal and fish oil. The total amount of fish received from the artisanal fleet is considered to be greater than what is actually reported.

Image 1: The team visits *Pesquera Jada S.A.* in Chimbote, Peru. The plant is one of many fishmeal and canning plants in Peru and the image is showing the neighboring 'residual' sister plant. Photo credit: Yoel Kirschner (July 2012)

Residual Processing Plants

For sanitation reasons, all new DHC plants are required to have an adjacent, smaller production facility (a residual plant) to convert "residual" fish into fishmeal. Residual fish are portions of the supplied raw material that do not meet sanitary standards (i.e. the fish are too small for processing, rotten, etc.) and cannot be used in the production of DHC products. These residual fish are used to make lower-quality fishmeal, called "Traditional" (higher grades are "Prime" and "Super-Prime"). Plants are permitted to direct up to 40% of fish received from LS fleets to these plants. This stipulation was originally created in order to improve DHC profits margins, which would otherwise be too low to sustain operations.

DHC Products

There are a number of direct human consumption products made from anchoveta available for both the domestic and international markets. Until August 2012, anchoveta products were produced for the government's social program PRONA, which was created with the goal of providing low-income citizens with accessible nutritious food. A number of products were developed by Peru's Technological Institute, or *Instituto Tecnológico de Perú* (ITP).

There are four main types of products: canned, frozen, cured, and dried. The process for canned products begins with the cleaning of the raw fish using a saltwater solution. The cleaning process finishes with a cold-water rinse and the fish is then placed in cans (either in their whole or shredded form) and cooked. During the cooking process, different liquids are added in order to achieve the desired product (such as tomato sauce, vegetable oil, smoked flavored olive oil or salt water). Once the fish have been adequately cooked, the cans are sealed, creating a vacuum and are then placed in an autoclave for sterilization.

Cured products, also called anchoas, undergo a salting process. To make these products, a similar initial cleaning process is completed to prepare the fish. They are then cured in salt, after which they are packed in vacuum-sealed bags or jars. These products are particularly popular in international markets, and are mostly sold to European distributors.

Frozen and dried products are less common than the other two, and have been processed mainly for domestic markets. Frozen anchoveta products are generally made with an anchoveta pulp. An example of this type of product is anchoveta "nuggets." Dried anchoveta is stored in bags, and, similarly to canned products, has a relatively long shelf life and does not require a cold chain for distribution therefore making it ideal for transporting to remote regions.

Image 2: Anchoveta fillets are salted and cured in barrels for 6 months or more (A, B). The final fillets are then cleaned (C) and packed into aluminum cans for export. Photo credit: Yoel Kirschner (July 2012; *Compania Americana de Conservas* Pisco, Peru).

Canning Plants

The canning industry possesses nearly 5% of the total processing capacity across all Peruvian anchoveta industries and is able to process 1.25 million MT of fish per year (Table 2). While the canning industry was mainly focused on processing tuna, skipjack and mackerel, most of this capacity is now directed to processing anchoveta. Sixty-five percent of the capacity is located in Ancash and 25% in Piura (Figure 9). Pisco, Lima, and Callao account for 18%. The processing capacity of canning plants is calculated in number of boxes per shift, where a shift is typically considered to be a 12-hour work day equivalent. The number of cans per box varies among the different type of products, but an average of 48 cans per box is typical for canned anchoveta. In order to estimate the volume of raw material that can be processed in a year, it was estimated that 60 boxes can be produced from 1 MT of anchoveta (Infante, personal communication 2012. Also it was approximated that 2 shifts of 12 hours each can be accomplished in one day and that the plant could operate 200 days per year. It is important to highlight that not all of the capacity is intended for processing anchoveta exclusively. The production of canned products of other species depends on availability and prices, among other factors.

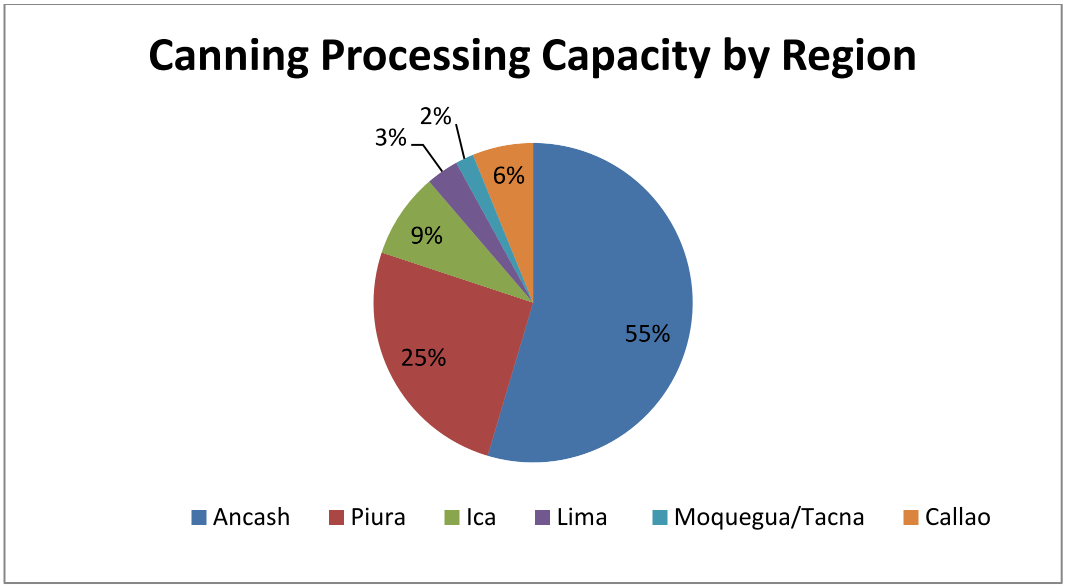

Figure 10: Most of Peru's canning capacity is located in Piura and (PRODUCE)

Cured and Frozen Fish Plants

The cured processing sector is fairly small in comparison with other anchoveta industries with a total production potential of only 21,000 tons a year. Cured plants are concentrated in Pisco and Chincha, in the region of Ica, where the curing industry is especially important in terms of jobs. The frozen and fresh fish industries for anchoveta are not included in our analysis as their plant capacities and processing volumes are relatively small.

Landings and Production

The reported landings destined for production of DHC products from 2003 to 2011 are shown in Figure 11. Landings for cured and frozen production of anchoveta have been relatively constant, while landings for fresh products have declined to negligible levels and landings for canned have increased by approximately 70,000 tons since 2005. Figure 11 shows the percentage of total anchoveta landings destined for DHC products, by port, in 2011. The Chimbote and Coishco ports are located in the region of Ancash, the Pisco port is located in the region of Ica, and Paita is located in the region of Piura.

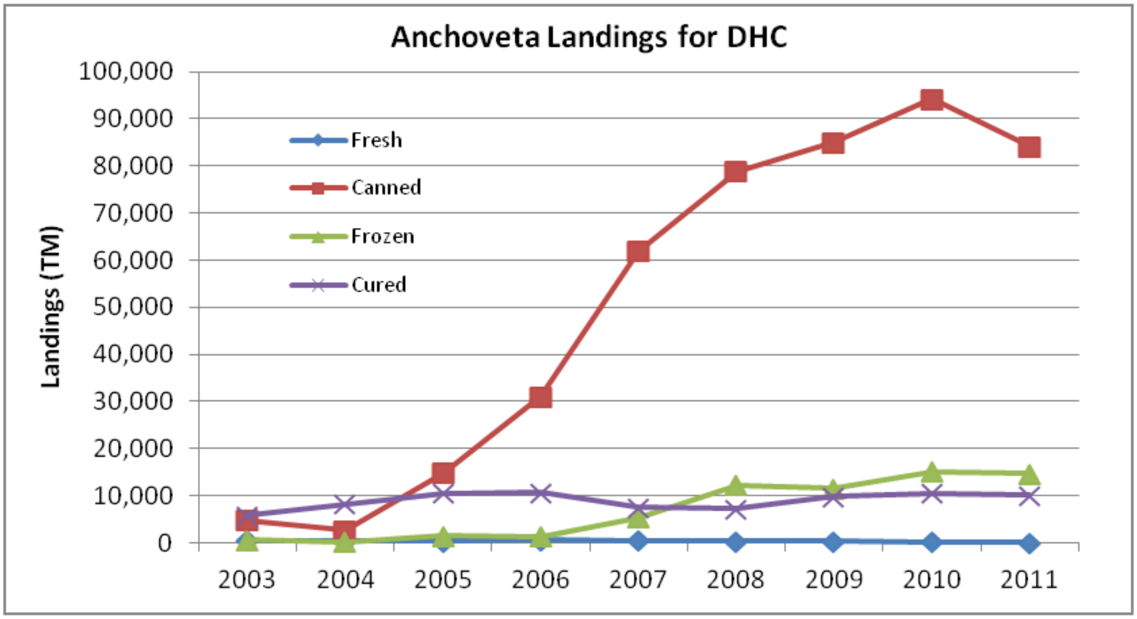

Figure 11: Total landings destined for production of DHC products from 2003 to 2011 (PRODUCE)

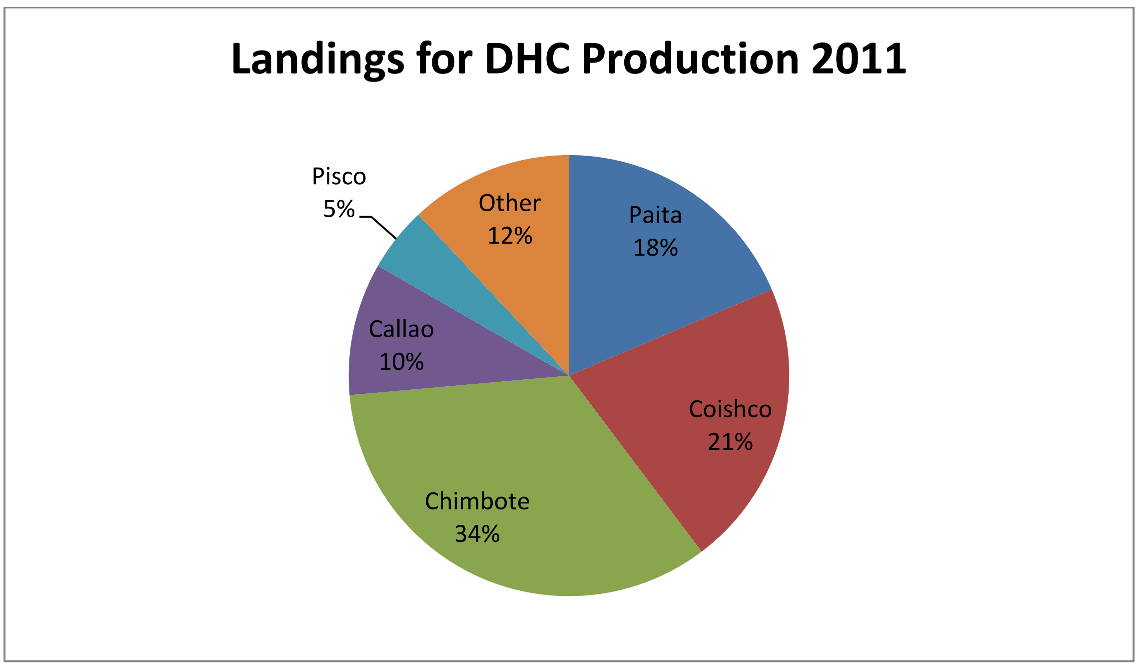

Figure 12: The percentage of total anchoveta landings destined for DHC products by port in 2011. Ancash (Chimbote and Coishco) and Piura (Paita) are the ports with the highest landings (PRODUCE 2011)

Materials

The following materials were used to conduct both qualitative and quantitative analyses of the anchoveta fishery.

Interviews

Interviews were conducted by the Anchoveta Group Project team from June-July 2012 in Peru to obtain information regarding the biological, economic, and social dynamics of the anchoveta fishery. Representatives from the processing, governmental, academic, and NGO sectors participated in these interviews. In many cases, the quantitative and qualitative data gathered during these interviews would have otherwise been unavailable. The site visits and time spent with the fishery's various stakeholders helped frame this study within the larger context of Peru and its social and political realities. Information collected through the interviews was analyzed to determine the nature of the incentives, barriers, and infrastructural components that have an effect on the flow of anchoveta within the fishery.

Government officials from IMARPE, and the Ministry of Production (PRODUCE), and the Peruvian Congress were interviewed to gain insight into the scientific and political processes of Peruvian fisheries management. Employees of CERPER, one of Peru's premier certification entities, and managers of various fish processing facilities were interviewed, and were instrumental understanding the dynamics of food and fishmeal production. Lastly, Peruvian leaders from the academic and non-governmental community helped consolidate social and ecological considerations into the project's analysis. A complete list of the interviewees and their respective organizations can be found in the appendix (Appendix A).

Agency Data

Fleet Capacities

Data from the PRODUCE website was used to measure industrial and DHC fleet capacities by metric ton and cubic meter, number of vessels per fleet, number of active and licensed vessels, number of fishing permits for anchoveta by port, total hull capacity by port, and percent of quota owned by respective industrial firm.

Landings and Production

Landing and production statistics were obtained from the Peruvian Ministry of Production (PRODUCE) on their official website. PRODUCE datasets provided information on fisheries landings by species, by final utilization (as destined for either fishmeal or for human consumption products), and by region of final processing. The majority of these datasets provide annual statistics, with some more recent datasets providing monthly statistics as well. PRODUCE also provides data regarding the production of raw material, including the tons of fishmeal and canned products produced by species and port, which again are provided on a monthly and annual basis.

Systems Thinking Qualitative Analysis: Status Quo Fishery Dynamics

Introduction to Systems Thinking and Causal Loop Diagrams

Fisheries are widely recognized as complex systems with many interactions among different subsystems that integrate fisheries, markets, governments, industries, fishermen, and coastal communities (Garcia & Charles 2007). The inclusion of human dimensions (socioeconomics) increases the complexity of the fisheries system, particularly when linked with the natural processes that support them such as natural productivity, ecosystem composition and biodiversity, environmental events, and more recently, climate change. Explaining these interactions becomes complicated mainly because the human language works in a linear (cause and effect) way, while most of the fisheries subsystems interact, influence, and affect one another with different patterns of behavior. These types of processes make fisheries hard to control, predict, optimize, and understand (Garcia & Charles 2007) and this translate into risks to sustainability or collapse of the stocks and industries.

"System thinking" or "system dynamic" models have been proposed as a method to understand and solve complex problems (Garrity 2011). System thinking methods are tools that assess the organization of a system and how each part interacts with others in order to better understand the most effective way to address complex problems. This tool helps one to consider problems as complex systems comprised of different interacting parts, as opposed to isolated events. An overarching weakness of typical "event-driven" problem analyses is the amount of time and resources dedicated to determining the initial causes of a problem, without progressing to the root cause and eventual solution. System thinking processes analyze the whole structure of a system, determine the patterns of behavior, and identify intervention points for systemic changes to solve the problem (Kirkwood 1998). System thinking approaches use cyclical representations of the interactions, which are described by causal loop diagrams.

Casual loop diagrams (CLDs) are graphical notations that allow us to represent a system structure. Because non-linear relationships are hard to explain verbally, CLDs are helpful tools to explain circular chains of cause-and-effect processes (Kirkwood 1998). Circular chains refer to interactions where a variable indirectly influences itself over time. When these indirect influences occur we say that a feedback or causal loop is closed. Richardson and Pugh (1981) define a feedback loop as "a closed sequence of causes and effects, that is, a closed path of action and information." Feedback is emphasized because it is usually a critical component of management systems as a source to understand the patterns of behavior (Kirkwood 1998).

The first step in representing a system with a CLD is to recognize the different variables that form part of the systems: the stocks and flows. After recognizing the parts of the system, we have to understand how these variables behave over time: the patterns of behavior. Arrows linking the variables show the direction of causal influences. The arrows can be positive (+) or negative (-), which represent how the independent variable affects the dependent variable. A positive notation represents a direct relationship between variables (an increase in one variable leads to an increase in the other, and a decrease in one variable leads to a decrease in the other), while a negative notation represents an inverse relationship (an increase in one variable leads to a decrease in the other; Garrity 2011). Finally, the sign of the loops show if feedback creates a balance to the systems (noted as negative loops) or if it reinforces a certain pattern (positive loops).

Causal Loop Diagram of the Anchoveta Fishery

A system thinking approach was used to address the complexity of the anchoveta fishery and understand the interactions among the different stakeholders and the environment. A CLD representing the biological, economic, and social aspects of the anchoveta fishery was developed by examining the different forces that interact in the fishery. These three sections were developed together, and each interaction was determined as positive or negative. The diagram was then converted to a format that represented the fishery via stocks and flows. From a fishery perspective, the goal is to show the relationship between the stock of anchoveta and both DHC and industrial fleets. After understanding its flow dynamics we integrated the processing industry for direct human consumption and residual fishmeal, as well as industrial fishmeal plants. Next, the market forces that drive demand and supply of raw materials and final products were included, as well as the effect of the production sector and the fishery on the total welfare of the coastal community (represented as income and job stability). Finally, policy section was incorporated to show the interactions and influences from the different stakeholders in the decision-making process. An important goal of this system thinking process was to identify the causes of the perverse incentives present in the fishery, and identify intervention points for applied solutions to eliminate those incentives and avoid threats to sustainability.

Figures 13, 14, and 15 are systems thinking and causal loop diagrams of the Peruvian anchoveta fishery. More diagrams can be found in Appendix B.

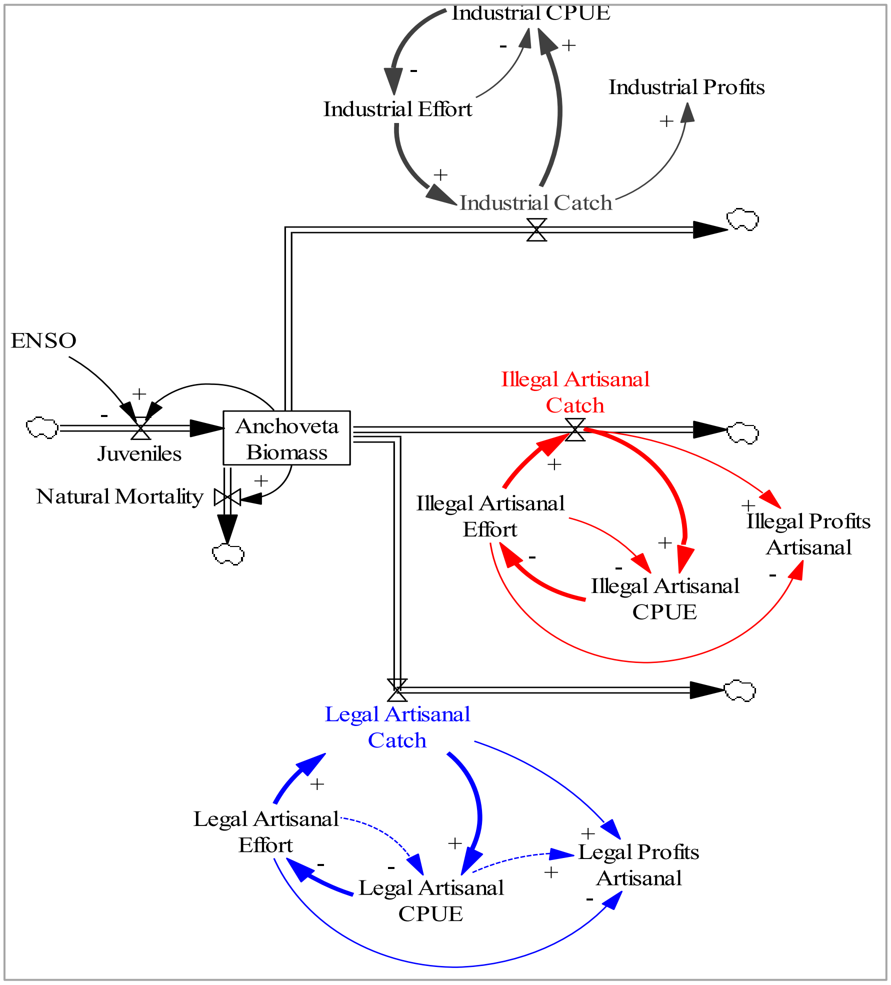

Figure 13: This system thinking model of the anchoveta fishery shows three fishing pressures that have an effect on the fish stock. These pressures are the Legal Artisanal (meaning DHC fleet) Catch, Illegal Artisanal (DHC fleet) catch, and Industrial Catch. Each catch represents a “stock” or store of the anchoveta resource. The arrows and +/- signs indicate how different aspects affect the stock. A positive sign represents a positive relationship – for example, as legal artisanal effort increases, the legal artisanal catch increases. Similarly, as legal artisanal effort decreases, legal artisanal catch decreases. Outlined arrows represent the “flow” of the anchoveta resource. Each of the three fleet’s harvest is influenced by effort, catch per unit effort (CPUE), and profits.

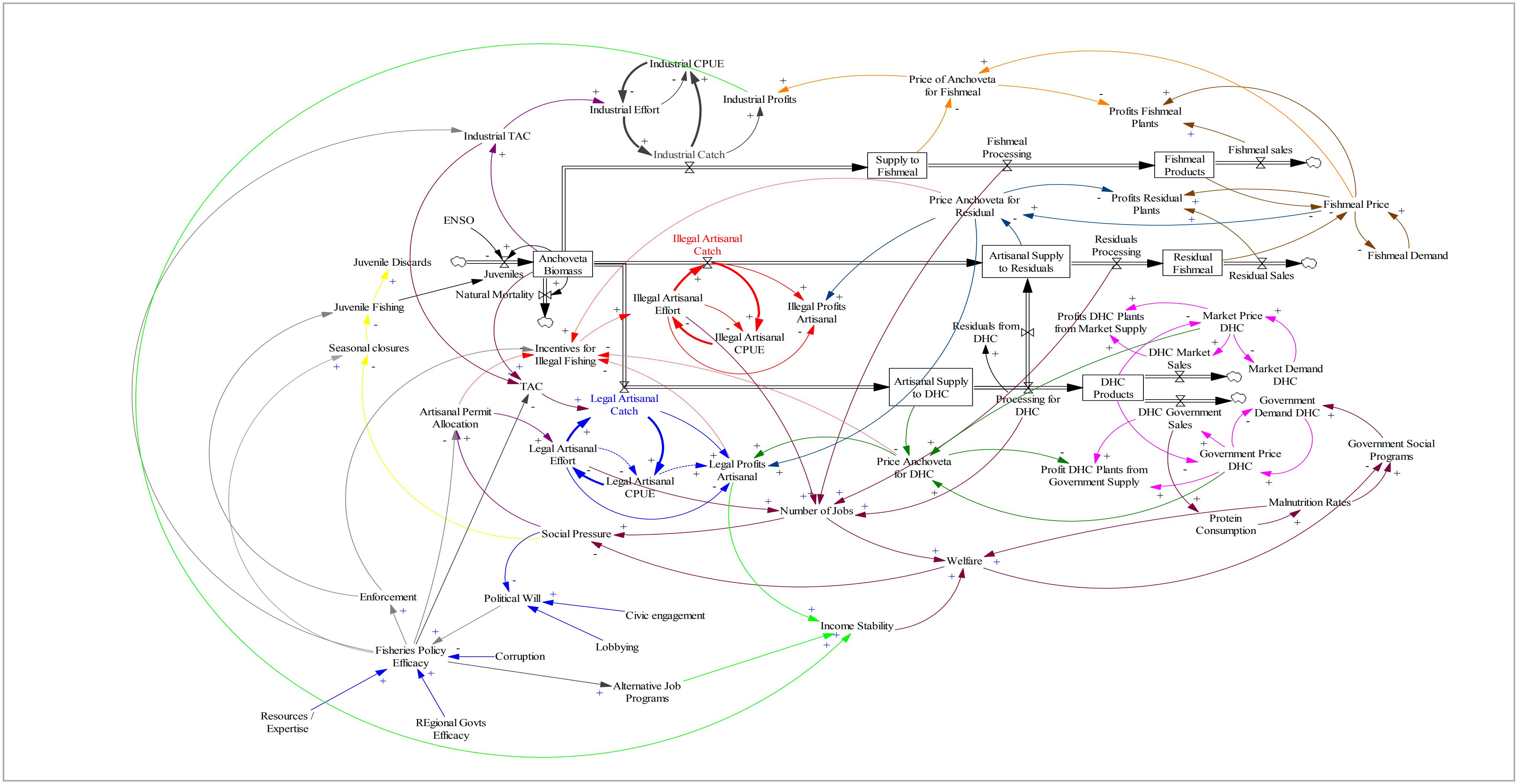

Figure 14: This causal loop diagram includes natural mortality and variability in the fishery, legal and illegal fishing pressures from the DHC fleet, industrial fishing pressure, market forces driven by the fishmeal and DHC processing sectors, market forces driven by the domestic and international fishmeal and DHC markets, governance, fishing policy, and the Peruvian government's demand for anchoveta products. Using this diagram, one can determine how different aspects affect the anchoveta biomass, income stability, and welfare.

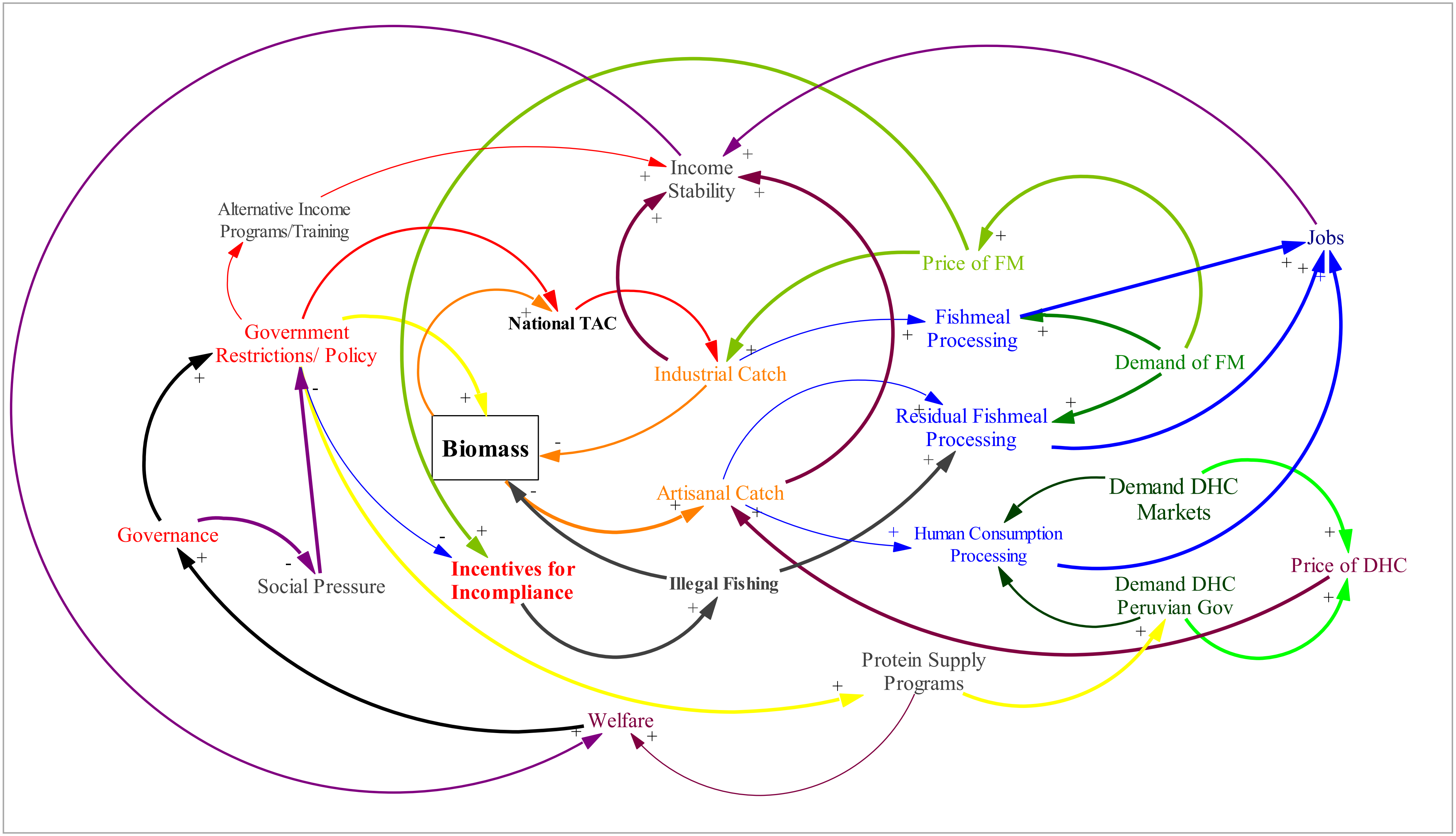

Figure 15: This causal loop diagram is a simplified version of Figure 13.

Qualitative Analysis: Current Problems Associated with DHC Fishery

Lack of Management

Limited Harvest Restrictions

A major concern for the anchoveta fishery arises from the lack of regulation for the artisanal and low-scale fleets. This sector is not managed by a TAC or restricted by seasonal closures, allowing for unlimited harvesting year-round. While it is incredibly difficult to know the amount of fish harvested by these fleets (landings are not required to be reported), some estimate that they already extract up to 700,000 MT each year (Echevarria, personal communication, June 2012). As more vessels gain entrance to this fishery, the amount of fish that the DHC fleet harvests is likely to increase (see *DHC Fleet Overcapacity*). In addition, they are permitted to fish in the first ten nm off the Peruvian coast, which includes critical spawning habitat for the anchoveta. Many fear that unrestricted fishing activity in these regions could have important implications on anchoveta spawning and recruitment, and could therefore have deleterious effects on the stock that go beyond how many fish they catch (Cervantes, personal communication, July 2012). These factors, combined with industrial fishing, place immense pressure on the fishery and threaten the long-term sustainability of the biomass. The historical freedom allocated to this sector has made it challenging for the Peruvian government to impose new regulations, as this typically generates an unfavorable response from the artisanal fishing community.

DHC Fleet Overcapacity

The regional governments, which have been responsible for permit allocation, have over-allocated permits in a way that does not reflect the relative DHC processing capacities of the regions. The number of permits allocated by regional governments is significantly higher than the number of boats needed to fulfill the demand of the processing plants of each region (Figure 16). In Chimbote, the regional government has authorized 150 LS boats to fish for anchoveta (each with capacity of about 30 metric tons [MT]) even though Chimbote's DHC plants (with a total processing capacity of 1,500 MT/day) could be adequately supplied by 70-80 boats fishing for DHC. The official DHC fleet has the potential to land about 2,250 MT per day if fishing properly for DHC, creating a potential 750 MT of excess harvest each day (Infante, personal communication 2012). The actual excess harvest is expected to even greater, as it is believed that there are actually more than the officially registered 150 boats operating in the area, and that the boats fishing are already landing 2,500 MT per day (Infante, personal communication 2012). In some cases, permits were allocated in regions without any DHC plants: fishing permits for human consumption were given in Moquegua (MOQ), a region were no human consumption plants exist. In this case, the national government has had to create a special exception for Moquegua fishermen, who are now permitted to sell their catch directly to industrial fishmeal facilities. Permits continued to be issued despite the fishery legally being closed to new entrants.

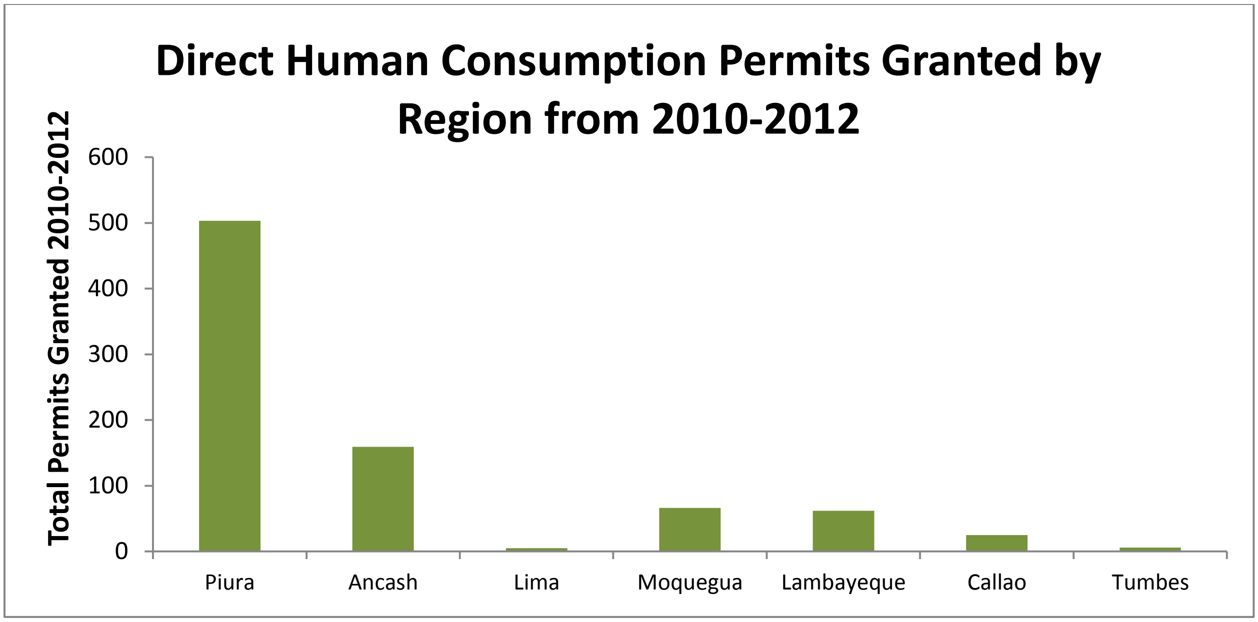

Figure 16: Piura and Ancash issued significantly more permits than other ports, suggesting poor regional planning in regards to matching plant capacity and hull capacity by region

Infrastructural Problems with Landing Facilities

Once the artisanal vessels reach port, the fish catch enters another part of the supply chain that must also be in accordance with safety and quality standards for DHC fish. Therefore, even if artisanal fishermen maintain the quality of the anchoveta up until the moment they land the fish, they will not be able to sell for DHC if the landing facilities are inadequate. Durand and Seminario (2009) identified 36 anchoveta landing ports along the Peruvian coast in 2009 and recognized that many of these facilities had structural deficiencies that impact the quality of landings. Official inspection by the Peruvian sanitation authorities often show that the facilities do not fulfill the requirements set down in the Sanitary Norm for fishery and aquaculture (*Ibid*). According to PRODUCE's most recent census (released in 2012) of the then artisanal (now DHC) sector, of the 116 ports along the coast, only 31 have cold storage rooms, 22 have ice-makers, and 9 have insulated vehicles, all of which are necessary for maintaining the quality of fish that is appropriate for the DHC sector.

Incentives for Illegal Activity within the DHC Fleet

Price Differences between Fishmeal and DHC fish

Profit maximizing DHC fishermen have an incentive to sell their catch to fishmeal plants, because the price for anchoveta paid by fishmeal processors greatly exceeds the price paid for anchoveta for DHC. DHC vessels habitually offload their catch directly to residual fishmeal and waste plants (*Plantas de reaprovechamiento de residuos solidos*), because the fishers can get a higher price from these misused and illegitimate fishmeal plants. Residual plants pay an average of US$200 per ton of fish, while DHC plants pay between US$110 and US$160 (Sanchez, personal communication, July 2012). Also, the cost of fishing for fishmeal is lower than fishing for DHC – fishermen do not need to purchase ice or storage boxes, and are able to fish the vessel's entire hull capacity. When fishing for the DHC sector, fishers effectively forfeit half of their fishing potential, because half of the hull must be filled with ice. As a result, it is estimated that 60-70% of the anchoveta meant for DHC is actually sold for fishmeal production because of the higher marginal benefit, and higher demand, for fishmeal (Galarza, personal communication 2012). In some regions, such as Pisco, it is estimated that at certain time periods 77% of fish landed by the artisanal fleet became fishmeal (Majluf & Sueiro, personal communication 2012). In some cases, fishermen will purposefully allow their catch to become rotten prior to landing, making it unfit for DHC processing. By default, these landings can only be directed to residual plants for fishmeal production. Since the industrial IVQ system was implemented, fishmeal prices have increased due to the reduced supply resulting from quota restrictions (Sueiro, personal communication 2012; Table 2).

Fishmeal Prices		
Before IVQ	**2010**	**July 2012**
$90/ton (Industrial)	$300/ton (Industrial)	$300/ton (Industrial)
(Residual – NA)	(Residual – unknown)	$220/ton (Residual)
$110-160/ton (DHC)	$110-160/ton (DHC)	$110-160/ton (DHC)

Table 2: The table shows the difference in prices paid for the raw material by fishmeal and DHC processing facilities. Prior to 2010, fishmeal and DHC prices were more or less comparable, reducing the incentive for fishermen to sell for fishmeal. After 2010, fishmeal prices rose, surpassing DHC prices by a significant margin. Prices were obtained from CERPER and Juan Carlos Sueiro (2012).

Constant Demand from Fishmeal Plants

A growing number of residual fishmeal processing plants and waste plants have further increased fishmeal processing capacity, which creates demand for anchoveta in addition to what is supplied by the legal industrial quota. Due to various factors, particularly a lack of governmental enforcement, some DHC plants have built rather large and fully operational residual plants (personal observation of the authors, July 2012) that process and sell illegally obtained fish into fishmeal. In some cases the fishmeal from these residual plants is of the highest quality, "Prime" or "Super-Prime." Anecdotal evidence also suggests that some "DHC" plants do not function at all and merely exist for the purpose of building fully functional, and much larger residual plants. In Ancash and Piura, for example, there is a fast growth rate for residual plants with the clear objective of directing more fish to fishmeal and not direct human consumption.

Gross fishmeal processing overcapacity in addition to the limited demand for raw material from the DHC processing plants create the incentive for artisanal and LS fishers to illegally supply anchoveta to the fishmeal processing sector. DHC processing plants can only process a limited amount of raw material, and therefore do not require constant supplies from the entire fleet. Fishers complying with the laws would have to restrict the number of fishing days. However, the overcapacity of fishmeal processing plants ensures a constant demand for illegally supplied raw material.

Lack of and Challenges to Enforcement

Lack of enforcement is widely recognized as one of the leading enablers of illegal artisanal landings for fishmeal (Galarza, Majluf, & Rubio, personal communication 2012). With its limited budget, IMARPE cannot currently place observers on every artisanal vessel, enabling artisanal fishers to land directly at residual plants (Rubio, personal communication 2012). Loopholes in current regulation allow for many of these problems. Due to ambiguous laws, inspectors cannot access residual plants, severely weakening the state's ability to regulate most illegal artisanal landings in Peru (Urban, personal communication 2012). In addition, new DHC plants are often built and stocked with old, non-functioning canning equipment. Because the law requires all canning plants to process their own residual fish, fishmeal production equipment is also installed in the new "DHC" plant. Functionally, the fishmeal equipment represents the only operating equipment in the plant. In this way, individuals seeking to enter the fishmeal industry can do so by misusing direct human consumption regulations (*Ibid*).

On the regional scale, special interest groups can influence local government through bribes, reducing the effectiveness of enforcement efforts. Often times, regional fisheries leaders are wholly untrained in natural resource management and receive advice from advisors who may be under the influence of private interests (Majluf and Sueiro, personal communication 2012). In the worst of cases, regional government officials still own fishing vessels or retain other direct links to private fishing and processing enterprises (Urban, personal communication 2012).

Regional Capacity Discrepancies

The discrepancy between the hull capacities, processing capacities, and landings exposes the potential for regions with excess boats to sell their catch to fishmeal. Figure 13 shows the landings of anchoveta for DHC products and the production of residual fishmeal by port in 2010. Theoretically, residual fishmeal should only be produced from the residual material that comes from the production of canned and cured anchoveta products, and should therefore be correlated with the landings for human consumption products. This figure demonstrates that there seems to be a discrepancy between the amounts of residual fishmeal that is being produced relative to the tons of anchoveta landed for human consumption production. Given that ports should have the same production efficiencies in terms of the amount of residual material produced per ton of fish input, the wide differences in landings-residual ratios between ports suggests that certain ports may be receiving inputs for residual fishmeal production from illegal sources, rather than from residual materials from human consumption plants. No data are available that quantify the total production of anchoveta products for human consumption (only canned production is available), which is why landings for overall DHC are compared to residual production to assess this relationship.

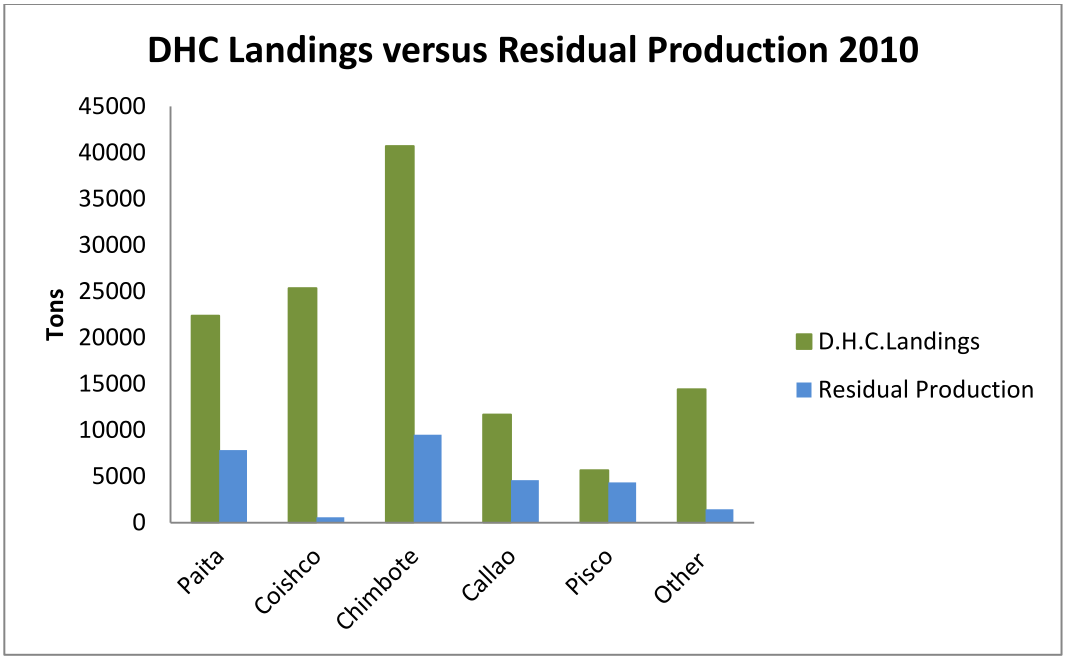

Figure 17: The landings of anchoveta for DHC products compared to the production of residual fishmeal by port in 2010. Wide differences in DHC landings to residual fishmeal ratios suggests that residual fishmeal is not wholly sourced from legal landings (PRODUCE 2010)

Direct Human Consumption Mandate: Goals and Limitations

Lowering Domestic Malnutrition Rates through DHC of Anchoveta Products

One of the goals of the DHC mandate was to increase domestic direct human consumption of anchoveta products in an effort to lower malnutrition rates. Small pelagic fish such as the anchoveta are an excellent source of high-quality animal protein (Durand & Seminario 2009) and other micronutrients that are not usually found in basic foods. The fish contains high amounts of potassium, iron, phosphorous, calcium, fatty acids, and vitamins A and D, all of which are important for the proper development of the brain and body (*Ibid*). Market research in Peru shows that people are increasingly aware of the nutritional value of anchoveta (Durand & Seminario 2009). However, this increased popularity of the fish is centered on larger cities in Peru where access to anchoveta products is easier and more affordable (Majluf, personal communication 2012). Efforts are being made to increase human consumption of anchoveta among communities in Peru, but these efforts are impeded by a number of barriers.

First, there are a number of barriers to increasing domestic direct human consumption that exist within the fishery. Due to the requirements associated with fishing for DHC processing, the artisanal fleet has the incentive to illegally misdirect catches to fishmeal processing facilities. Additional costs related to fishing for DHC include the cost of boxes used for properly storing the fish and ice used for preserving the fish. These requirements are put in place in order to keep the fish in a condition that is fit for human consumption. In addition, because fishermen can only fill 50% of their hull when fishing for DHC processing (the other half must be ice), they experience the opportunity cost of the forfeited storage capacity. The price difference between anchoveta for DHC and fishmeal processing also acts as an incentive to misdirect landings. Not only are the fishmeal processing facilities willing to pay a higher price for the raw material, but plant overcapacity has created a situation in which there is constant demand from this sector of the market. Finally, the lack of enforcement and monitoring creates a situation in which fishermen are able to misdirect landings regularly. Ultimately, DHC plants are not able to receive as much raw material as they should, and therefore are unable to add as many products to the domestic market.

There are also a number of infrastructural barriers that prevent the DHC processing sector from receiving the desired amount of fish. Most ports have structural deficiencies that impact the quality of landings, which makes them unfit for the human consumption processing sector. These degraded fish are not permitted for DHC processing, and are therefore sold to the fishmeal market. According to the most recent census of the artisanal sector, of the 116 ports along the coast, only 31 have cold storage rooms, 22 have ice-makers, and 9 have insulated vehicles, all which are necessary for maintaining a quality of fish that is appropriate for the DHC sector.

In addition, there are a number of distributional barriers to increasing domestic DHC of anchoveta products. First, the lack of cold chain facilities throughout the country makes the distribution of fresh and frozen products to remote regions nearly impossible. Second, there is a lack of secondary and tertiary roads to remote regions that the products are intended for, making delivery of any of these products from the coast quite difficult. In addition, PRONA, the government program that was supposed to distribute anchoveta products (among others) to low income groups has been discontinued and replaced with a new food program, Qali Warma, which will not be supplying much anchoveta to these communities.

Finally, and perhaps most importantly, there are many barriers in terms of the demand of domestic consumers that have thus far hindered increased domestic consumption of anchoveta products. First, many people do not want to consume these products, because they do not like the taste or because of the stigma attached to them. Many view anchoveta as a fish that is used for making fishmeal, and not as a fish that people eat directly. Finally, many anchoveta products, especially the canned products (which are the most widely distributed) are relatively expensive, creating a situation in which their accessibility to low-income groups is restricted.

Increasing Employment Opportunities

Perhaps the most important justification for the direct human consumption (DHC) mandate in the artisanal industry is the fact that DHC processing facilities typically employ more people (particularly women) living in Peru's coastal regions. The DHC processing facilities employ a significantly greater number of workers per ton of fish processed than the fishmeal processing plants. Initially, the political support for the DHC mandate might have had more to do with the social goal of employing people in the canning industry than the desire to provide low-income households with nutritious food (Urban, personal communication 2012). Importantly, many facilities that process anchoveta, such as the *Compañía Americana de Conservas* in Pisco, employ women from the

Andes, a region with few opportunities to earn a sustainable income that also suffers from some of the highest malnutrition rates in the country (Echevarria, personal communication 2012). The superintendent of the canning facility *Pesquera Jada S.A.*, Arturo Cardenas Infante, estimates that the canning industry employs 7,000 people in Chimbote alone (personal communication 2012). Overall, the DHC mandate is important for providing jobs along the country's coast.

However, under current conditions, these plants cannot financially sustain operations without the provision permitting them to sell some of their fish into the more lucrative fishmeal processing market. Using current technology, the profit margins for DHC products are quite small due to the high cost of cans, which can account for 50% of production costs (Infante, personal communication 2012). In order to make the processing sector profitable, legislation was created that allows the DHC processing sector to supply up to 40% of the raw material to fishmeal production (Urban, personal communication 2012). However, some have argued that this ratio was arbitrary and that a more efficient ratio should be estimated (*Ibid)*.

While it is unclear if increasing the amount of DHC products available domestically will translate into lower malnutrition rates and greater accessibility to nutritious foods throughout the country, the jobs provided by the DHC processing plants provide people with higher wages, enabling them to access nutritious foods that previously might have been considered expensive. In this way, the DHC processing sector can indirectly work towards the social goal of lowering malnutrition rates while directly addressing the goal of providing more jobs.

Biological, Economic, and Social Implications

Problems associated with the current management of the DHC sector of the anchoveta fishery pose a significant potential risk to the long-term sustainability of the resource, which has important environmental, economic, and social implications. The artisanal and low scale fleets harvest is unrestricted and unmonitored, creating a situation in which authorities are not able to accurately assess its level of exploitation. In addition, they are given exclusive and year-round access to critical anchoveta spawning grounds, which could be responsible for overall decreases in fishery production. Because anchoveta are the base of the Humboldt Current food chain, a decreased anchoveta population can have deleterious effects on the surrounding environment and other important coastal fisheries as a whole. Importantly, the economic value of the fishery is directly linked to the biomass – a less productive fishery is also less valuable in economic terms. In addition, threats to the long-term sustainability of fishery can negatively impact the many people who depend on the fishery and its associated industries for their livelihoods.

Potential Management and Regulatory Approaches

Given the specific context of the Peruvian anchoveta fishery, there are a number of management schemes for the DHC fleet that have the potential protect the long-term sustainability of the fishery.

Such measures would control effort levels, thus improving harvest and preventing the rent dissipation that occurs under open access conditions. In addition, new market-based regulatory approaches could be used to accomplish social goals using the value of the fishery. Two fishery management options explored in this analysis are a total allowable catch (TAC) and individual quota (IQ) system. Taxation is explored as a market-based approach to using the fishery to address social issues.

Total Allowable Catch (TAC)

A total allowable catch (TAC) sets a quota for how many tons or number of a given species of fish can be caught in a certain area, usually over a discrete period of time (European Commission 2009). A TAC differs from an open access fishery in that a limitation is set on the amount of fish that can be extracted over a given period. For this reason, TACs are often referred to as "regulated open access" (Pascoe 2003). Depending on the governmental structure of the regulating state, a TAC set at an initial biological limit will be increased to address economic concerns (Pena Torres 1997).

A TAC can have positive effects on the biological health of the stock if limits are set to ensure biological recruitment for future fishing seasons by restricting the effort (or harvest) to the maximum sustainable yield (MSY) levels (Aguilar *et al.* 2000). TACs are often set as a response to or to avoid overfishing in an open access regime, and therefore take the biological health of the species or fishery in account.

TACs in Peru

In Peru, TACs based on IMARPE's scientific advice have been implemented with some success since 1984 for the industrial anchoveta fishery, with overall positive results in the management of the stocks despite some severe biological shocks cause by El Niño events (Schreiber 2012).

IMARPE calibrates an industrial TAC twice a year based mainly on the stock´s health as well as economic considerations. Generally, IMARPE's guideline for stock conservation rests on the principle of leaving a certain amount of the spawning anchoveta biomass in the ocean at the onset of each spawning period (also called target escapement) in order to ensure stock recruitment for future fishing seasons and for the conservation value to other pelagic species, birds, and other wildlife (Freon *et al.* 2008). This biomass could range from 4 to 6 million tons; the rest is allocated as a TAC (Mariano Gutierrez, personal communication 2012). Currently, the industrial sector fishes all of this pre-set TAC without detraction from any other sector. The artisanal and low-scale fleets extract anchoveta throughout the year, and this harvest is not subject to or included in the industrial TAC (IMARPE - Chimbote Field Office, personal communication 2012).

The artisanal and low-scale fleets have effectively been extracting fish from the target escapement, since their effort does not diminish the commercial industrial TAC. It could be argued that this "invisible" take has little effect on the stock, making it possible to consider sourcing the artisanal and low-scale TAC as a portion of the 5 million tons of anchoveta normally set aside for biological stock recruitment and conservation. However, since the artisanal fleet's potential capacity has increased over the past decade, its real and potential impact on the anchoveta stock must be further understood.

Methods for Determining a TAC

Hull Capacity: In some fisheries, the TAC has been allocated by taking into consideration the hull capacity of the fleet. In the case of the Peruvian Anchoveta fishery, three separate fleets utilize the resource simultaneously—the industrial, low-scale, and artisanal fleets.

Processing Capacity: A TAC could also be allocated based on DHC processing capacity in order to align harvest allowances with the volume of raw material that would fulfill supply needs of DHC plants. In this way, harvest is capped at the amount of raw material required by DHC plants, and illegal misdirection of excess catch may be quelled. However, there is currently a large discrepancy between boat capacity and DHC processing capacity on a per region basis, with boat capacities permitted to fish anchoveta far exceeding DHC processing capacities. While a TAC based on current processing capacity might aid in reducing excess fleet capacity and misdirection of catch to fishmeal, it might also preclude DHC plant expansion in a given region and concentrate anchoveta harvest in regions that currently have greater DHC processing capacity.

Historical Landings: Historical landings can be used to determine the TAC proportion allocated to the fleet. However, this is difficult to achieve if landings have not been adequately recorded (as in the case of the artisanal and LS fleets).

National TAC: Under a National TAC, the ministry of fisheries would be responsible for enforcing a nation-wide TAC for the DHC fleet. All ports would be allowed to accept boats from any region. The regional governments would relinquish their enforcement power to IMARPE and the national ministry. In this case, boats would likely fish in areas with the highest yields and land where they would get the best price for their catch. Regions with dense schools of anchoveta, like Chimbote, would likely attract many fishermen. These regional ports, as a result, could exceed their capacity, forcing fishermen to sell to residual plants. Ports with a large plant capacity but a less optimal fishery may experience lower production, and thus economic hardship, as boats move away from their waters in favor of more plentiful areas.

Regional TAC: Under a Regional TAC, regions would each be given a separate TAC for their respective region. The regional government would be responsible for making sure that TAC is not exceeded. Boats from outside districts would not be allowed to enter the port and unload their catch. Ports may respond to this management scheme in different ways depending on the balance of fleet and plant capacity present.

In areas with high fishmeal and DHC plant capacity and moderate fleet capacity, such as Ancash, the race to fish would most likely cause a spike in production of DHC products as well as fishmeal. During a race to fish in regions with insufficient processing capacity, the quality of DHC products could be compromised due to the decrease in production efficiencies. In addition, raw material waiting to be moved to processing facilities would likely degrade due to the long wait.

If every region were to have an equal portion of the artisanal TAC, both fleet and plant capacity would not be used to their most efficient levels. Also, the fishing season would vary widely in length of time depending on collective hull capacity for the port. For example, a port like Piura, with a large number of boats in comparison to plants, the fishing season would be very short, while the processing plants would be ill-equipped to deal with a high influx of fish. Ancash, on the other hand, with a better balance of boats to capacity, may operate more efficiently compared to other ports under an equally divided TAC system. Ports like Moquila, with no human consumption plants, would face the same problems as in the conventional regional TAC.

Pros and Cons

Setting any TAC, whether regional or national, can result in a "race for fish" where the boats are in a race to catch the most fish before the total allowable catch is met and the fishery closed for the season. Depending on the processing capacity on land, this race for fish can result in a combination of:

- A surplus of value-added products such as cans flooding the market at one time
- Lower quality products
- A higher ratio of tonnage devoted to fishmeal
- Increased challenges to effective enforcement do to spike in activity
- A disconnect between landings and DHC plant capacity, resulting in greater diversion to fishmeal production

A regional TAC places enforcement responsibility on local governing bodies that do not have prior experience or capacity for enforcing fish landings and processing. Since local governments are more easily influenced by local fishing unions than the national government, a regional TAC could result in increased corruption.

A national TAC places added pressure on the cash-poor Peruvian federal government. However, if adequate funding were secured, the national government may be able to enforce the fishery more effectively than regional governments with no prior experience.

Individual Quota (IQ)

While setting a TAC for the artisanal harvest of anchoveta could serve as the foundation for ensuring that a sustainable number of fish are being extracted, a TAC alone would likely result in a race to fish as fishers compete to catch as much as they can before the quota is met. An individual quota (IQ) system can serve to complement a TAC and quell the race to fish by assigning exclusive individual rights to harvest a specific share of the set TAC (Dewees 1998, Griffith 2008, Gómez-Lobo *et al.* 2011). Individual quota participants seek to maximize return from their quota holdings, and this can take the form of value-added products, innovative market timing, and in some cases high-grading, where fishers selectively harvest the highest quality fish. While this increases the price received for the raw material, it also increases discarding at sea, and reported landings may not reflect actual harvest levels.

The objective of an IQ system is to eliminate the race to fish under a TAC by creating a market for catch shares where all participants, quota sellers and buyers, can become profitable. Individuals, in the context of IQs, can refer to an individual licensed fisher, a licensed vessel, or a group, and once allocated, these quotas can be transferable (ITQ), or nontransferable (INTQ). Quota transferability enables the greatest opportunity for efficiency gains within a fishery, but is not always politically feasible. An ITQ system could serve as the foundation for promoting economic efficiency within the artisanal sector of the anchoveta fishery, and in achieving social and biological goals (Sumaila *et al.* 2010).

IQs in Peru

In Peru, the individual vessel quota (a form of IQ) system was implemented in June 2008 and used a separate allocation system for the steel and wooden fleets (Tveteras *et al.* 2011). The steel fleet was allocated quota shares based on historical catches (best year of catches since 2004) and hull capacity. The wooden fleet was allocated quota based entirely on historical landings. The IVQs are not directly transferable, because a company can own several fishing vessels and can pool individual quotas among a smaller number of vessels. There is also an option to rent IVQs between vessels with different owners for a maximum of three years. The options allow for some degree of transferability. Within two or three years after the implementation of the IVQ system, there was evidence that it had put an end to the race to fish and the fishery's profitability was increased (based on indicators such as a reduction in the number of operating vessels per day, and lengthening of the annual fishing season; *Ibid*).

Methods for Designing an IQ System for Artisanal and Low-Scale Fleets

When considering implementation of an ITQ system for the DHC sector for the fishery, there are several ways in which the quota can be allocated and shares distributed.

Hull Capacity: This model would follow the method used to determine the IQ system for the industrial steel fleet, where 100% of the quota share is allocated based on hull capacity per vessel in the artisanal fleet. The artisanal and LS shares of the national TAC could be allocated either to each vessel based on the total hull capacity or each region based each region's total hull capacity.

Processing Capacity: In Peru, fleet and processing capacities grew together but have recently become disparate with some regions seeing more fleet capacity than what the processing plants can handle. If the quota share were allocated to the artisanal fleet based on processing capacity, then it would be based on available processing capacity for frozen, canned, and cured fish. The artisanal IQ could either remain static, or it could grow in unison with the growing DHC processing capacity.

National IQ: Once an appropriate TAC has been assigned to the artisanal sector of the fishery, it could then be initially allocated as quotas to eligible artisanal and LS fishing vessels based on a vessel's share of the artisanal TAC. A vessel's quota share could be based on its hull capacity relative to the total hull capacity of the entire artisanal fleet. This is expressed by the following equation:

$$IQ_i = \text{Artisanal TAC} * \frac{HC_i}{HC_{entire\ fleet}}$$

While the proportion of the quota share, $\frac{HC_i}{HC_{entire\ fleet}}$, allocated to a vessel (i) will be constant, because the artisanal TAC will change every season with the biomass, the actual quota (ITQ_i) that a vessel can fish in a given season will be variable. All artisanal vessels owned by fishermen permitted to fish anchoveta would be eligible to receive a share of the artisanal TAC for anchoveta. Allocation of the quota could be via granting every eligible vessel their share of the quota, based on their relative hull capacity to the fleet (described above). While the quota is initially allocated on a per-vessel basis, it is operationally under the hands of the owners of each vessel. Auctioning quota is an alternative option in the initial allocation of quota, but is rarely done in fisheries. There would likely be limited transferability of quotas between artisanal vessel owners opposing social pressure.

Pros and Cons

From a broader, whole fishery perspective, both theoretical and empirical evidence strongly support the idea that ITQs improve aggregate economic value of fisheries (Costello *et al.* 2010; Grafton *et al.* 2000). Implementing an ITQ system for the artisanal fleet could improve economic efficiency in the sector by incentivizing improved harvest efficiency and added value to the harvested product (Costello *et al.* 2010; Gómez-Lobo *et al.* 2011). Because there is no longer a need to race to harvest the greatest quantity of the resource, individual quota owners are instead motivated to obtain the most value out of their allotted share of the quota. This gain can be made by decreasing the costs associated with harvest by improving the efficiency of operations and/or by increasing the value of the raw material harvested. With no need to race, quota owners can also extend the days over which they harvest and improve the quality of their catch (Costello *et al.* 2010). Fishers may also have more time and resources to invest in adding value to their allocated quota through innovative marketing, quality improvements, and market timing. After the introduction of the IVQs for the industrial fleet of the anchoveta fishery, the average landing prices of anchoveta increased 37% from 2008 to 2009, which also reflects how the reform shifted negotiating power from the processors to vessel owners (Tveteras *et al.* 2011).

ITQs promote efficiency in the fleet as a whole by reducing overcapacity, as those quota-holding entities who can profit the most from harvesting their allocated quota (given their individual operational costs and the price at which they can sell their harvest) will accumulate quota in the long run. As consolidating quota into the most efficient boats will improve profits, fishermen with multiple vessels will be motivated to retire vessels, operating fewer more efficient boats overall. Although quotas with limited transferability might be more politically feasible, complete quota transferability would be necessary to allow for these efficiency gains.

Individual quota systems can achieve biological, ecological, and social goals as well. Eliminating the race to fish benefits the stock itself as fishing pressure is no longer concentrated into a short time period (Griffith 2008). This may allow for greater stock recovery over the long term. In terms of social goals, a quota system extends the season, increasing the number of working days that a fisher would be employed. Catches are also more predictable and steady under an ITQ system, which is beneficial to both the harvesting and processing sector in terms of employment security.

In considering an ITQ system for the artisanal sector, it is important to consider several drawbacks of this option. Firstly, an effective enforcement and monitoring program is required for the successful implementation of such a system. There would also likely need to be a large investment, in both funds and time, in coordinating regional and national government bodies in allocating quota, tracking landings, and maintaining and updating a fisher database to ensure that quota restrictions are being met. Successful implementation of an ITQ system also requires a high level of cooperation from fishers and other stakeholders in the industry, and may be politically infeasible because it has historically lacked the necessary support of these stakeholders. Another consideration to note would be that an ITQ system, while setting a cap on landings and fostering greater care for the resource, would not necessarily eliminate the misdirection of landings to fishmeal without enforcement beyond ports.

However, a well-designed ITQ system has the potential to address a number of these drawbacks. First, in some situations the increased profitability of the fishery resulting from the implementation of an ITQ system can more than compensate for the increased costs associated with coordinating governments, program design and implementation, monitoring, and enforcement. In addition, the potential for increased profitability of the fishery can provide a financial incentive for fishers and other stakeholders to participate in such a program. For this reason, effective communication of the potential economic and biological improvements from an ITQ system to relevant stakeholders is an important step towards gaining their support.

Fishery Tax

The DHC mandate was implemented with the goals of increasing domestic human consumption of anchoveta products, therefore lowering malnutrition rates throughout the country and increasing jobs. While DHC processing facilities certainly employ many people, it remains to be seen if the mandate can have an effect on malnutrition levels. In addition, the economic incentives to sell illegally to fishmeal processing plants and the lack of enforcement within the fishery create a situation in which much of the raw material is illegally diverted to fishmeal processing plants. Without an adequate anchoveta supply, the processing plants are not able to process as much as they would like, and are therefore unable to employ as many people in the industry. These problems create a situation in which the mandate is not able to efficiently or effectively accomplish its desired goals at the expense of the artisanal fishermen.

A taxation system is a market-based tool that can be used within the market to work towards the same social goals intended to be addressed by the DHC mandate. Instead of requiring artisanal fishermen to sell their catch to the DHC industry, the fleet could be given the opportunity to participate in either market. A tax on all anchoveta landings could be levied on the entire fishery, both generating tax revenue for social programs and potentially changing the behavior of some fishermen. Theoretically, depending on how the tax was determined, some artisanal fishermen would choose to sell their catch to the untaxed DHC processing market. The tax revenue could also be used to fund a government subsidy used to promote DHC processing by either paying fishermen to redirect sales to the processing sector or by investing in the processing sector to reduce production costs.

Raising Revenue

Tax revenues can be used to accomplish a variety of government social goals. Generated at a very low cost, tax revenues typically have nearly 100% profitability. In this case, these funds could be directed in two ways: one could be to finance a social program, for instance a food program that would provide subsidized food for lower income families, and a second option could be to finance an artisanal enforcement program in order to increase compliance and fishery monitoring. In this case, a tax would be set to generate enough money to fund enforcement programs for the artisanal and LS fleets. However, implementing a tax successfully can be difficult. A large amount of information is needed to determine an optimal tax policy and includes all catch and quota prices, operation costs, expected profits over time, etc. In the case of a tax raising revenue to finance food programs, the tax could theoretically replace the DHC law, allowing the market to determine where the raw material is sold. This does not address the issue of enforcement, which is important for ensuring the successful implementation of any management scheme. Regardless of the management system implemented, overcapacity in the fishmeal processing sector will remain a problem and this could allow illegal fishing to persist. However, the difference in this case is that the actual harvests are illegal (harvesting over the allowable quota), and not the direction of fish supply. While the anchoveta might not be used to directly to feed malnourished citizens, the fishery could generate funding that could be used to provide them with some poverty alleviation.

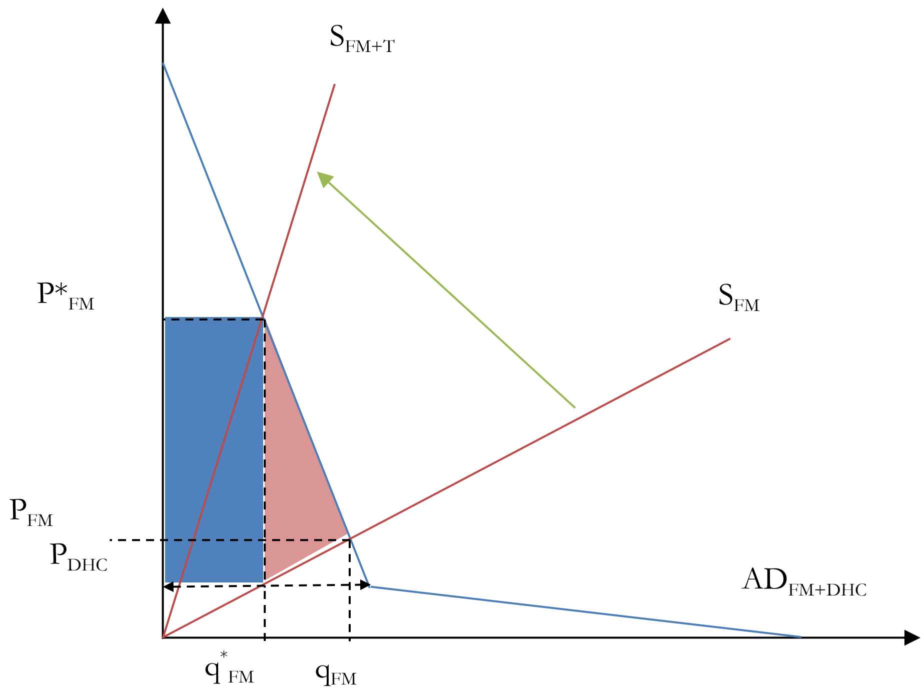

Figure 18: This graph represents an imposition of a landing tax on the DHC fleet fishermen. The red line labeled SFM represents the initial DHC fleet's supply of raw material, which in this diagram is shown as being sold to the fishmeal processing sector. The blue line represents the aggregate demand of the fishmeal and DHC markets (AD_{FM+DHC}). This demand curve joins both partially inelastic FM demand (the steeper part to the left of the kink) and partially elastic DHC demand (the blue line to the right of the kink). The implementation of a landing tax increases the costs experienced by fishers and creates a disincentive for landing. P^*_{FM} is the price paid by fishmeal plants for the resource after the implementation of a tax, and the economic loss to the fishery, or deadweight loss, is represented by the red triangle. The tax revenue raised by the government is the blue square.

Raising Revenue and Utilizing a Subsidy

If the social goal is to provide jobs along the coast of Peru, the government might want to promote policies that provide the DHC processing sector with a minimum amount of anchoveta in order to ensure a certain amount of employment in this sector. In this scenario, a tax would work in at least two ways to promote the DHC sector. First, the tax would raise revenue from each landing sold to the fishmeal industry. This tax would shift the supply curves in the fishmeal market down. For some artisanal fishermen, a tax could create a situation in which it is actually more profitable to sell their catches to the DHC processing facility, increasing the amount of fish being directed to this industry. Second, the revenue raised could be reinvested into the DHC processing sector to further promote its growth. The government could use this money to compensate fishermen who sell into the DHC sector at the lower market prices, effectively raising the amount of money that they receive to what they would have received selling the resource to the fishmeal market.

Alternatively, the revenue could be reinvested into the actual processing facilities to lower production costs, effectively raising the price that these plants are able to pay for the raw material. These might include investments in the cans used in the process (which can account for up to 50% of processing costs), or investments in new technologies such as vacuum sealers that significantly reduce processing costs by eliminating the need of cans, but have high upfront costs. Importantly, while these measures might result in more anchoveta being directed to the DHC processing sector and therefore more coastal jobs, it would be difficult to determine the level of tax and the proper investment that would lead to the desired amount of employment.

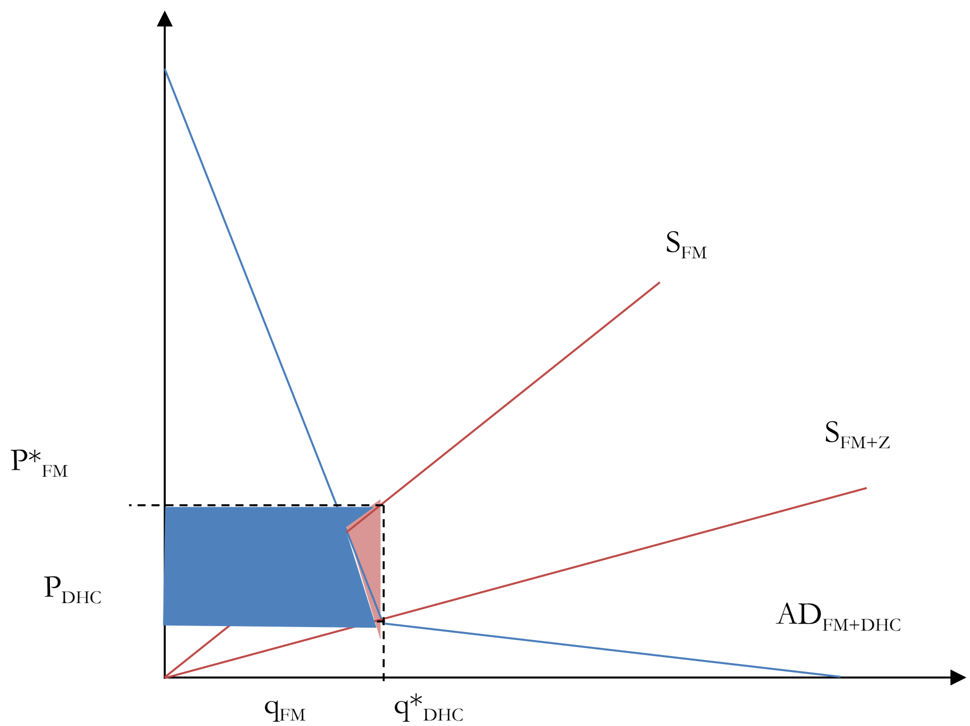

Figure 19: This graph represents an imposition of a subsidy over catch to the DHC fleet fishermen. Initially fishers supply fish for FM (S_{FM}). Again, the aggregate demand for anchoveta from the DHC and fishmeal processing sectors is represented by the demand curve AD_{FM+DHC}. After subsidy application, fishermen have a greater incentive to sell for DHC because the government raised the price artificially. The price of DHC (P_{DHC}) is hit due to price change for fishermen. P^*_{FM} is the price paid by fishmeal plants to the fishermen with DWL in this case is the red triangle and the government tax revenue is the blue square.

Bio-economic Model

Based on an analysis of the status quo, the following motivating question was developed: Which, if any, alternative regulatory strategies could be applied to the DHC sector of the fishery in order to eliminate biological threats and maintain or improve the economic value of the fishery?

To answer, a bio-economic model was developed to:

1. Evaluate the effect of the alternative regulatory approaches for the artisanal sector on the biomass,
2. Determine the effect of these approaches on the economic value of fishery
3. Examine the social implications of each approach, and the effectiveness of the current DHC mandate

Bio-Economic Model Description

We created a model in MATLAB that ties together the biological and economic components of the fishery in a dynamic way, tracking a number of biological and economic indicators. In this model, the DHC sector is defined as the artisanal sector (DHC harvest as artisanal harvest, etc.), but includes both LS and artisanal vessels. The model produces outputs for twenty individual fishing seasons, or time-steps, as well as summary outputs for the entire 20-season time-horizon. Each run consists of 1,000 repetitions. The indicators that are reported by season include total biomass, total recruits, industrial effort, artisanal effort, industrial catch per unit effort (CPUE), artisanal CPUE, total yield, industrial profits, and artisanal profits. For each time-step, or season, MATLAB reports the means and standard deviations generated by the 1,000 runs for each output. Because the model consists of 1,000 repetitions, the value that is reported is an average of these iterations. Summary outputs assessed by this model include the mean biomass, recruits, industrial fleet effort (or length of season), artisanal fleet effort (or length of season), total yield, industrial yield, artisanal yield, industrial profits, and artisanal profits, as well as the total net present value (NPV) of total fishery profits, NPV of artisanal profits, NPV of industrial profits, and the proportion of times biomass reaches a defined critical level. MATLAB reports the average and standard deviations of these summary outputs. The model runs with an adequate burn-in period to allow for calibration.

Different regulatory scenarios applied to the model alter inputs and parameters that influence both components of the model, ultimately generating different biological and economic outputs. The model is also run under variable ENSO climate conditions, and two distinct market conditions, which also influence model inputs. Summary outputs are used to compare biological and economic indicators in different regulatory scenarios, which vary in terms of allowable artisanal harvest and if the artisanal fleet is participating in the fishmeal or direct human consumption (DHC) market. A conceptual diagram (Figure 20) shows a simplified overview of the model.

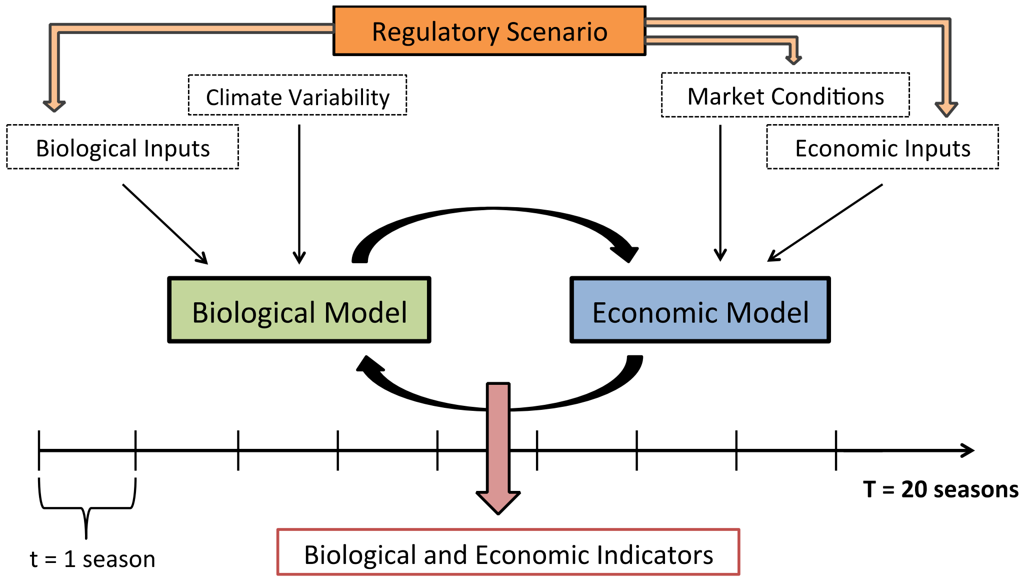

Figure 20: Conceptual Diagram of Bio-Economic Model

Regulatory Scenarios

Using the model, the current regulatory scenario and three alternative regulatory scenarios summarized below were analyzed. Over all scenarios, it was assumed that each fleet is comprised of identical boats. The industrial fleet is comprised of 1014 separate boats, each with the same storage capacity (SC_i), technology parameter (A_i), fixed costs (FC_i), variable costs, and semi-variable costs (cea_i). For the purposes of this model, the artisanal fleet (again, comprised of both artisanal and LS vessels) is assumed to be comprised of 927 boats, each with the same storage capacity (SC_i), technology parameter (A_i), fixed costs (FC_i), variable costs, and semi-variable costs (cea_i).

1. Artisanal Restricted Open Access

The model is designed to initially display the current fishery dynamics in which a total allowable catch (TAC) restricts the industrial fleet's allowable yield and there is no restriction on the artisanal fleet's allowable yield. No new boats are permitted to enter the fishery for either sector. This initial scenario is designated as the artisanal restricted open access regime, based on the assumption that the government is theoretically not granting new permits to the anchoveta fishery. Therefore, it is assumed that the number of boats is fixed to the current number.

In this current scenario, the target escapement, which represents the biomass left in the water in order to ensure the health of the stock, is set at the average value of 5 million metric tons. The TAC allocated to the industrial fleet in a given season is calculated as the difference between total biomass at the beginning of the season and the target escapement. If the biomass is low enough that industrial TAC would be set below a set social quota (SQ) value, the SQ is allocated to the industrial fleet. In this scenario, no TAC is set for the artisanal fleet.

2. Artisanal Variable TAC

As an alternative to the open access regime is the imposition of a TAC for the artisanal fleet. In this scenario, the artisanal fleet and the industrial fleet are allocated a proportion of a set National TAC. The national TAC is calculated in the same way that the industrial TAC was set in the open access scenario, and then it is divided in varying proportions to the industrial and artisanal fleets. In this scenario a social quota is set for both the industrial and artisanal fleet, so that if the biomass is at a low enough level, each fleet is allocated their associated social quota.

3. Artisanal Fixed TAC #1

In another regulatory variation, the artisanal fleet is allocated a fixed TAC that does not vary over time. In this fixed TAC option, the artisanal TAC effectively takes away from the industrial TAC, so that the industrial TAC is calculated as the difference between total biomass in a given season, and the sum of target escapement and the artisanal TAC for that same season.

4. Artisanal Fixed TAC #2

The last regulatory scenario analyzed is a second fixed TAC option in which the artisanal fleet is again assigned a constant TAC that does not vary over time, but in this iteration, the industrial TAC is calculated in the same way as in the artisanal restricted open access scenario, and is unaffected by the artisanal TAC.

ENSO Variability

The model explores the effects of variations in both ENSO intensity and in the frequency of an ENSO event occurring, by incorporating an ENSO function that affects inputs to the biological component of the model.

Market Conditions

The model also explores the different implications associated with the artisanal fleet participating in the direct human consumption (DHC) processing market and the fishmeal market. These differences are explored because under the current management regime, the artisanal fleet is mandated to sell its harvest to the DHC processing market. However, research has shown that the artisanal fleet illegally sells much of its catch for the production of fishmeal. To explore the different implications of these markets, each scenario is modeled under conditions specific to the fishmeal market and the DHC market. When fishing for the fishmeal market, each fisherman can harvest his boat's entire storage capacity each day and receives US$220 per MT of fish landed. Contrastingly, when fishing for the DHC market, each fishermen is only able to harvest 50% of his boat's capacity (the rest of the space must be filled with ice in order to maintain a quality of fish that is acceptable for human consumption) and only receives US$160 per MT of fish landed. These prices were determined through interviews and represent the maximum price garnered in these respective markets.

Biological Model

To model the dynamics of the north-central anchoveta stock (*Engraulis ringens)* under a set of different regulatory regimes and initial conditions, an underlying age-structured model was used. This model is based on a model presented by Oliveros-Ramos & Peña (2011), and is used to estimate the biomass and fishery yields at each theoretical season or time-step (t) over a 20-year period. A season is assumed to be 0.5 years in our model (Δt = 0.5 years). The life span of anchoveta is assumed to be three years, with recruitment occurring every season. The harvestable stock is divided into four cohorts, each separated by a 6-month age increment, beginning with a cohort of 0-6 months in age. We assumed individuals die in their third year, and are therefore not subject to harvest. The four cohorts exist simultaneously in the model, each as a state variable defined by abundance (N) of the cohort and biomass (B) of the cohort, based on the length-weight relationship for *E. ringens* (Villavicencio & Muck 1983). The average length of a cohort (L) was based upon a parameterized von Bertanlanffy growth model (Oliveros-Ramos & Peña 2011).

The processes considered in this model were recruitment, growth in age-class, natural mortality, and fishing mortality (catch at age by both the industrial and artisanal fleets). Industrial yield (Y_i), or harvest, takes place every time-step (season) and is constrained by the theoretical total allowable catch (*TAC*) for that season. In the first artisanal restricted open access scenario, the industrial TAC is based upon the total harvestable biomass at the beginning of a season and the target escapement biomass. When biomass levels are at or below the target escapement biomass (*TE*), industrial TAC is equal to a social quota (*SQ*). The industrial TAC that is generated in each season is fed into the economic component of the model which determines the actual harvest of the industrial fleet in that season, based on the biomass available in that season and a profit maximization function (described in *Economics Section,* below*)*.

Harvest by the artisanal fleet depends upon the regulatory scenario being analyzed. Under the open access regulatory scenario, the artisanal harvest is un-constrained by any quota, and dictated primarily by the economic model, which takes into account the available biomass in that season, and a harvest and profit maximization function. In the variable artisanal TAC scenario, the artisanal harvest is determined in a similar way, except that it is constrained by a TAC generated by the biological model. In this scenario, the artisanal fleet is allocated a social quota if the established quota is too low. For the two regulatory scenarios that allocate the artisanal fleet a fixed TAC, artisanal harvest is also constrained by a TAC, but in these scenarios the TAC is fixed value that remains constant over the time-horizon and does not vary with biomass availability.

Recruitment

Recruitment occurs at the beginning of each time step, with the magnitude of recruitment (in number of individuals) determined by a pre-generated stream of recruits over the time horizon. The stream of recruits for a given simulation over the time horizon is randomly chosen from a log-normal distribution of recruit biomass, which is distributed around an estimated mean of 550 billion individuals, with a standard deviation of 250 billion individuals (Oliveros-Ramos & Peña, 2011). Recruit abundance is given by the equation below:

$$\vec{r}: \log - N(\mu, \sigma^2) \quad (1)$$

Where:

$\vec{r}$: Vector of a random recruits drawn from random log-normal distribution

Environmental Variability

The anchoveta fishery has historically been highly dependent upon natural stock fluctuations due to the sensitivity of the stocks to ocean-climate variability, most notably to El Niño Southern Oscillation (ENSO). ENSO warm periods (El Niño) are characterized by increases in sea surface temperature, and are negatively correlated with anchoveta catches (Ñiquen & Bouchon 2004; Schreiber *et al.* 2011). This has been found to be due, at least in part, to the effect on biological processes, such as recruitment (Ñiquen & Bouchon 2004; Swartzman 2008).

To simulate El Niño, we first assumed that an El Niño event would only affect recruitment, with a proportion of the recruits removed from the system prior to entering the population. We also assumed that El Niño events only last for a season, and thus affected recruitment only for that season. This assumption is based on the fact that El Niño events have an average duration between a few weeks and a few months (Schreiber *et al.* 2011). The intensity of an El Niño (*I)* varies in the fraction of recruits that are removed from the stock prior to entering the first age-class. This variation in intensity reflects the variable and unpredictable impact of El Niño on the anchoveta stock experienced in Peru. The probability of an ENSO (*f*) event was varied across scenarios to reflect the variable frequency of El Niño events, which has been documented to occur at intervals between two to seven years (Swartzman 2008). In our model we explored the following combinations of El Niño intensities and probabilities of occurrence:'

	El Nino Iterations						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Probability of El Nino (f)	0	2/20	2/20	2/20	1/20	3/20	10/20
Intensity (I)	0	0.2	0.5	0.8	0.5	0.5	0.95

Table 3: El Nino Iterations, given by a probability of occurrence over the 20 season time-horizon, and intensity

Cohort Dynamics

To model cohort dynamics, we assumed growth to the next age-class is given by a decrease in number of individuals due to the effect of natural and fishing mortality. The abundance of the first age-class (N_1) is based upon the number of successful recruits from the previous time-period, which is given by a decrease in the number of individuals due to the effect of natural mortality and due to the potential occurrence of an El Niño event. Fishing mortality, or harvest (*H*), in a given season is dependent upon the harvestable biomass and fleet yields available at the beginning of the season, and is given by Equation (10) described below. To calculate the associated abundance of the harvested biomass of a given age-class, harvest of an age-class, *j*, is divided by weight at *j*.

$$N_{j,t} = \begin{cases} \mathrm{r}_{t-1}\, e^{-am}\, (1 - (ENSO \cdot I)\,) & ;\forall\{\mathrm{j} = 1\} \\ \mathrm{N}_{j-1,t-1}\, e^{-am} - \sum \left({}^{H_{j-1,t-1,k}}\!/_{w_j} \right) & ;\forall\{\mathrm{j} > 1\} \end{cases} \quad (2)$$

$$ENSO_t = X\!: B(T, f) \quad (3)$$

Where:

N: Abundance of each age-class $j \in \{1,2,3,4\}$, for every season t
I: Intensity of the ENSO event in terms of total recruit mortality.
ENSO: Binomial variable that indicates when El Niño occurs over the simulation period (*T*) with probability f .
a: The length of the time-step (in years), which is estimated to be a fishing season, or 0.5 years in this model
m: Natural mortality at each age-class

Biomass Estimation

The biomass of each age-class for a season (t) is estimated using the abundance of each age-class and the average weight of individuals of that age-class. The biomass of the entire stock vulnerable to harvest is the sum of all cohort biomasses of that season. This is described by the following two equations:

$$B_{j,t} = N_{j,t} w_j \quad (4)$$

$$TB_t = \sum_t B_{j,t} \quad (5)$$

Where:

B : Biomass of each age-class for every season t
w: Individual weight at a given age-class j
TB : Total biomass of the population at a given season t

Industrial and Artisanal Take Restrictions

In order to reflect the effect of fishing mortality on the stock, the yield of the fishery is divided into the two different fleets, industrial and artisanal. The allowable yield for a given season generated in the biological model is then passed to the economic model, where a harvest and profit function determine the total actual harvest by each fleet in that season. This harvest is what ultimately determines the effect of fishing mortality on the stock, and is described below in Equation 7. The allowable yield for each fleet varies between each regulatory scenario. In the artisanal open access scenario, industrial yield is based upon the total harvestable biomass available, target escapement, and/or the social quota. Artisanal yield is based upon what the artisanal catch (H_a) under either the baseline open access conditions or under the different artisanal TAC (TAC_a) regulatory scenarios. While catch limits may be set under the artisanal TAC scenarios, the fleet's actual harvest in a given season is based upon harvestable biomass and profit maximization. This is described in more detail below (*Economic Model, Scenarios Section*). Catch limits are thus given by the following expressions:

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$$TAC_{t,f} = \begin{Bmatrix} \max\{TB_t - TE, SQ_i\} & ; \forall\{f = i\} \\ No\ TAC\ set & ; \forall\{f = a\} \end{Bmatrix} \quad (6)$$

Variable TAC

$$TAC_{t,f} = \begin{Bmatrix} \max\{\text{ProportionTAC}_i * (\text{TB}_t - \text{TE}), SQ_i\} & ; \forall\{f = i\} \\ max\ \{(1 - \text{ProportionTAC}_i) * (\text{TB}_t - \text{TE}), SQ_a\} & ; \forall\{f = a\} \end{Bmatrix} \quad (7)$$

Fixed TAC #1

$$TAC_{t,f} = \begin{Bmatrix} \max\{TB_t - (TE + TAC_{t,a}), SQ_i\} & ; \forall\{f = i\} \\ 150{,}000MT & ; \forall\{f = a\} \end{Bmatrix} \quad (8)$$

Fixed TAC #2

$$TAC_{t,f} = \begin{Bmatrix} \max\{TB_t - TE, SQ_i\} & ; \forall\{f = i\} \\ 150{,}000MT & ; \forall\{f = a\} \end{Bmatrix} \quad (9)$$

Where:

$TAC_{t,f}$: Total yield allowed for each fleet $f \in \{i, a\}$, for industrial and artisanal fleets respectively.
TE : Target escapement of the population in biomass units.
SQ_i: Social quota is a constant minimum quota designated for the industrial fleet when biomass levels are low, which is set at 800,000 MT in this model
SQ_a: Social quota is the constant minimum quota designated to the artisanal fleet in the Variable TAC scenario. This value is 150,000 MT in this model.
$ProportionTAC_i$: For the Variable TAC scenario, this is the proportion of the "National TAC", calculated in the same way as the Industrial TAC for all other scenarios, which is allocated to the Industrial fleet as their TAC.

Industrial and Artisanal Harvest

The actual harvest in a given season is based upon the industrial and artisanal harvests that are derived from the Economic model, given the constraints dictated by the regulatory scenario being analyzed. Given the total harvest by each fleet, the biological model then determines how much of each age-class are actually removed in that season. The harvest of each age-class in a season by each fleet is represented by the following equation:

$$H_{j,t,f} = \begin{Bmatrix} H^*_{t,f}\left(\frac{c_f B_{j,t}}{B_{1,t}c_f + \sum_{j>1} B_{j,t}}\right) & ;\forall\{\mathrm{j} = 1\} \\ H^*_{t,f}\left(\frac{B_{j,t}}{B_{1,t}c_f + \sum_{j>1} B_{j,t}}\right) & ;\forall\{\mathrm{j} > 1\} \end{Bmatrix} \quad (10)$$

Where:

H: Total harvest of individuals for each class, at time t by fleet k
H: This is the total harvest at time t, by fleet k, that is derived from the economic model*
c: Juvenile catchability coefficient for fleet k

Juvenile Catchability

The juvenile catchability coefficient in our model reflects the proportion of juveniles (N_1) caught by each fleet relative to their harvest of all other age-classes (which are caught in proportion to the proportion of the total biomass that they represent). When this coefficient is equal to one ($c = 1$), juveniles are caught in proportion to their biomass relative to the total harvestable biomass. A coefficient that is less than one ($c < 1$) signifies that the proportion of juveniles caught in a fleet's harvest is less than the juvenile biomass relative to the total biomass in that season, while a coefficient that is greater than one ($c > 1$) signifies that the proportion of juveniles caught in a fleet's harvest is greater than the juvenile biomass relative to the total biomass in that season. In our model we assume a juvenile catchability for the industrial fleet of 0.8 to represent the fact that the industrial fleet is both (a) excluded from the first 5 nm of coastline (where spawning and lower age-classes are typically concentrated; Sanchez 1966) and (b) subject to seasonal closures during spawning seasons, which is assumed to lower their catch of juveniles. We assume a juvenile catchability for the artisanal fleet of 1.0 for baseline conditions, which reflects the fleet's ability to fish in the first 5 nm, and during seasonal closures.

Economic Model

Artisanal Harvest

The artisanal fleet's harvest in the restricted open access scenario in a given season is calculated by summing each artisanal boat's seasonal harvest. Since each boat is assumed to be identical, all artisanal boats are assumed to have the same harvest. It is also assumed that each fisherman has perfect information and will therefore fish the number of days that will maximize his total profit. The following equation is used to determine each artisanal boat's seasonal harvest:

$$H_{t,a} = A_a * \; E^{\alpha_a}{}_{t,a} * SC^{\beta_a}{}_a * B^{\gamma}{}_t \quad (11)$$

Where:

$H_{t,a}$: Individual harvest of one artisanal boat in season t
A_a = 5.7317e-7: Technology coefficient for artisanal fleet
$E_{a,t}$: Effort measured in number of days of an individual artisanal boat in season, t
SC_a : Storage capacity of an individual artisanal boat
α_a = 0. 8168311 (Salgado *et al.* 2011, pg. 22): Elasticity of effort for the artisanal fleet
β_a = 0.3591844 (Salgado *et al.* 2011, pg. 22): Elasticity of storage capacity for the artisanal fleet
B: Biomass
ϒ: Elasticity of the biomass=1

Each season, $H_{A,t}$, or the artisanal fleet's total harvest is the sum of each individual's harvest. Because each boat harvests the same amount of fish in this model, the number can be determined by multiplying $H_{a,t}$ by the number of boats in the fleet, or 927. If $H_{A,t}$ is less than the artisanal social quota (150,000 MT), then the entire artisanal harvest for that season will equal the social quota. This was included in all scenarios except for the fixed TAC scenarios, in which the fleet is guaranteed to harvest this amount of the resource (providing that the biomass is high enough to allow for this).

Technology Parameter, A_a

The technology parameter reflects variables such as the type of gear used, age of the boat, etc. This parameter affects catchability of the fish. While in reality this parameter likely varies for different types of artisanal boats, it is assumed in this model that each vessel has the same power and gear capacity on average. A single technology parameter A_a = 5.7317e-7 was calculated for the boats that comprise the artisanal fleet using the above harvest equation with the following parameters:

HT = Average seasonal total take of an individual artisanal boat. This was calculated using 927 boats and an average annual artisanal fleet harvest of 300,000 MT. This harvest was determined from interviews with people involved in the anchoveta fishery. Therefore, *H* = 150,000 MT.
$\bar{E}$= 180 days. This is the maximum length of the artisanal fishing season (just under half a year).
$\overline{SC}$ = The average storage capacity for an individual artisanal boat is 9.35 MT.
α = 0. 8168311: (Salgado *et al.* 2011, pg. 22)
β = 0.3591844: (Salgado *et al.* 2011, pg. 22)
B = 5,000,000 MT. This is the biomass left in the water by the industrial fleet.
ϒ= 1: taken from the literature (Salgado *et al.* 2011, pg. 22)

The equation of A is:

$$A = \frac{HT}{\bar{E}^{\alpha}\overline{SC}^{\beta}B^{\gamma}}$$

Artisanal Effort, E_a

Effort is measured in number of fishing trips for an individual artisanal boat in a given season. It is assumed that boats can only take one trip per day. Therefore, effort is measured in fishing days, and reflects the length of the artisanal fishing season. Also, it is assumed that effort for each artisanal boat is the same. Each fisherman's individual decision regarding how many days to fish is determined by the model, which chooses the number of days that will maximize the fisherman's profits. This is explained in more detail below. Effort cannot exceed the SL_a, or the total allowable fishing days in a given season. Because the artisanal fleet is not subject to seasonal closures, each fisherman can fish up to 180 days (just less than half a year).

Storage Capacity, SC_a

The average storage capacity of an artisanal boat was calculated to be 9.35 MT. When the model reflects the artisanal fleet participating in the fishmeal market, each individual fisherman can harvest his boat's entire hull capacity. Contrastingly, when the model reflects the artisanal fleet participating in the DHC market, each individual fisherman can only harvest half of his boat's hull capacity, which equals 4.675 MT.

Elasticity of Effort, α_a

This parameter represents the artisanal fishermen's sensitivity to changes in biomass relative to their respective efforts. An inelastic value (smaller than one) suggests that fishermen do not change their fishing effort in response to changes in the biomass. An elastic value (greater than one) suggests that fishermen will change their effort depending on the size of the biomass. The value used in this model was taken from the literature (Eide *et al.* 2003; Salgado *et al.* 2011) and is relatively inelastic, suggesting that fishermen will attempt to fish regardless of the size of the biomass.

Elasticity of Storage Capacity, β_a

This parameter represents the artisanal fishermen's sensitivity to changes in the biomass relative to their respective hull capacities. An inelastic value (smaller than one) suggests that fishermen do not change their fishing behavior based on available hull capacity. An elastic value (greater than one) suggests that fishermen will change their fishing behavior in response to changes in the biomass regardless of their storage capacity. An inelastic value (less than one) suggests that fishermen will change their fishing behavior based on the available biomass and their storage capacity. The value used in this model was taken from the literature and is relatively elastic, suggesting that fishermen are sensitive to changes in the biomass relative to their hull capacities.

Biomass, B_t

Biomass is the total anchoveta biomass at the beginning of a given time period, *t*. Details concerning this variable are described above in the Biological Model section.

Elasticity of Biomass, Υ_a

This parameter represents how harvest responds to a change in biomass. In this case there is a unitary relationship between harvest and biomass, so a 1% increase in the biomass translates to a 1% increase in the harvest. This reflects a robust fish and a resilient stock to bear higher intensity effort levels.

Artisanal Profit

The artisanal fleet's total profit in the restricted open access scenario in a given season is calculated by summing each artisanal boat's seasonal profit. Since each boat is assumed to be identical, all artisanal boats are assumed to have the same profit. Since it is assumed that each artisanal fisherman fishes in order to maximize his profits, the model adjusts the values for $E_{t,a}$ and $H_{t,a}$ in order to maximize the profit value. The following equation is used to determine each artisanal fisherman's seasonal profit:

$$\pi_{a,t} = (p_m * H_{a,t}) - (ce_a * E_{a,t}) - (ch_a * H_{a,t}) - FC_a \qquad (12)$$

Where:

$\pi_{a,t}$: profit of an individual artisanal fisherman a for a given season, t
p_m : price of raw material, where:
p_m = $160 USD/ MT under DHC market conditions
p_m = $220 USD/ MT under fishmeal market conditions
$H_{a,t}$: Individual harvest of one artisanal boat in season t
ce_a: Cost per fishing trip in $USD
ce_a: = $400 USD/ MT under DHC market conditions
ce_a: = $600 USD/ MT under fishmeal market conditions
$E_{a,t}$: Effort measured in number of days of an individual artisanal boat in season, t
ch_a = $USD 20: Cost per MT of fish landed in $USD
FC_a = $USD 80: Fixed costs per season in $USD

Each season, $\pi_{t,A}$, or the artisanal fleet's total profit is the sum of each individual's profit. Because each individual earns the same amount of profit in this model, the number can be determined by multiplying $\pi_{t,a}$ by the number of boats in the fleet, or 927.

Price of Raw Material/ MT, pm

The price at which the artisanal fishermen will sell their catch per MT depends on the market conditions being modeled. When the artisanal fishermen are behaving under fishmeal market conditions, the price is US$220 / MT. When the artisanal fishermen are behaving under DHC market conditions, the price is US$180 / MT.

Individual Artisanal Fisherman's Harvest in a Given Season, $H_{a,t}$

This number is determined by the profit maximization function and restricted to the allowable take. In scenarios in which the artisanal fleet is subject to a TAC, each fishermen is restricted the TAC divided by the number of artisanal vessels. The TAC restrictions for the entire artisanal fleet per regulatory scenario are calculated in the biological component of the model, described above (*Industrial and Artisanal Take Restrictions*).

Cost per fishing trip, cea

The cost per fishing trip is the cost that each artisanal fisherman bears for each trip he takes. These costs differ depending on if the artisanal fleet is fishing for anchoveta destined for DHC or fishmeal production. The cost per fishing trip is higher when fishing for the fishmeal industry because it is assumed that the fishermen's trips are longer and cover more distance. These costs include the cost of fuel, oil/lubricants, crew members, food, and incidentals, and were determined from interviews with members of the industry (Infante, personal communication 2012).

Artisanal Effort, Ea

Effort is measured in number of fishing trips for an individual artisanal boat in a given season. It is assumed that boats can only take one trip per day. Therefore, effort is measured in fishing days, and reflects the length of the artisanal fishing season. Also, it is assumed that effort for each artisanal boat is the same. Each fisherman's individual decision regarding how many days to fish is determined by the model, which chooses the number of days that will maximize the fisherman's profits. This is explained in more detail below. Effort cannot exceed the SL_a, or the total allowable fishing days in a given season. Because the artisanal fleet is not subject to seasonal closures, each fisherman can fish up to 180 days (less than half a year).

Cost per MT of Fish Landed, cha

These costs include the cost of the required permit (calculated by MT landed), the captain's payroll, and the crew's payroll. Importantly, as of August 2013, while artisanal boats are exempt from the permit fee, the low scale boats are not. For the purposes of this model, the artisanal boats were not divided into artisanal and low scale. The value for ch_a that was used was estimated with the consideration that some larger boats would be required to pay for this permit. This value was determined from interviews with members of the industry (Infante, personal communication 2012).

Fixed Cost per Season, FCa

These costs include capital costs, the cost of the crew, insurance, nets, maintenance, navigation permit from the port authority, and others and were determined from interviews with members of the industry (Infante, personal communication 2012).

Maximizing Profits – Artisanal Fleet

Effort is chosen by the model to optimize for the individual fisherman's profit:

$$\max_{E_{a,t}} \pi_{a,t}$$

$$\begin{aligned} &S.T. \\ &E_{a,t} \leq SL_a \\ &H_{a,t} \leq IAH_{a,t} \end{aligned} \qquad (13)$$

Where:

SL_a = 180 days: maximum season length
$IAH_{a,t}$: Allowed catch for each individual artisanal fisherman at a given season, t

As the model optimizes for maximized profits, it will determine the appropriate E_a and H_t for a given time period.

Maximum Season Length, SL_a

The maximum season length is the number of days that the fishery is open to the artisanal fleet for anchoveta fishing. This was determined to be 180 days, or just under half a year (subtracting some days for to represent holidays in which fishermen will not fish), because the artisanal fleet is currently not restricted by any season closures.

Allowable Catch for Each Individual Fisherman, $IAH_{a,t}$

The allowable catch for each individual artisanal fisherman depends on the regulatory scenario being investigated (See *Industrial and Artisanal Take Restrictions*). For the restricted open access scenario (or status quo), the artisanal fleet is not restricted by a TAC. Therefore, $H_{a,t}$ is restricted to the biomass divided by the number of boats, or $B/927$. In the fixed TAC scenarios, $H_{a,t}$ is restricted to the fixed TAC divided by the number of boats, or 150,000/927. Finally, in the variable TAC scenario, $H_{a,t}$ is restricted by the artisanal percentage of the national TAC divided by the number of boats.

Artisanal Net Present Value (NPV)

In order to determine the total value of the fishery over the 20-season timespan for the artisanal fleet, the net present value (NPV) of profits was calculated by applying a discount rate. The following equation was used to make this calculation:

$$NPV_A = \sum_{t=1}^{20} \pi_{A,t} \left(\frac{1}{(1-r)^t}\right) \tag{14}$$

Where:

$\pi_{A,t}$: total artisanal profits at a given season, t
r: discount rate

Discount Rate

The discount rate used for this exercise was 0.05, which is a standard discount rate. However, given that artisanal fishermen are mostly subsistence workers, their discount rate is likely higher. This was not initially explored given the fact that a given policy would have the goal of moving the discount rate closer to 0.05. However, a larger discount rate would suggest that the fishery over time is actually less valuable than what is described in the outputs generated for this study.

Industrial Harvest

The industrial fleet's harvest in the restricted open access scenario in a given season is calculated by summing each industrial boat's seasonal harvest. Since each boat is assumed to be identical, all industrial boats are assumed to have the same harvest. It is also assumed that each fisherman has perfect information, competing for resources, and will therefore fish the number of days that will maximize his total profit. The same harvest equation used to determine artisanal harvest is used for the industrial fleet. Different parameters are used to reflect this fleet, and the total harvest of all industrial boats each season is restricted to the fleet's TAC, which is determined from the biological model. The following Cobb-Douglas equation is used to determine each industrial boat's seasonal harvest:

$$H_{t,i} = A_i * \; {E^{\alpha_i}}_{t,i} * {SC^{\beta_i}}_i * {B^{\Upsilon}}_t \qquad (15)$$

$$S.T.$$

$$H_{t,i} \leq TAC_I$$

$$E_{t,i} \leq SL_i$$

Where:

$H_{t,i}$: Individual harvest of one industrial boat in season t
A_i = 1.99e-6: Technology coefficient for industrial fleet
$E_{i,t}$: Effort measured in number of days of an individual industrial boat in season, t
SC_i : Storage capacity of an individual industrial boat
α_i = 0.82 (Salgado *et al.* 2011): Elasticity of effort for the industrial fleet
β_i = 0.36 (Salgado *et al.* 2011): Elasticity of storage capacity for the industrial fleet
B: Biomass
ϒ = 1: (Salgado *et al.* 2011) Elasticity of the biomass
SL_i = 130 days: Season length for the industrial fleet
TAC_I: Total Allowable Catch for the industrial fleet

Each season, $H_{t,I}$, or the industrial fleet's total harvest is the sum of each individual's harvest. Because each boat harvests the same amount of fish in this model, the number can be determined by multiplying $H_{t,i}$ by the number of boats in the fleet, or 1014. In seasons in which the $H_{I,t}$ determined by the model is less than the industrial fleet's social quota (800,000 MT), the fleet's entire harvest will equal the social quota, provided that the biomass is large enough to allow for this. This was included into the model because the industrial fleet currently receives a social quota in year when biomass is low. Mostly recently, the social quota has been 800,000 MT.

Season Length (SL_i)

The season length was determined by adding the number of permitted fishing days in each year (four months) and dividing by two.

Industrial Total Allowable Catch TAC_I

In the initial restricted open access scenario, only the industrial fleet's harvest is limited to a TAC. The TACs for each season are determined using the biological model and the following equation:

$$TAC_{I,t} = B_t - TE \tag{16}$$

Where:

$TAC_{I,t}$: Industrial fleet's total allowable catch for a given season, t
B_t: Biomass for a given season, t
TE = 5 million MT: Target escapement

Industrial Profits

The industrial fleet's total profit under all regulatory scenarios in a given season is calculated by summing each industrial boat's seasonal profit. Since each boat is assumed to be identical, all industrial boats are assumed to have the same profit. Since it is assumed that each industrial fisherman fishes in order to maximize his profits, the model adjusts the values for $E_{t,i}$ and $H_{t,i}$ in order to maximize the profit value. Importantly, the model chooses these values as it is maximizing for artisanal profits. The following equation is used to determine each industrial fisherman's seasonal profit:

$$\pi_{i,t} = (p_{i,m} * H_{i,t}) - (ce_i * E_{i,t}) - (ch_i * H_{i,t}) - FC_i \tag{17}$$

Where:

$\pi_{i,t}$: profit of an individual industrial fisherman for a given season, t
$p_{i,m}$ = $USD 300: price of raw material
$H_{i,t}$: Individual harvest of one industrial boat in season t
Ce_i : Cost per fishing trip in $USD
$E_{i,t}$: Effort measured in number of days of an individual industrial boat in season, t
ch_i : Cost per MT of fish landed in $USD
FC_i : Fixed costs per season in $USD

Each season, $\pi_{I,t}$, or the industrial fleet's total profit is the sum of each individual's profit. Because each individual earns the same amount of profit in this model, the number can be determined by multiplying $\pi_{i,t}$ by the number of boats in the fleet, or 1014.

Price of Raw Material/ MT, $p_{i,m}$

The price at which the industrial fishermen will sell their catch per MT is always US$300. This number was determined from industry interviews.

Individual Industrial Fisherman's Harvest in a Given Season, $H_{i,t}$

This number is determined by the model as it optimizes for maximum artisanal profit, and it limited by the total allowable catch. The TAC_i is determined by the biological model, and is dependent upon which regulatory scenario is being analyzed. This is described above by Equation (6) through (9). Given the regulatory scenario being analyzed and the associated harvest restriction (or TAC_i) for that season, the following equation represents the harvest for each individual industrial fisherman:

$$H_{i,t} = \{TAC_i)/FS_i\} \qquad ; \forall \{TAC_i \text{ dependent on regulatory scenario}\} \qquad (18)$$

Where:

B_t : Biomass at a given season, t
TE : Target escapement
FS_i = 1014: Number of industrial boats
$IAH_{a,t}$: Individual allowable artisanal harvest

Cost per fishing trip, ce_i

The cost per fishing trip is the cost that each industrial fisherman bears for each trip he takes. These costs include the cost of fuel, oil/lubricants, crew members, food, and incidentals, and were determined from interviews with members of the industry (Infante, personal communication 2012).

Industrial Effort, E_i

Effort is measured in number of fishing trips for an individual industrial boat in a given season. It is assumed that boats can only take one trip per day. Therefore, effort is measured in fishing days, and reflects the length of the industrial fishing season. Also, it is assumed that effort for each industrial boat is the same. Each fisherman's individual decision regarding how many days to fish is determined by the model, which chooses the number of days that will maximize the fisherman's profits. Effort cannot exceed the SL_i, or the total allowable fishing days in a given season. Based on the seasonal closures for the industrial fleet, each fisherman can fish up to 131 days.

Cost per MT of fish landed, ch_i

These costs include the cost of the required permit (calculated by MT landed), the captain's payroll, the crew's payroll, and costs that fund pension, enforcement, and alternative labor programs. The alternative labor program, FONCOPES, provides funding to industrial fishermen who choose to leave the fishery (General Fishery Law 2012). This value was determined from interviews with members of the industry (Infante, personal communication 2012).

Fixed Cost per Season, FC_i

These costs include capital costs, the cost of the crew, insurance, nets, maintenance, navigation permit from the port authority, the cost of satellite systems, and others and were determined from interviews with members of the industry (Infante, personal communication 2012).

Maximizing Profits – Artisanal Fleet

Effort is chosen by the model to optimize for the individual fisherman's profit:

$$\max_{E_{a,t}} \pi_{a,t}$$

$$S.T.$$
$$E_{a,t} \leq SL_a \qquad (19)$$
$$H_{a,t} \leq IAH_{a,t}$$

Where:

SL_a = 180 days: maximum season length
$IAH_{a,t}$: Allowed catch for each individual artisanal fisherman at a given season, t

As the model optimizes for maximized profits, it will determine the appropriate E_a and H_t for a given time period.

Maximum Season Length, SL_a

The maximum season length is the number of days that the fishery is open to the artisanal fleet for anchoveta fishing. This was determined to be 180 days, or just under half a year (subtracting some days for to represent holidays in which fishermen will not fish), because the artisanal fleet is currently not restricted by any season closures.

Industrial Net Present Value (NPV_I)

In order to determine the total value of the fishery over the 20-season timespan for the industrial fleet, the net present value (NPV) of profits was calculated by applying a discount rate. The following equation was used to make this calculation:

$$NPV_I = \sum_{t=1}^{20} \pi_{I,t} \left(\frac{1}{(1-r)^t}\right) \qquad (20)$$

Where:

$\Pi_{T,t}$: total industrial profits at a given season, t
r = 0.05: discount rate

Total Net Present Value (NPV_T)

In order to determine the total value of the fishery over the 20-season timespan for both fleets, the net present value (NPV) of profits was calculated by applying a discount rate. The following equation was used to make this calculation:

$$NPV_{IT} = \sum_{t=1}^{20} \pi_{T,t} \left(\frac{1}{(1-r)^t}\right) \qquad (21)$$

Where:

$\pi_{T,t}$: total profits at a given season, t
r = 0.05: discount rate

Total Profits at a Given Season, $\pi_{T,t}$

In order to calculate the total profits in a given season, the two fleet's profits are summed ($\pi_{I,t} + \pi_{A,t} = \pi_{T,t}$).

Results

Results from the static models show that a total allowable catch (TAC) system could increase the total value of the fishery while maintaining higher levels of biomass in the water. The total anchoveta biomass increases as a progressively higher proportion of the TAC is allocated to the artisanal fleet, with slightly higher biomass values overall under the DHC market condition. Since a TAC allocation that exceeds artisanal harvest is equivalent to increasing target escapement, a greater biomass is available for harvest. As biomass increases, CPUE increases, raising the amount of anchoveta caught per fishing trip and reducing the costs associated with fishing effort. Because of the higher CPUE, the total Net Present Value (NPV) of fishery profits increases until the artisanal TAC passes a certain point, which is 70% in this model. At this point, the fishery begins to reduce in value since the absolute catch obtained is too low to generate a sufficient profit, despite extremely high catch efficiency. The Maximum Economic Yield (MEY) of the fishery is achieved at a biomass level of 9.5 – 9.7 million metric tons (MT), when the MEY reaches its peak at US$3.5 to US$3.9 billion, after which reduced fishing effort becomes too low to achieve sufficient profits to cover fixed and variable costs.

While the industrial fleet would increase its profit if the artisanal fleet is mandated to fish for DHC, artisanal profit decreases when it fishes solely for DHC. When the artisanal fleet fishes for fishmeal, however, artisanal profits increase while industrial profits are reduced. However, both the artisanal and industrial fleets could experience profit gains by applying a TAC to the artisanal fleet and effectively raising target escapement. While the average industrial harvest decreases with the application of an artisanal TAC, the data concludes that the costs associated with fishing effort are reduced enough to compensate for the loss in fish yield. Although this conclusion is strongly influenced by the effect of the biomass on the catchability and thus on the cost of fishing, it allows exploration of the possibility of achieving higher economic profits for both fleets while leaving more fish in the water. The increase in anchoveta biomass may also result in additional ecosystem benefits, such as increased forage for predators such as seabirds (guano birds), marine mammals, mollusks, and higher trophic-level fish species.

Biological Results

Results from the bio-economic model show that there is a high level of variability on the biomass when the artisanal fleet is managed under the current restricted open access system. Of all the scenarios explored, the open access scenario clearly has the greatest impact on the biomass level. The impact is significantly higher if the fleet is not mandated to fish for DHC, due mostly to the fact that the artisanal fleet has a reduced capacity under the DHC mandate. Impacts of the artisanal fleet can be significantly higher under ENSO events of increasing frequency and intensity. If a TAC for the artisanal fleet is not imposed, the fleet is essentially given the potential to significantly affect the recovery of the biomass after such events.

Figure 21 represents the performance of the total biomass under a range of artisanal TAC proportions. In both market scenarios, the biomass increases considerably with the proportion of the TAC allocated to the artisanal fleet because the capacity of the fleet is insufficient to catch the entire quota. Biomass increases more rapidly when DHC is mandated, because the capacity of artisanal boats is further reduced. The biomass continues to increase until the artisanal portion of the TAC reaches 90%. The biomass reduction beyond a 90% artisanal TAC is likely due to the anchoveta stock reaching carrying capacity. Effects of escapement on the biomass are presented in Figure 22. The model shows that an increase in the artisanal TAC proportion has similar effects on the biomass as an increase in escapement.

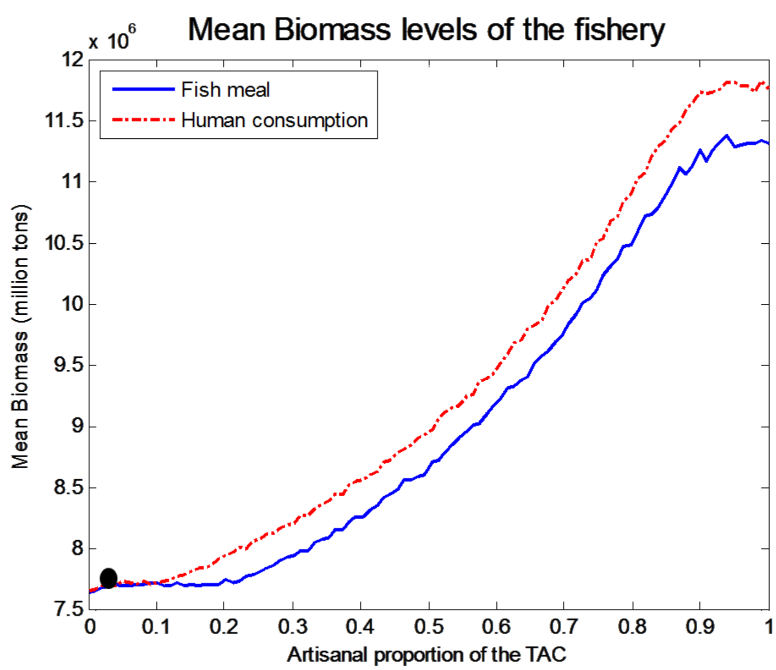

Figure 21: Mean biomass levels of the fishery under different artisanal allocations of the national TAC.

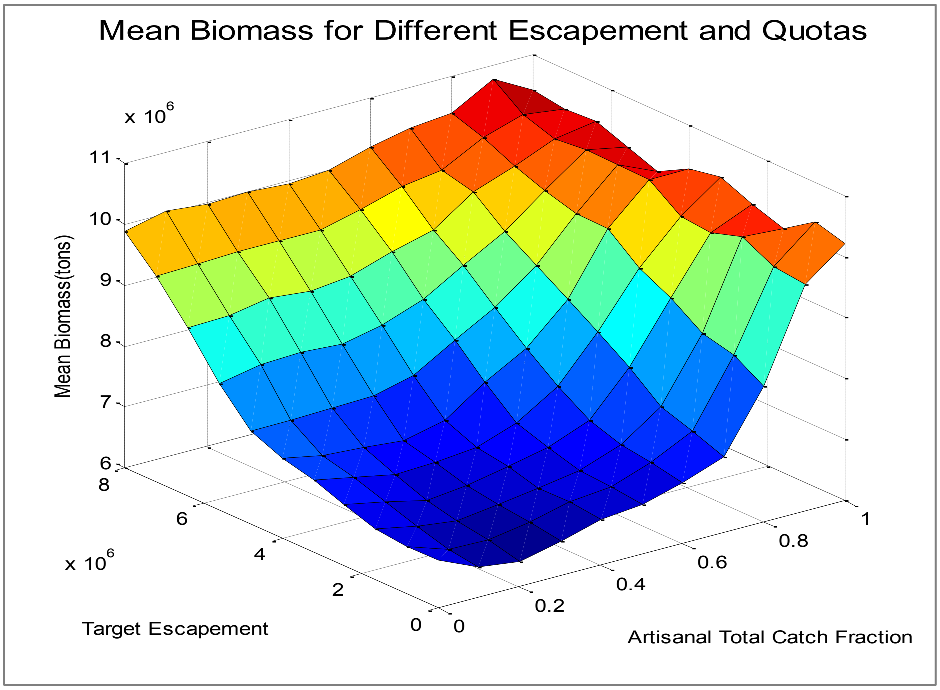

Figure 22: Effects of target escapement and artisanal fraction of national TAC on the biomass

Over the range of artisanal TAC proportions (0 to 30%) that can be feasibly harvested by artisanal fleet (given their hull capacity), the greatest biomass can be achieved given the highest level of target escapement (Figure 23). While there is no great change in biomass over the low levels of target escapement, from zero to 4 million tons, the rate of change in biomass increases starkly beyond 4 million tons, with an increase in biomass of 3 million tons with an increase of around 2 million tons in escapement. This suggests that raising the escapement from the current average volume of 5 million tons could have significant positive effects for the biomass and associated ecosystem benefits. Results also show that there is no significant effect on the biomass with increases in the artisanal TAC proportion up to 30%, because this does not affect the number of fish being caught.

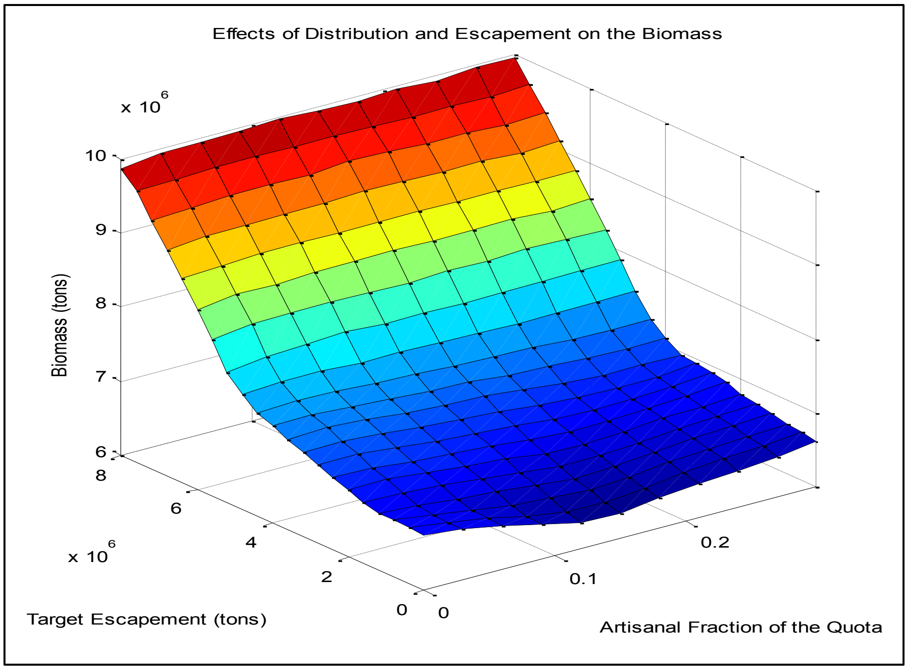

Figure 23: Effects of target escapement and artisanal fraction of the TAC (0-30%) on biomass

Economic Results

The model shows that the total NPV of profits of the anchoveta fishery is lower in "restricted open access regimes," regardless of whether the artisanal fleet fish for DHC or Fishmeal. When a TAC is assigned at levels that are proportional to the artisanal fleet's hull capacity (4% of the total hull capacity in the fishery), the fishery gains value in a range that fluctuates from US$200 to US$300 million over a 10-year horizon, which represents 10% of the maximum value obtained. With this TAC allocation, the protected biomass is not harvested, artisanal harvest decreases, and the industrial fleet captures harvest that was fished by the artisanal fleet in the open access scenario. Regardless of the TAC allocation between the industrial and artisanal fleets, total NPV of the fishery is greater when the artisanal fleet is managed under a TAC due to increased productivity of the fishery associated with hitting target escapement. In open access, the artisanal fleet's seasonal harvest cuts into the protected biomass (or target escapement), reducing the stock over time which in turn decreases the industrial fleet's TAC. When a TAC for the artisanal fleet is set, the artisanal fleet's fishing capacity is restricted and the industrial fleet receives a portion of the overall TAC as opposed to the entire TAC for a season. However, because the artisanal TAC ensures that the protected biomass is not harvested, the fishery becomes more productive overtime allowing for larger overall national TAC allocations than under open access regimes and improvements in fishing efficiency. Therefore, the increase in the NPV of the whole fishery is due to the effect that maintaining the protected biomass has on fishery productivity. In other words, whatever is fished by the artisanal fleet will affect the catch of the industrial fleet in the following years. The total NPV for the fishery is higher in all management scenarios when the artisanal fleet is fishing for fishmeal rather than mandated to fish for DHC (Figure 24).

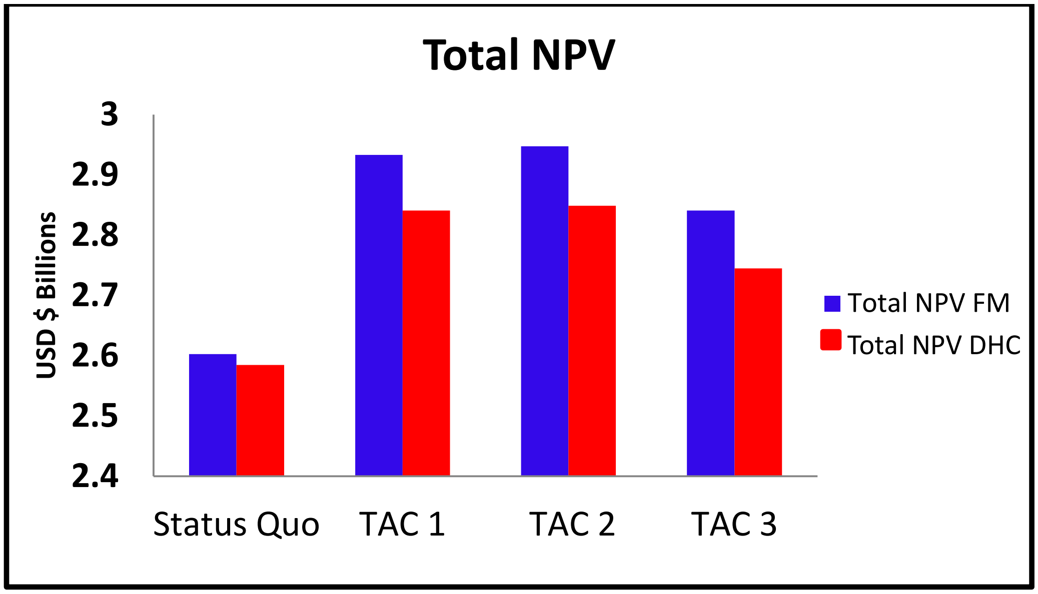

Figure 24: Net present value (NPV) of the anchoveta fishery under different management strategies

Figure 25 shows the total NPV of fishery profits under a range of artisanal TAC proportions. The blue dot represents the value obtained by the fishery under an open access regime. Under a progressive TAC system, the overall value of the fishery increases significantly. Maximum NPV is obtained when the artisanal TAC ranges from 60-70% for both fishmeal and DHC market scenarios. Again, the artisanal fleet reaches a point where it does not fish its entire proportion of the national TAC – this results in more fish being left in the water and lower overall yields. Therefore, the maximum NPV of the fishery is achieved in the model by allocating the artisanal fleet a proportion of the TAC that they do not completely harvest, and effectively raising the total escapement in the fishery. After passing the 70% threshold of artisanal TAC allocation, the fishery begins to reduce in value. Despite an extremely efficient catch effort, the absolute catch obtained is too low to generate a sufficient profit.

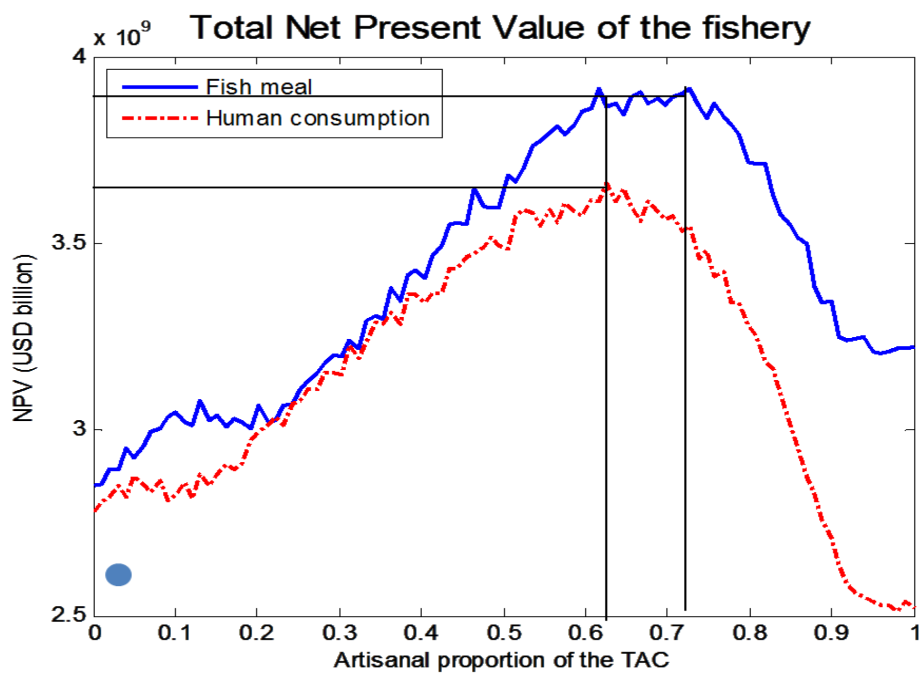

Figure 25: Total NPV of the fishery at different artisanal TAC proportions

The maximum economic yield (MEY) of the fishery is achieved at a biomass level of 9.5 – 9.7 million metric tons. The MEY NPV of profits ranges from US$3.5 to US$3.9 billion if the artisanal fleet is mandated to fish for DHC or if it sells its catch for fishmeal production (Figure 25). The blue dot represents the maximum NPV of the open access scenario, which is significantly lower than any of the values achieved under a TAC regulation.

At the current average target escapement of 5 million tons, an increase in the artisanal TAC from 0% to 60% results in an increase in the total NPV of the entire fishery over the 20-season (or ten-year) time-horizon. As any artisanal TAC allocation above 30% is above that which the artisanal fleet can actually catch, the increase in net present value beyond this TAC proportion can be attributed to a greater volume of fish being left in the water (above the set target escapement), and thus greater harvest efficiency for both fleets. Raising target escapement should be done directly through clear fisheries policies that include appropriate enforcement to avoid increases in artisanal capacity. Focusing only on the 0 to 30% artisanal TAC proportion under the current average target escapement level, the slight increase in NPV suggests that allocating a proportion of the TAC to the artisanal fleet, despite the corresponding decrease in the TAC allocated to the industrial fleet, increases the overall value of the fishery over time. This is due to the fact that at these levels of artisanal TAC allocation, the fleet does not fish from the intended protected stock and target escapement of 5 million tons is actually maintained. Over time, this creates a more productive fishery and therefore more efficient fleets, which increases the overall value of the fishery. If target escapement is raised beyond the 5 million ton average, the value of the fishery continues to increase across the 0 to 30% range of artisanal TAC proportion, which is likely explained by the increases in harvest efficiency resulting from the greater biomass left in the water (Figures 26 and 27). When target escapement is set below the 5 million ton value, the value of the fishery dramatically declines.

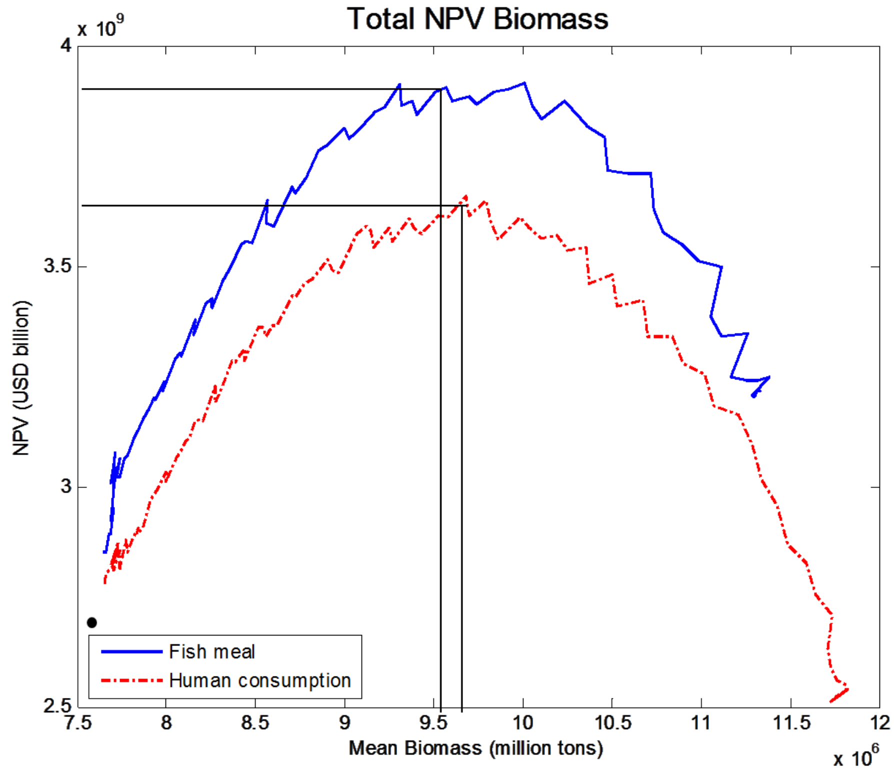

Figure 26: Total NPV of the fishery at different biomass levels

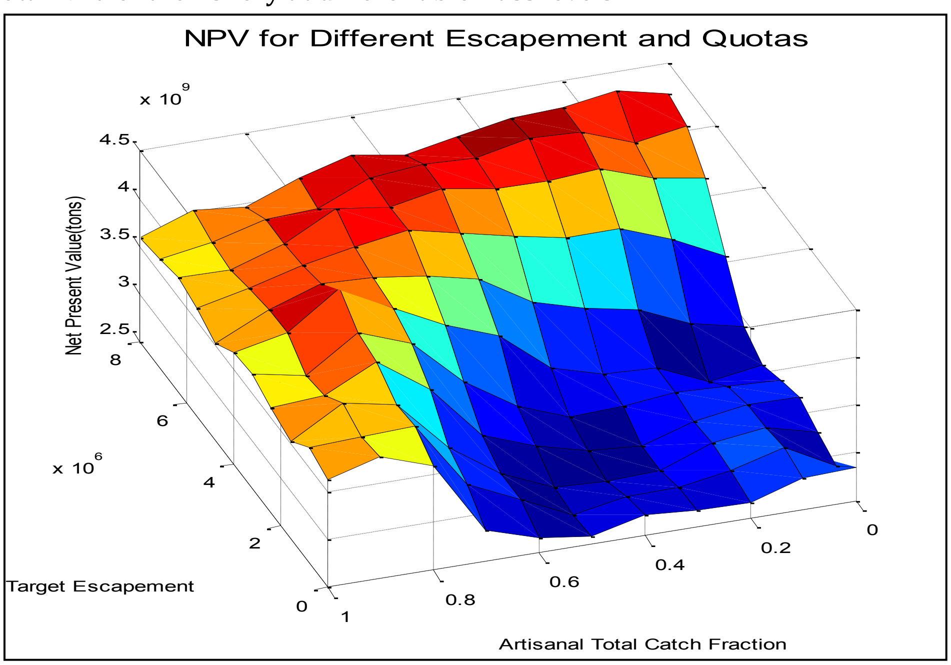

Figure 27: Net present value of the fishery given variations in target escapement and artisanal TAC allocation

The results indirectly indicate that raising target escapement and decreasing the national TAC (or the total yields from the fishery) has the potential to increase the anchoveta biomass while simultaneously increasing the value of the fishery. Although this model indicates that these results can be achieved by giving the artisanal fleet relatively large TAC allocations, the practical application of this method would be difficult and likely have undesirable consequences. First, it would be politically infeasible to allocate a proportion of the total harvest to the DHC with the intention of preventing that harvest from actually occurring. In addition, proving the artisanal and low scale fleets with a large TAC would likely create the incentive for capacity building. While they might not initially harvest their entire allocation, having the right to more fish would encourage further illegal entry of new vessels.

Profit Distribution and Fishing Efficiency

A trade-off frontier of profits can be generated by comparing profits of the industrial and artisanal fleets under a range of different artisanal TAC allocations (Figure 28). The dots represent the open access scenario for both fleets, while the lines show the distribution of profit under a range of proportions of artisanal TAC. The graph demonstrates that an open access scenario is the least efficient system. Both artisanal and industrial fleets could be better off by applying an artisanal TAC. The industrial feet could experience the greatest profit gains if the artisanal fleet fully complies with the mandate to fish for the DHC sector.

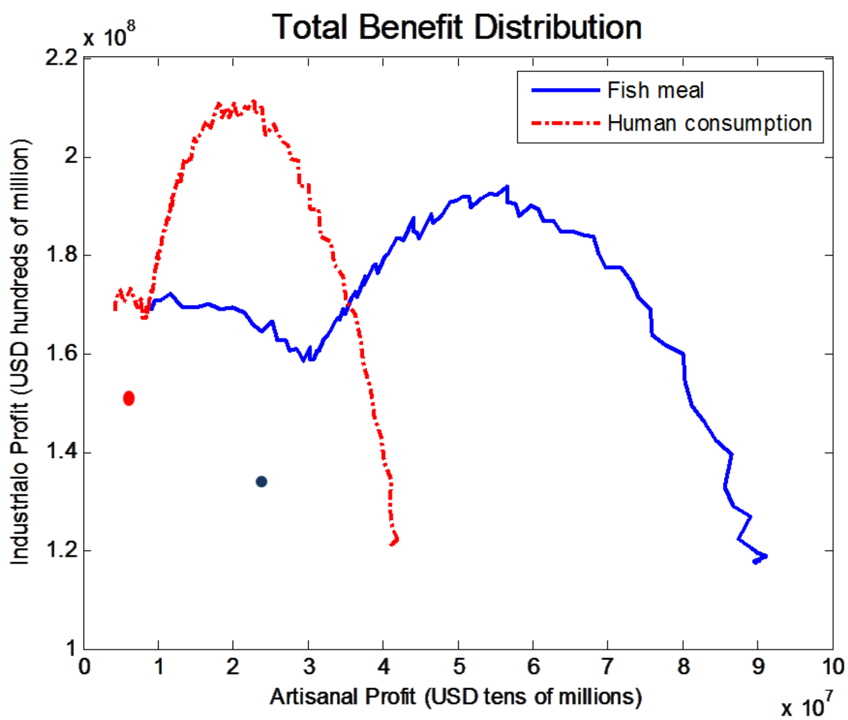

Figure 28: Total benefit distribution for industrial and artisanal fleets

The industrial fleet achieves a maximum profit of US$210 million while the artisanal fleet realizes a profit of over US$20 million, which is three times higher than under open access conditions. When the artisanal fleet fishes for fishmeal, as compared to the DHC market scenario, the industrial profit is reduced. When the artisanal fleet catches fishmeal exclusively, maximum profit of the industrial fleet reaches US$190 million, while the artisanal fleet earns a profit of US$55 million. Beyond this peak in profits, as the artisanal quota increases past this point the industrial fleet becomes inefficient as its fishing capacity is too large relative to the catch quota available, generating a stronger race to fish and resulting in a reduction in profits.

Figure 30 shows the profit distribution under different artisanal TAC scenarios. When the artisanal fleet fishes for DHC (red), the profit of the industrial fleet reduces until the artisanal TAC passes 10%. After this point, industrial profit begins to increase as a response to increased biomass. Again, the biomass grows as a result of the artisanal fleet's unharvested quota share. This results in a greater biomass left in the water, which subsequently increases the industrial fleet's catch efficiency. The same trend is observed when the artisanal fleet fishes for fishmeal (blue), although the effect of the biomass increase is delayed due to a higher storage capacity of the artisanal fleet when fishing for fishmeal. In both cases, the industrial fleet reaches its maximum profit when the artisanal TAC is set at 60%, a value that is higher than the artisanal fishing capacity. The rate at which artisanal profits increase is a function of the TAC. The profits of the artisanal fleet increase significantly if it is not mandated to sell its catch for DHC. The maximum profit realized under DHC is US$40 million, when the fleet receives 100% of the TAC. In the fishmeal market scenario, this same profit of US$40 million is realized when the fleet receives just 45% of the TAC. The difference in profit is largely due to differences in the price-cost structure of fishing for fishmeal versus DHC, and the hull capacity limitations when fishing for DHC. Fishermen fishing for DHC can only harvest up to half of their true hull capacity, generating a difference of more than two times between fishmeal and DHC profits (Figure 29).

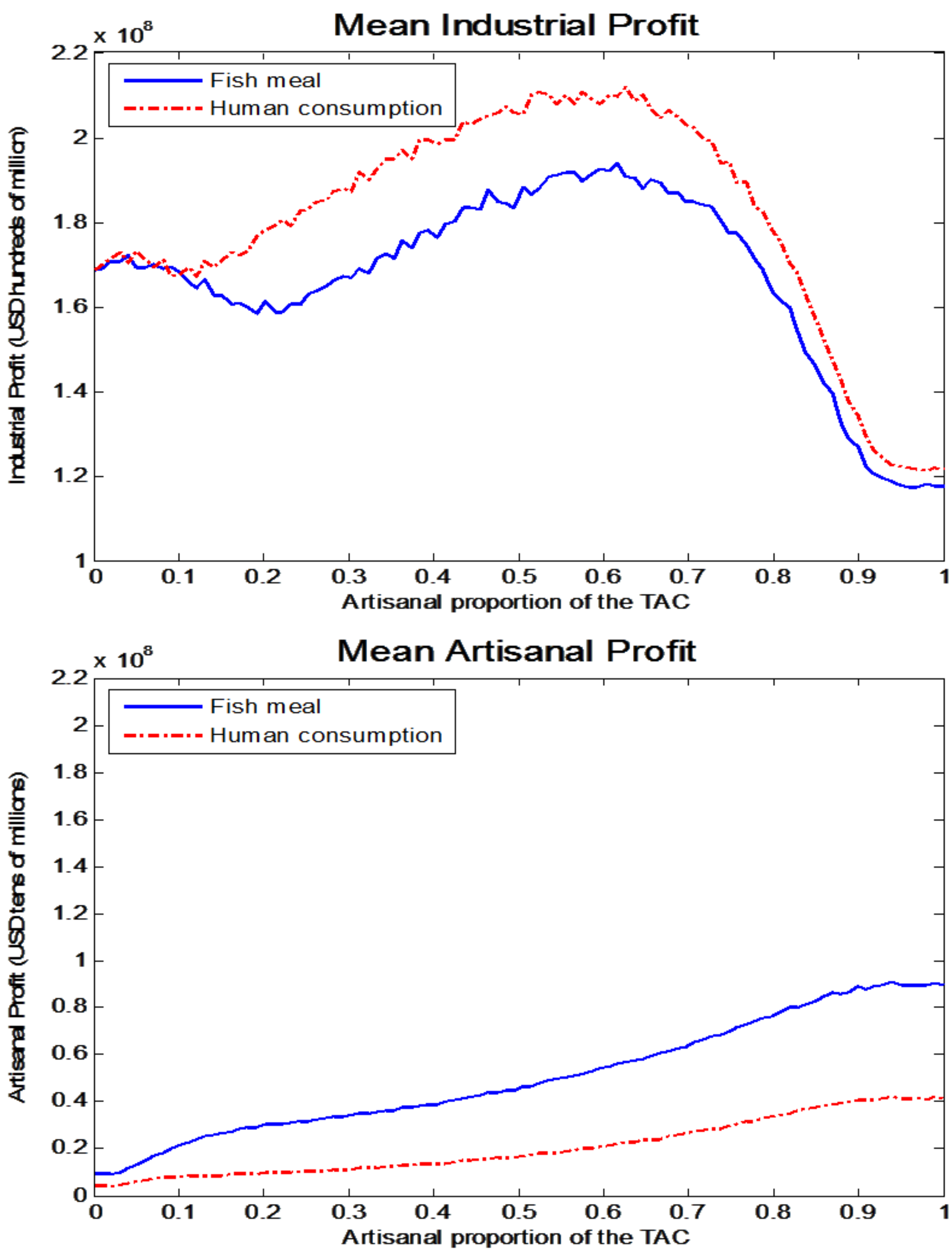

Figure 29: Mean industrial and artisanal profits at different artisanal TAC proportions

The red and blue dots in Figure 30 represent the maximum yields obtained under an open access regime, while the lines show the yield under a range of artisanal TAC allocations. Industrial yield decreases as the artisanal TAC increases. The model demonstrates that MEY for the industrial fleet is obtained when the artisanal fleet is allocated 60% of the TAC. Yields for the industrial fleet are higher overall when the artisanal fleet fishes for DHC, since their overall fishing capacity is reduced and they leave more fish is left in the water. Conversely, the artisanal yield increases as a function of the proportion of the TAC it is allocated. Marginal increases in artisanal yields significantly decrease when the fleet no longer harvests its TAC (shown in the figure where the curve begins to flatten). When DHC is mandated, the artisanal fleet increases its catch significantly before the first 10% of TAC. After the 10% TAC allocation, yield increases more slowly due to a slower increase in efficiency (catch per unit of effort) when more biomass is in the water. Under a fishmeal scenario, a similar trend is seen after 25% of the TAC is allocated. The maximum yield of this fleet reaches 700,000 metric tons and 1 million tons when fishing for DHC or fishmeal, respectively (Figure 30)

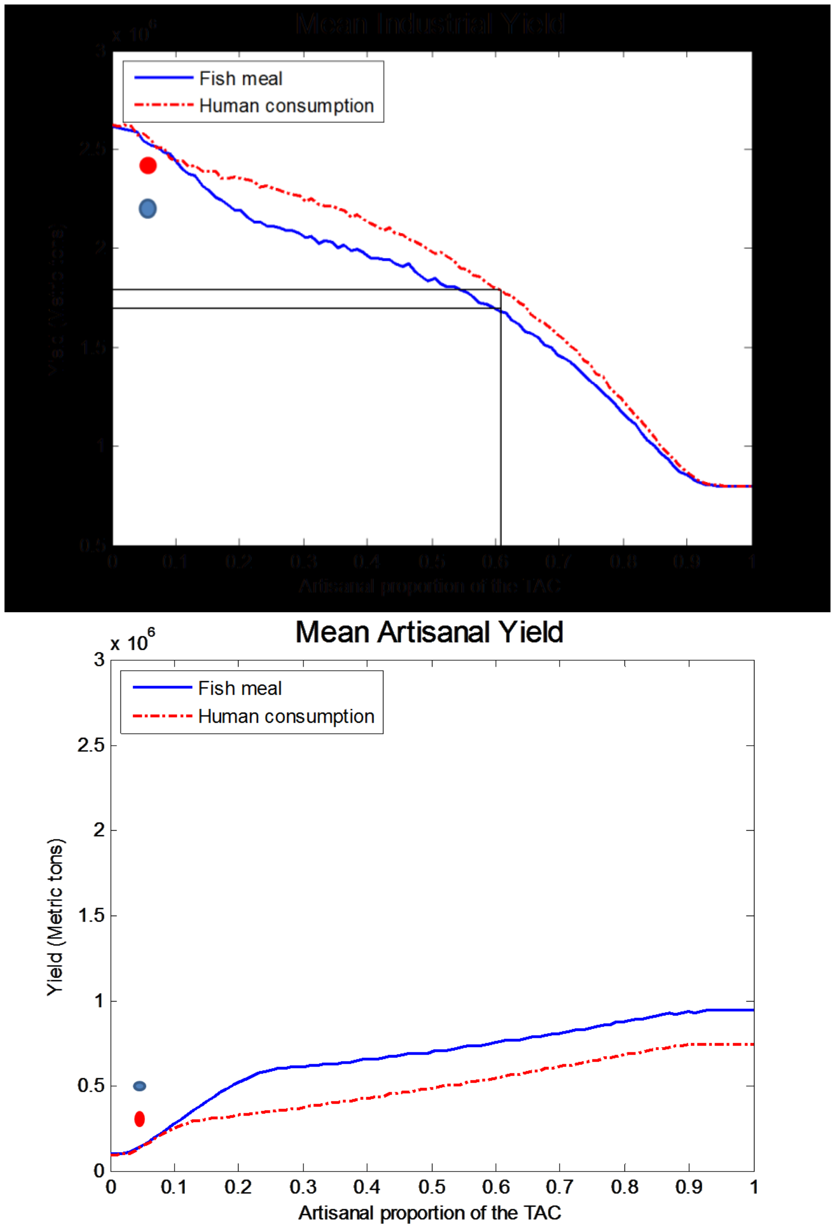

Figure 30: Mean Industrial and Artisanal Yields at different TAC proportions

Figure 31 also provides support for the notion that increasing target escapement beyond 4 million tons increases profits dramatically across all artisanal TAC proportions over the range of 0 to 30%. The greatest industrial profits are realized at the highest target escapement, when the artisanal fleet is not allocated any portion of the TAC. As the artisanal proportion of the TAC increases to 30%, industrial profits decrease by about US$50 million. It is also important to note that the industrial fleet realizes the same average profits at a target escapement of 4 million tons and an artisanal TAC proportion of 0% as with a target escapement of 6 million tons and an artisanal TAC proportion of 30%.

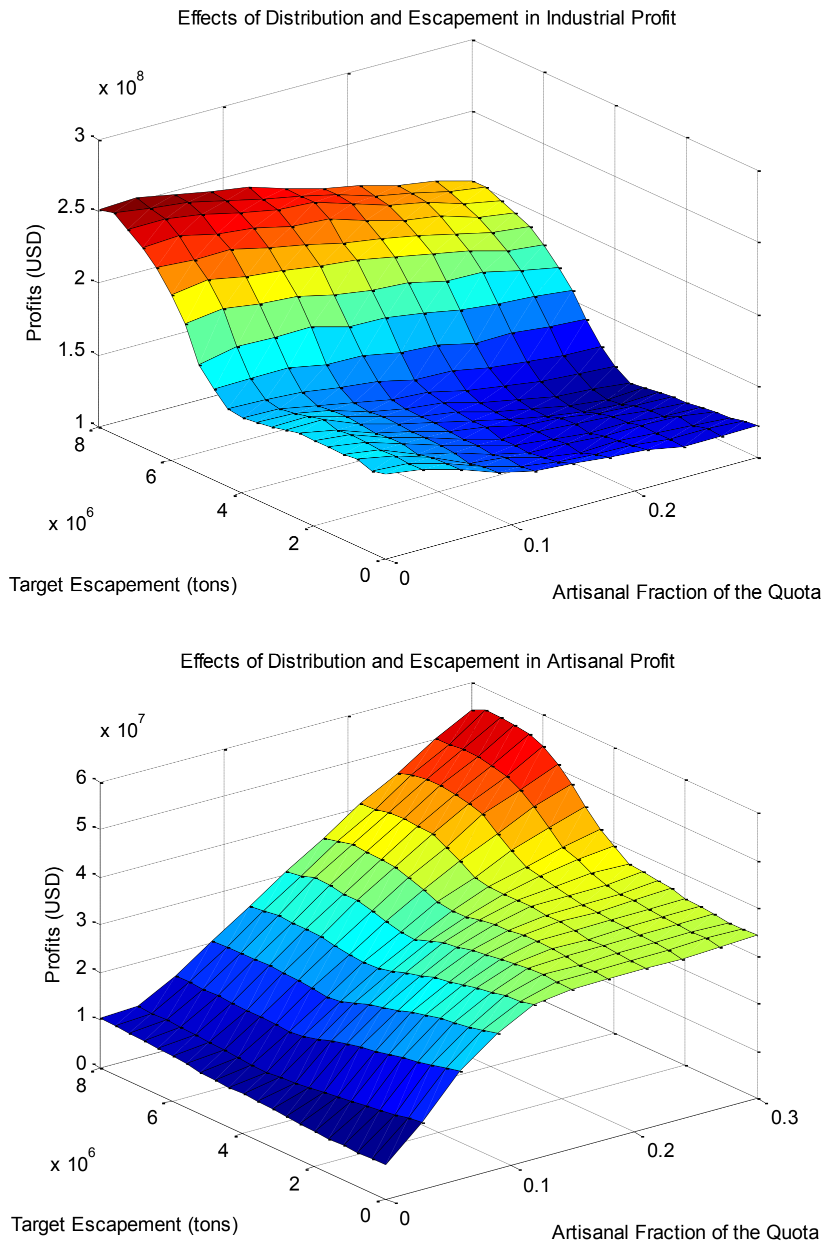

Figure 31: Effects of escapement and artisanal TAC allocation industrial and artisanal profits

When considering only target escapement values at or above 5 million tons, artisanal profits greatly increase with an increase in artisanal TAC proportion from 0 to 30%. With a target escapement of 5 million tons, increasing the artisanal TAC proportion from 0 to 30% results in an increase in artisanal profits of approximately $50 million USD.

Model Sensitivity Analysis

In order to test the accuracy of the model, a sensitivity analysis was performed in order to understand how sensitive the fishing model was to the biomass effects on the cost of catching fish. Figures 32 and 33 show the effects of different artisanal and industrial catchability parameters (see A_a and A_i) on their respective profits under varying levels of target escapement. As expected from our initial results, we identify that variations of +/- 25% do not affect significantly the qualitative results of the model. While different catchability coefficients have a quantitative effect on the outputs, the qualitative pattern remains unchanged. Therefore, one would expect to see the same trends with a variety of different catchability parameters for both fleets. An increase in the target escapement typically results in greater profits for the industry, although the magnitude of increase depends on the catchability parameter (Appendix C).

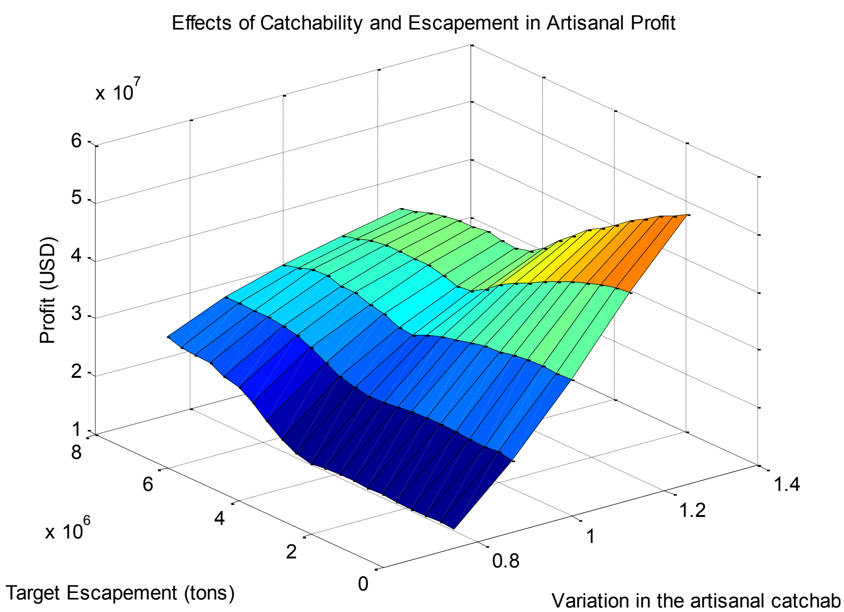

Figure 32: Effects of catchability and escapement on artisanal profits. "Variation in the artisanal catchability" refers to different values for the artisanal fleet's catchability coefficient.

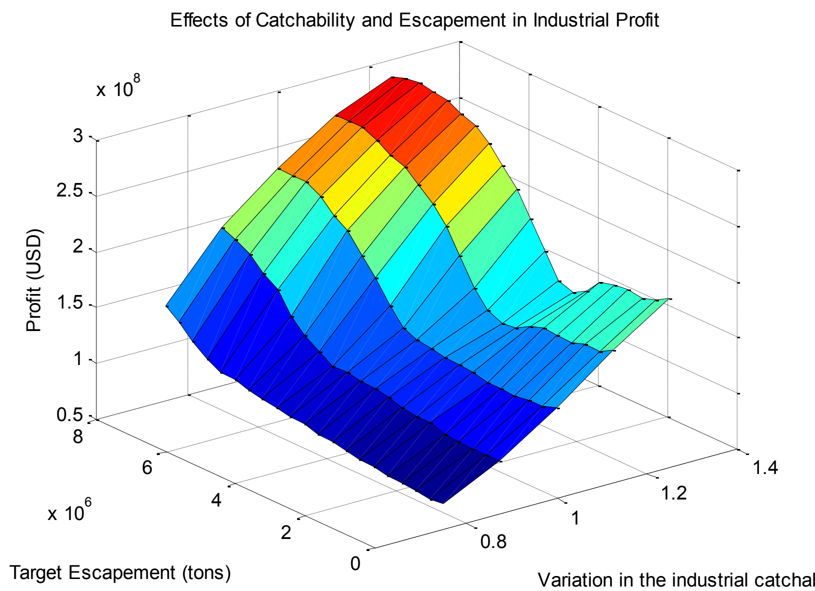

Figure 33: Effects of catchability and escapement on industrial profits. "Variation in the industrial catchability" refers to different values for the industrial fleet's catchability coefficient.

Discussion

Implications of Model Results on Current Regulatory System

The current management system for the artisanal and low scale fleets can threaten the health of the fishery due to the exclusion of both fleets from TAC allocations, lack of enforcement, and incentives for misreporting catches (Castillo & Mendo, 1987; CSA, 2009; Schreiber, 2011). The model suggests that the fishing potential of the DHC fleet is around 1 million MT each year, which is higher than what was originally assumed by the government. Since the new law does not stipulate a TAC for the DHC fleet, this potentially significant fishing pressure may put the stock at risk, especially during years with extreme ENSO events. This risk is exacerbated if artisanal boats fish for fishmeal since their fishing potential is twice as high as their potential under DHC conditions due to two effects: the price difference encourages fishermen to fish more and vessels have extra capacity when not using ice for preservation. Since the new law keeps the same incentives in place to fish for fishmeal, and provides ambiguous changes to enforcement, it can be assumed that an important proportion of the DHC fleet will in fact still fish illegally for fishmeal. Furthermore, this impact could be underrated if the number of boats with fishing permits for anchoveta is higher than the one consigned in PRODUCES database and used in our analysis.

From an economic perspective, it would make sense for fishery managers to set a national TAC that maximizes the value of the fishery. If this was the case, managers should set the allowable harvest level to result in the maximum economic yield (MEY) rather than the maximum sustainable yield (MSY). Fisheries economics suggest that the point at which harvest levels reach MEY is usually at a lower harvest level than MSY. The results from our model are consistent with this economic theory and show that if a higher target escapement is set (or more anchoveta is left in the water) the economic value of the fishery can be increased as fishers become more efficient with higher biomass levels. Furthermore, the biological benefits to the whole system through the ecosystem services that a higher biomass of anchoveta could provide are not being included or quantified in the analysis, which would likely increase the overall social value of the fishery. A higher biomass level will also make the anchoveta stock, and the whole Humboldt Current ecosystem, more resilient to environmental variability such as El Niño events, reducing the risk of huge economic shocks associated with depleted fish stocks.

Currently, lower escapement as a result of unaccounted artisanal fishing pressure reduces CPUE and increases costs to all fleets in the fishery. The new legislation, however, does not restrict artisanal and LS harvest, which is a shortcoming within the law. Most importantly, the model shows that given the current management status, the ability of IMARPE and PRODUCE to set a national TAC that sets the harvest level at a sustainable yield is compromised by not knowing how much anchoveta the artisanal and low scale fleets are actually harvesting. Allocating a specific TAC to these fleets could provide biological, economic, and social benefits to the fishery as long as it is effectively enforced (Aguilar et al. 2000).

The model shows potential benefits to both profits and biomass as a result of increased escapement. Our model results indicate that fishery managers have space to increase the overall value of the fishery, or to manage for the maximum economic yield (MEY). The distribution of these profits through specific TAC allocations for each fleet could help the government achieve social goals related to increased welfare in coastal communities. Even though we analyze quota allocations ranging from 0 to 100 percent for the DHC fleet, we would not advise proving them a quota allocation higher than 10% due to their relatively small representation of anchoveta fishing capacity within the fishery. We acknowledge that this type of distribution is subject to protest and pressure from all groups and stakeholders involved in the fishery. Although, as our results suggest (Figure 28) there is a wide frontier of potential results that could result in higher profits for artisanal, LS, and industrial fishers, which could be translated in a win-win-win solution. Allocating a specific TAC to these fleets could provide biological, economic, and social benefits to the fishery as long as it is effectively enforced (Aguilar et al. 2000).

Although the results of our model suggest allocating the DHC fleet a proportion of the national TAC could result in economic and biological benefits, it is important to recognize that management regimes with a TAC do not fully account for inefficiencies in the fishery, and often result in a race to fish. This type of fishing behavior was observed in the industrial anchoveta sector prior to the implementation of the Individual Vessel Quota (IVQ). A race to fish generates inefficiencies such as over capitalization of processing facilities. It also leads to a decrease in the price of the fish due to an increase supply in short periods of time for a limited demand. In places where a race to fish has being generated as a respond to TAC allocations, individual quotas (IQ's) that divide TACs and give fishers property rights over the resource have provided substantial economic gains and some sustainability benefits.

Due to lack of detailed data and information regarding current individual vessel harvest levels and cost structures within the DHC fleet, we were unable to develop a quantitative analysis investigating the implications that an individual quota system could have within the artisanal and low scale fleets. Through a qualitative approach we can suggest that an Individual Quota (IQ) system, whether it is transferable or not, may further increase the profits of the artisanal and LS sectors due to an increase in efficiency as seen in the industrial sector and other IQ fisheries worldwide. There are three main benefits that could arise from the implementation of such systems: 1) prevent the race to fish within the artisanal and LS fleets that usually occurs once a TAC is allocated and the negative effects it might have on the industries, 2) provide incentives for self-enforcement and stewardship over the resource, and 3) higher profits to the DHC fleet based upon evidence in other settings where the cost of catching a fish declines and the prices increase. However, IQ systems are not perfect and commonly generate social distress among the different groups. Due to the social importance of the artisanal and LS fleets for coastal communities, the system should be designed to limit consolidation of shares.

Implications of the DHC Mandate

Both qualitative and quantitative analyses suggest that the DHC mandate creates incentives for illegal activity and inefficiencies in the fishery. Under the law, the DHC fleet should direct all harvest to the direct human consumption processing sector for substantially lower prices than what the resource is worth in the fishmeal processing market. In addition, in order to maintain a high quality of raw material, they are required to fill half of their boats with ice and use boxes for proper storage. A comparison between the potential profits under artisanal DHC and fishmeal market conditions reveal that this mandate, if complied with, reduces the overall economic value of the fishery. Importantly, the substantial reductions in fishery profits are entirely borne by the artisanal sector.

Due to the associated costs (actual and opportunity) of complying with the mandate, the price incentives to sell anchoveta illegally to fishmeal processing facilities, and the lack of enforcement within the sector, artisanal and LS fishermen often do not follow the regulation. Again, using the model results to compare the potential artisanal and LS profits under DHC and fishmeal market conditions, it is clear that there is a considerable economic incentive to misdirect catches to the fishmeal sector. In the modeled status quo scenarios representing artisanal restricted open access, the DHC fleet's profits are more than doubled if they participate in the fishmeal market. In addition, while the DHC processing facilities have a limited demand for raw material, the demand from residual fishmeal processing plants is constant. These differences in demand result from their relative processing capacities and external market forces: DHC processing plants have limited processing capacity, requiring only a fraction of the raw material that the DHC fleet harvests, and while demand for anchoveta food products is limited, fishmeal has remained in high demand. Processing capacity in the residual fishmeal sector continues to grow, as legislation requires canning plants to build residual fishmeal plants to process their discards, which creates further incentive for misdirection of landings and underreporting of catches. Finally, due to a poor decentralization process between the national and regional governments and a lack of political will to regulate the DHC fishery, their activities are largely unmonitored and unregulated, allowing for continued increases in fleet size and illegal activity within the sector. Fishing pressure is exacerbated by the continued distribution of new fishing permits in the sector by regional governments, despite the fact that the fishery is legally closed to new entrants.

The DHC mandate creates a situation in which the biomass is increasingly threatened by unregulated and unreported fishing activity, and the actual contribution of raw material to achieving the mandate's goals of lowering malnutrition rates and creating jobs is uncertain. Because there is constant demand for raw material from the fishmeal processing facilities, artisanal and LS fishermen have the incentive to fish as much as possible for this market in order to maximize profits. Perhaps the greatest risk to the biomass, however, is the fact that the artisanal sector is not restricted by any catch limits. Theoretically, the restricted demand from the processing sector would limit the amount of anchoveta that the artisanal fleet would be able to sell, but again, in practice, this does not happen for the reasons discussed previously. The lack of harvesting limits, sufficient effort restrictions, and efficient enforcement combined with the residual fishmeal sector's steady demand for illegally supplied raw material, allow for an unimpeded fishing pressure that can significantly impact the biomass.

It remains unclear if the DHC mandate, as written, can accomplish its goals of lowering domestic malnutrition rates and providing increased opportunities for employment. First, when artisanal harvest is misdirected into the illegal fishmeal market, fewer fish are processed into food products. This, in turn, could reduce the amount of products produced for the domestic DHC market. In addition, there are a number of barriers to increasing domestic direct human consumption of anchoveta that are external to the fishery, and it is also unclear how increased domestic DHC of anchoveta products would affect malnutrition levels. Finally, because the government's food program PRONA, which distributed anchoveta products to low-income groups, has been discontinued and replaced by Qali Warma, it seems that the government will no longer be providing anchoveta products in bulk to these communities. The new program will take a more localized approach to meeting nutritional needs throughout the country, and it has been reported that the government will not be providing large supplied of products previously distributed, including anchoveta (*Ministerio de Desarrollo e Inclusión Social*).

Increasing Domestic Direct Human Consumption of Anchoveta Products

If the government maintains the goal of increasing domestic direct human consumption of anchoveta products, a number of barriers and loopholes to compliance with the current mandate should be addressed in order to ensure greater success. Changes within the fishery would be the first step to addressing these problems. Improved monitoring and enforcement within the sector is essential to establishing higher compliance rates with any law. In addition, the various incentives associated with loopholes in the mandate, such as the incentive to purposefully let fish degrade so that they can be sold to the fishmeal processing sector, should be addressed with clearer regulation and increased enforcement. Landing facilities should be updated to provide the necessities for DHC fishing. An infrastructural problem within the fishery that might prove to be more difficult to address is the absence of DHC processing facilities at particular ports. There is also an over issuance of fishery permits in some regions that do not have the corresponding DHC processing capacity. Regardless of regulation, this discrepancy should be addressed, as it is nearly impossible to redirect and transport catches to regions that do have DHC processing facilities. Also, the incentives within the fishery should encourage the sale of anchoveta products into the DHC processing sector. One solution is to allow the artisanal sector to participate in both the DHC and fishmeal processing markets and provide incentives to direct catches to the DHC processing plants. This, as discussed previously, might be achieved by applying a landing tax in the fishery.

In addition, the barriers external to the fishery discussed previously (see *Direct Human Consumption Mandate: Goals and Limitations*) would need to be addressed. Distribution to isolated regions would have to be improved. With the discontinuation of the PRONA program, it seems that the government will no longer be aiding in the distribution of this product, further complicating this issue. Importantly, domestic demand would have to increase. This might be accomplished through education programs, marketing programs, and reduced prices.

Maintaining DHC Processing Sector to Increase Employment Opportunities

In order to achieve its goal of increasing employment opportunities within the DHC processing sector, the government should again ensure that a certain amount of raw material be directed to this sector. This would involve addressing the same barriers and loopholes in the fishery discussed above. Additionally, changes within the DHC processing sector might increase the price that these facilities are able to pay for raw material, increasing the amount of fish that is directed to this sector. An example of such an internal change could be decreasing the cost of processing. This might be accomplished by upgrading to more efficient technologies or decreasing the price, or eliminating the need, for aluminum cans, which can account for up to 50% of production costs. Increased international demand for anchovy products could also increase the amount of fish demanded by the processing sector, creating more jobs. One way of accomplishing these changes is by implementing a government subsidy to pay for them (see *Fishery Tax*). Also, if prices in the international market increase, the amount that the processing sector is willing to pay for raw material could also increase. A sustainable labeling certification, such as the Marine Stewardship Certification, could drive this kind of price increase as well.

Assumptions

To reflect the real motivations of individuals in a restricted open access scenario, and to replicate the profit motive of most business entities, the model's primary assumption was that fishermen always behaved in a manner that maximized their profit. One hundred percent of compliance with either fishmeal or DHC mandates was considered, thus no illegality is shown by the model. The model does not assess spatial distribution of the fleets, and it is assumed that both fleets are effectively interacting over the same geographic distribution. Model parameters were drawn from published, peer-reviewed sources and interviews of professionals in the field of fisheries management. Although the cost structures for artisanal and industrial boats varied between fleets, consistency was maintained within fleets, and prices were adjusted to current levels. The bio-economic model was developed using biological and economic parameters for the north-central stock of anchoveta. The southern stock was not considered in the modeling exercise because it was outside the scope of this study. Our recruit stream input, the basis for the biological model, was calculated from a published source with its mean and standard deviation specifically stipulated. Fished stock from older age classes did not reduce recruitment in subsequent seasons. Rather, recruitment numbers were drawn stochastically within a realistic range, and harvesting of adult populations subtracted fish from future age classes already within the model. We did not include a stock recruitment relationship in the biological model because published sources verifying the relationship between recruitment and stock size are lacking. If a stock effect actually occurs, the benefits of enhancing escapement could be larger than those predicted by the benefits of lower costs alone. After running the model, a sensitivity analysis was performed to evaluate the response of the model to changes in the technological (catchability) parameter "A", finding the model has low sensitivity to it.

Caveats and Challenges

The problem explored by this study is particularly complex, and therefore, as with any research project, there was a diverse set of caveats and challenges to the completion of this project. In most cases these complications, whether related to quantitative data or government policy, did not prevent obtaining answers to the study's most important questions. Frequent changes in the regulations of the artisanal and low-scale fleets occurred during the course of this study, which made policy analysis difficult due to the shifting baseline of regulatory frameworks of the fishery. Often, the policies themselves were ambiguous in terms of language, allowing for potential misinterpretation of laws. Quantitative data characterizing the artisanal and low-scale fleets were often incomplete and limited: landings statistics from IMARPE were inconsistent, and PRODUCE's fleet database recording vessel size, permit status and other specifications, was not updated. Limited access was given to information pertaining to the Peruvian Artisanal Fishermen Census, and the information available is poor and not adequately explained.

Conclusions

The potential fishing impact of the DHC fleet on the anchoveta biomass is considerably higher than expected. This impact could be even higher if there actually more permitted LS vessels than what is presented by the PRODUCE database.

Current legislation does not adequately address fishing pressure from DHC fleets, which may be unsustainable for the stock. The price incentives that drive the DHC fleet to illegally divert landings to fishmeal production still exist under the revised law (DS-005). In addition, the DHC vessels still have full access to anchoveta spawning areas at all times, which can interfere with spawning and recruitment and therefore threaten the sustainability of the biomass.

The current legislation remains unclear regarding enforcement of the LS fleet´s landings and the manipulation of the catch by DHC and residual plants.

The qualitative and quantitative analyses completed for this study suggest that the DHC mandate generates many problematic incentives for illegal activity and inefficiencies within the fishery. The mandate not only reduces the economic value of the entire fishery, but also creates conditions where the reductions in the fishery's profits are borne exclusively by the DHC fleets.

The unregulated harvest level of the artisanal and LS fleets can affect the profitability of the industrial fleet and fishmeal industry. There should be interest from the industrial sector to push for allocating a TAC to both fleets.

While both the industrial and DHC fleets can experience increased profitability when the DHC fleet is subjected to a TAC, significant differences in biomass levels and economic outputs were only found in situations in which the amount of fish left in the water (effectively escapement) was increased. These benefits could be obtained with a policy that increases target escapement, decreases the overall TAC, and reasonably allocates TAC between the two fleets. Depending on the biological, economic, and social goals, the TAC can be allocated to the fleet in varying proportions, all of which represent improvement from the status quo.

DHC production (with the exception of the cured anchovy plants) is significantly inefficient in economic terms because of high production costs, as well as low domestic demand and low international prices compared to fishmeal.

High levels of informality, poor and unavailable data, and ambiguous responsibilities of the national and regional governments over both artisanal and LS fleets makes the implementation (and even the analysis) of an individual quota system extremely complicated. However, evidence from other fisheries where individual quotas have been successfully implemented show a number of benefits including reducing or even eliminating the "race to fish," and providing an incentive for the fishers to conserve the natural resource. Furthermore, our estimates of the economic and biological benefits of management reforms are conservative and could potentially be increased further by implementing an individual quota system on the artisanal fleet. However, this individual quota management option warrants further study to assess the case-specific biological and economic benefits and costs.

Recommendations

The following are recommendations based on the modeling and conceptual analyses:

1. A national TAC for the northern stock of the anchoveta fishery that includes the industrial, low-scale, and artisanal fleets should be implemented. The TAC allocation among the

different fleets should be consistent with the national government's interests in terms of how much of the added benefits each fleet should receive. A policy favoring the DHC fleet would allocate a larger percentage of the overall TAC to this fleet.

2. The government should determine the ability of the DHC mandate to accomplish social goals. The mandate should be removed or altered to address the associated problems and inefficiencies that preclude its successful implementation.
3. If the interest from the government is to still promote DHC:
    a. New incentives and market tools such as landing taxes, subsidies for aluminum (cans) imports or improved technologies should be incorporated in order to reduce the economic and infrastructural barriers and to promote investments in more efficient processing technologies.
    b. TACs allocated for the LS and artisanal fleets should be consistent with the DHC processing capacity and the objectives of increasing DHC and jobs through the production of more DHC products.
4. The DS-005-2012 should be revised to address the following points:
    a. Technical information supporting the creation of the new reserve zone for the DHC fleet (5-10 nm)
    b. Include seasonal closures (vedas) during spawning periods (summer and spring) for the LS fleet.
    c. Incorporate SISESAT system to the LS fleet and clarify how this system will be financed.
    d. Incorporate the LS and artisanal fleets, and all DHC and residual plants to the anchoveta enforcement and control program.
    e. The enforcement program should not only monitor the raw material when it is landed at ports and received by processing facilities, but should also track the final products in order to ensure that the material is not illegally supplied to residual fishmeal plants.
    f. Clarify if DHC plants are allowed to derive up to 40% of their raw material received from LS boats into fishmeal.
5. TNC should leverage interest from the fishmeal industry to support a TAC allocation process for the artisanal and LS fleets, as economic gains for the whole anchoveta fishery can be generated if this happens

Future Work

The following are suggestions for future work:

- Perform a similar analysis with the following changes:
    - Use detailed and unique cost structures for the artisanal and LS vessels
    - Incorporate a spatial analysis that incorporates the potential impacts of the artisanal and LS fleets on the extended direct human consumption reserve zone (0 to 10 nm)

- Conduct a quantitative analysis of an IQ system for the artisanal and LS fleets by creating a model to simulate potential trading activity. This study requires detailed information on the cost structures of different sized vessels
- Explore how the new fishery regulations might affect the processing sectors of the anchoveta industry
- Evaluate the dynamics of the anchoveta black market for fishmeal by comparing the amount of DHC products produced and the reported landings, the production of residual fishmeal, and the internal and external commercialization of these products
- Explore the feasibility of using compensation or incentive programs to influence the price of raw material directed to the DHC processing sector in such a way that it is competitive with prices for the fishmeal market

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Appendices

Appendix A: Table of interviewees

Name	Date	Organization	Location	Subject	Interviewers
Sueiro, J.	2012, 25 June	The Nature Conservancy	Lima, Peru	Industrial fleet, IVQs, data consistency	J. Fuller, S. Thornton, T. Mangin
Galarza, E., Ghersi, F.	2012, 25 June	Universidad Pacifico	Lima, Peru	DHC, perverse incentives	J. Fuller, S. Thornton, Y., T. Mangin
Echevarria, P.	2012, 27 June	Compania Americana de Conservas	Pisco, Peru	DHC, MSC certification, DHC Cost structures	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
Balistreri, G.	2012, 28 June	Anchoveta S.A.C.	Chinca, Peru	Enforcement, Regional governments, domestic DHC markets	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
Urban, R.	2012, 9 July	CERPER	Lima, Peru	Labor issues, landing process, policy enforcement	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
Sarmiento, F. S.	2012, 10 July	Peruvian Congress	Plaza Simón Bolívar, Lima Central	Artisanal fleet, policy alternatives, fish processing	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
Infante, A. C.	2012, 11 July	Pesquera Jada S.A. (Grupo Cavenago)	Chimbote, Peru	History of fishery, environmental improvements, production costs, markets, loopholes	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
HAYDUK Corporacion	2012, 12 July	Tour of industrial fishmeal and canning facility	Chimbote, Peru	Labor practices, sanitation, international markets	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
Rubio, Dr., Cervantes, Ing.	2012, 12 July	IMARPE	Chimbote, Peru	Processing and fleet capacity, black	M. Caillaux, J. Fuller, Y. Kirschner, T.

				markets, ecological effects, management options	Mangin, S. Thornton
Sanchez, C. A.	2012, 13 July	Pesqueria Hillary	Chimbote, Peru	Domestic markets for DHC, industrial IVQ,, price/cost structures for FM and DHC	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton
Majluf, Patricia, & Sueiro, Juan Carlos.	2012, 31 July	Centro para la Sostenibilidad Ambiental (CSA)	Lima, Peru	Ecological and social factors, DHC, markets, biomass health	J. Fuller, S. Thornton, Y. Kirschner, & T. Mangin
Galarza, E., Ghersi, F.	2012, 6 September	The Nature Conservancy	Lima, Peru	Research approach, MSC certification, catch shares, price fluctuations	M. Caillaux, J. Fuller, Y. Kirschner, T. Mangin, S. Thornton

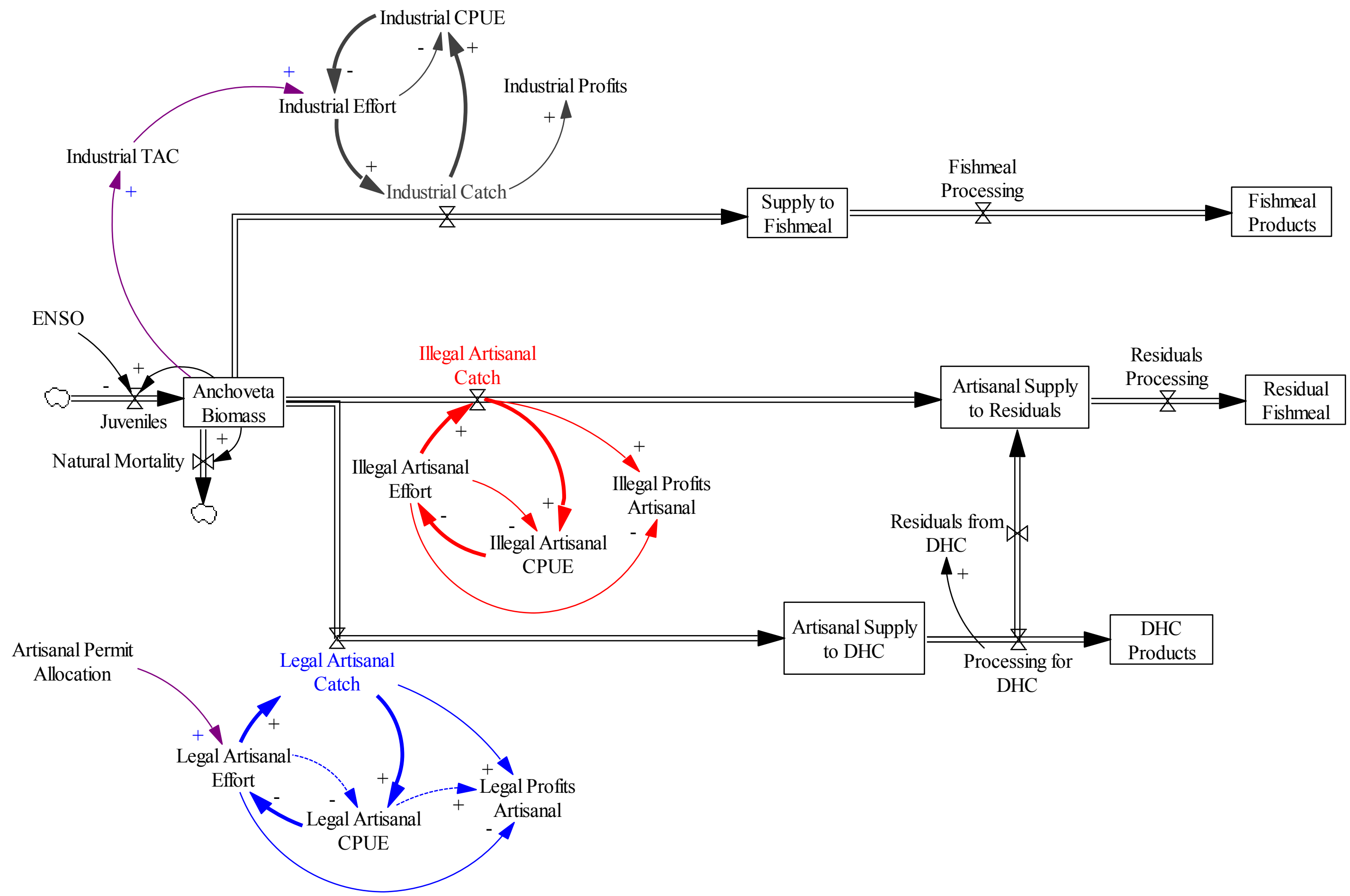

Figure 34: Systems thinking model of the anchoveta fishery. This model shows how environmental factors and fishing pressures affect the anchoveta biomass. In addition, it begins to incorporate market forces. The fishmeal and DHC processing sectors are represented on the right side of the model.

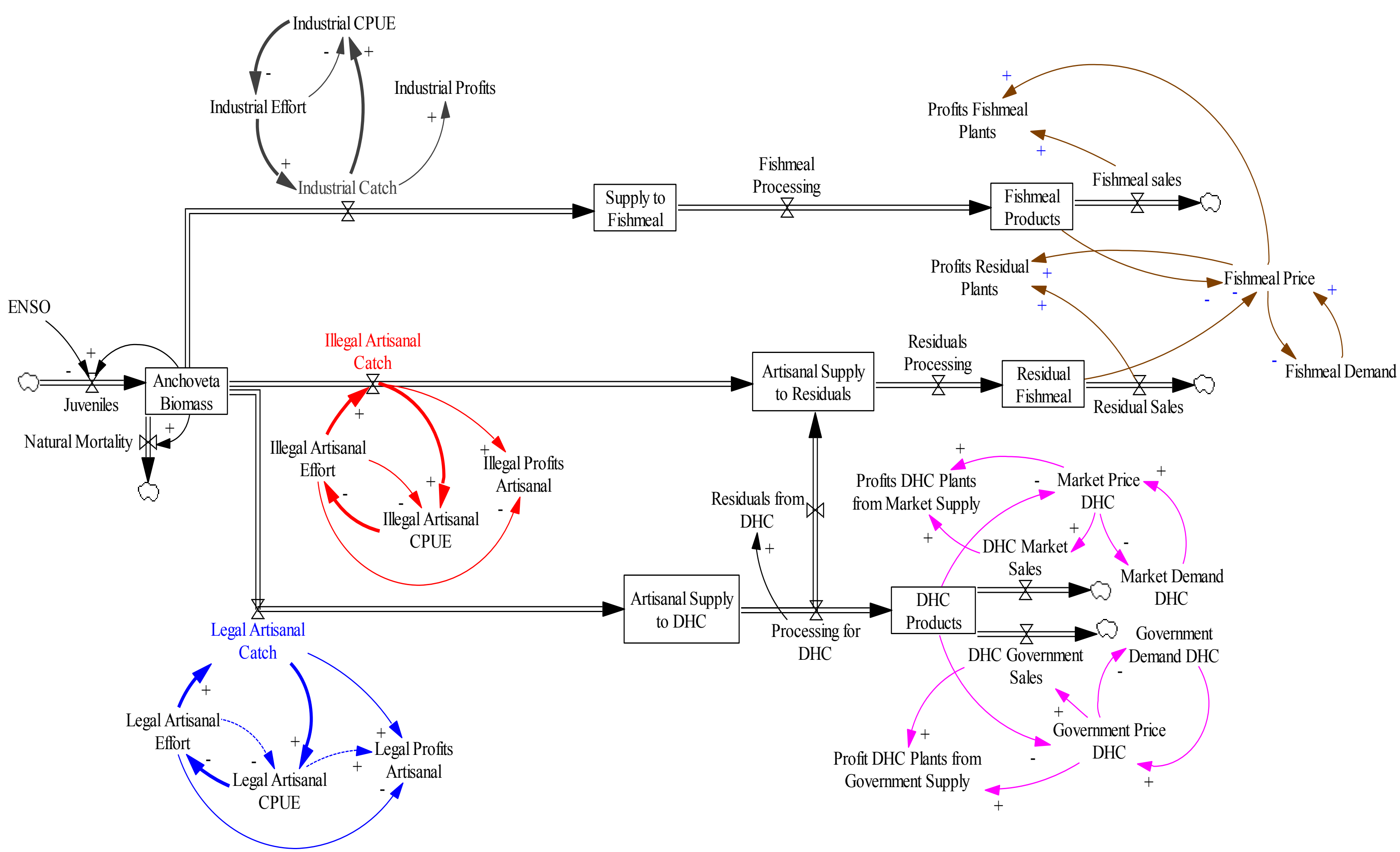

Figure 35: Expansion of Figure 34. This model expands on the market forces that affect the fishmeal and DHC processing sectors. Until recently, the government's social program PRONA provided anchoveta food products people who lacked access to affordable and nutritious protein products. The pink arrows represent this artificial market.

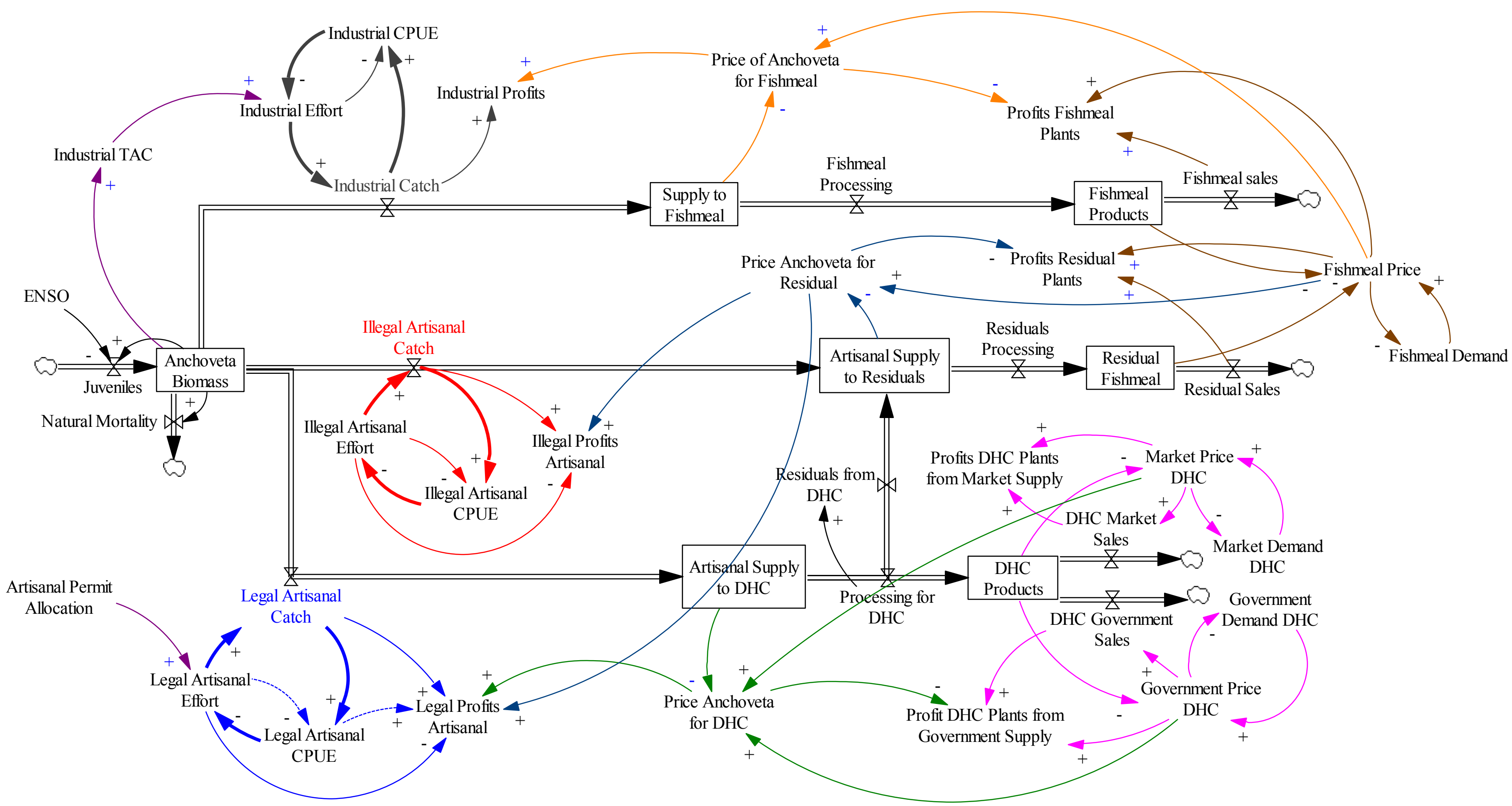

Figure 36: Expansion of Figure 35. This model connects the external market forces back to Peru's fishmeal and DHC processing sectors.

Appendix C: Effects of Catchability Coefficient

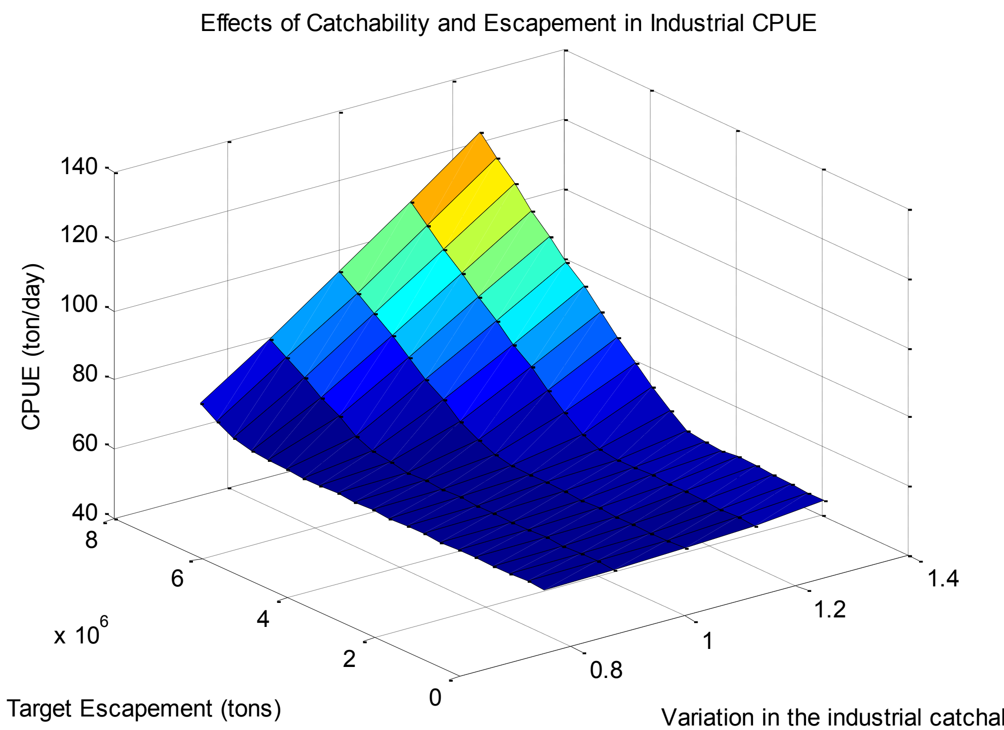

Figure 37: Effects of catchability and escapement on industrial CPUE

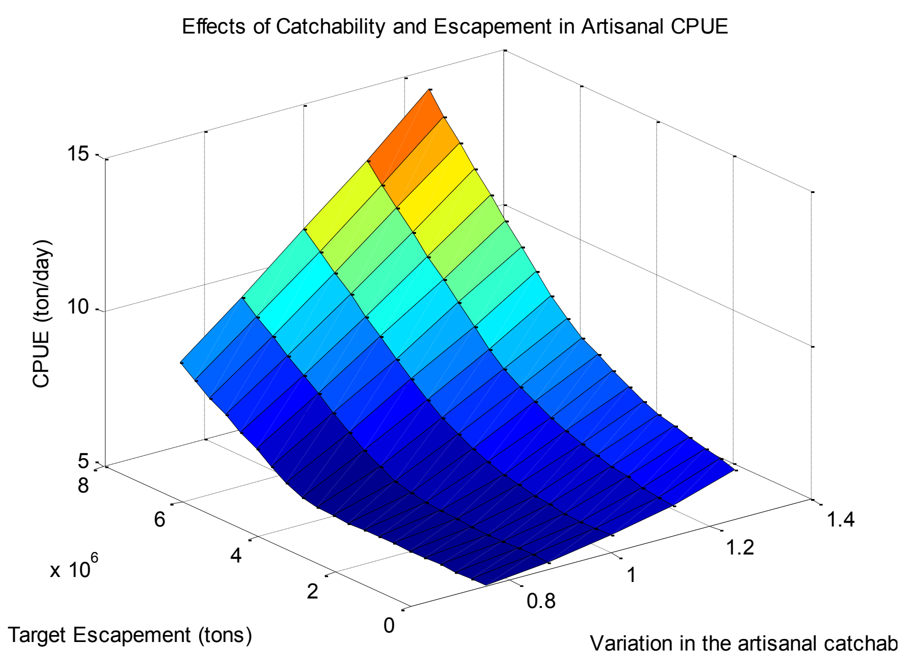

Figure 38: Effects of catchability and escapement in artisanal CPUE

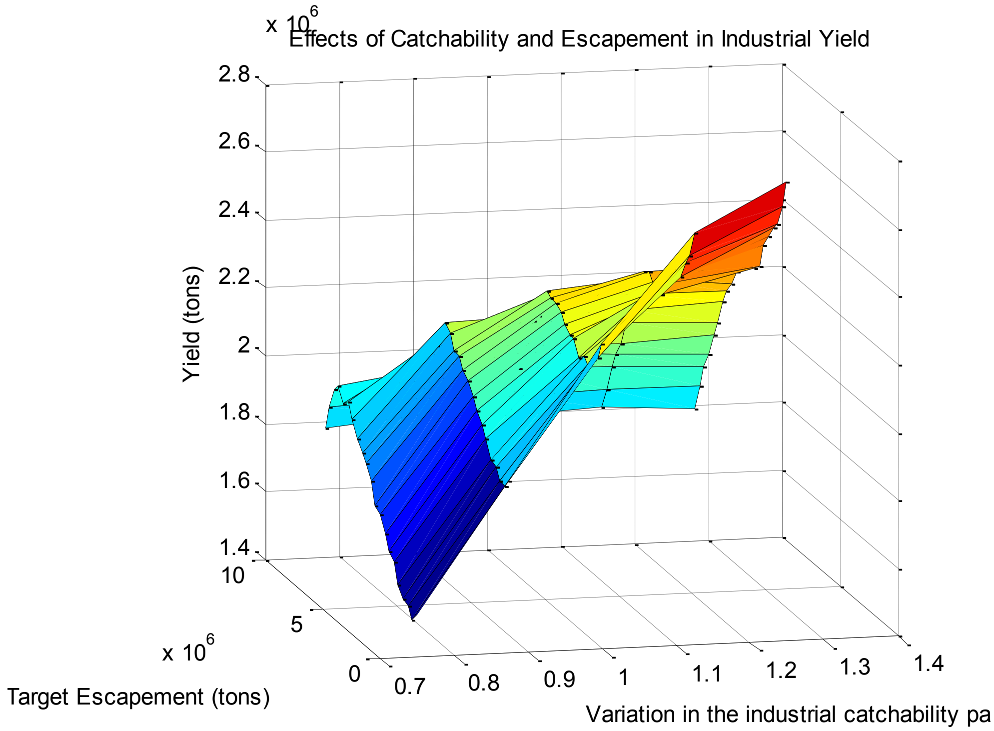

Figure 39: Effects of catchability and Escapement on industrial yield

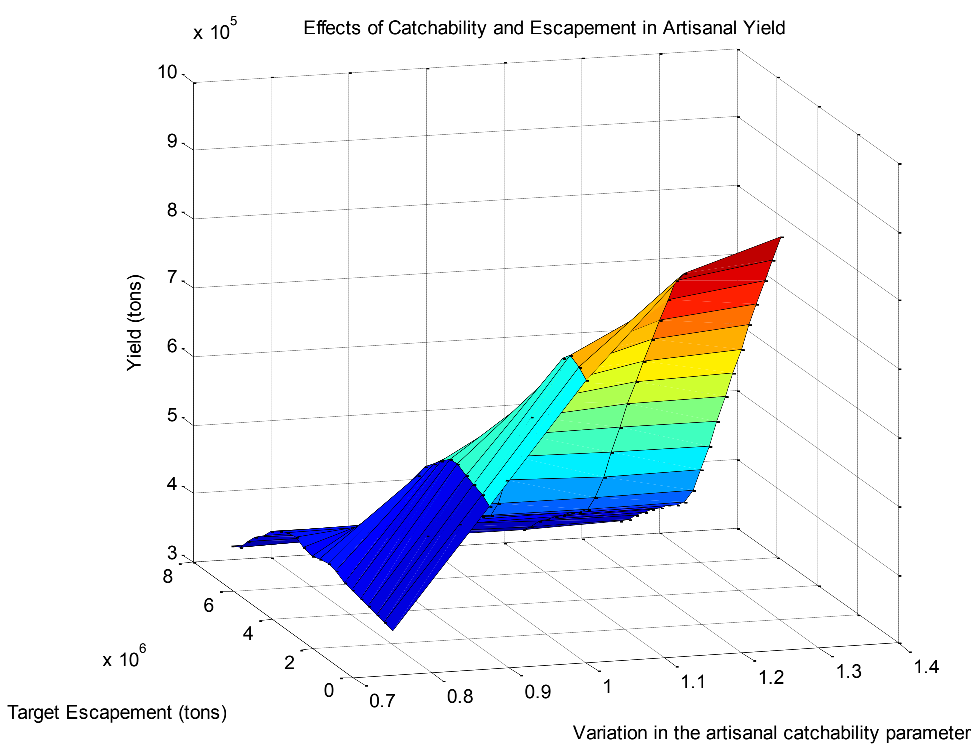

Figure 40: Effects of catchability and escapement in artisanal and yield