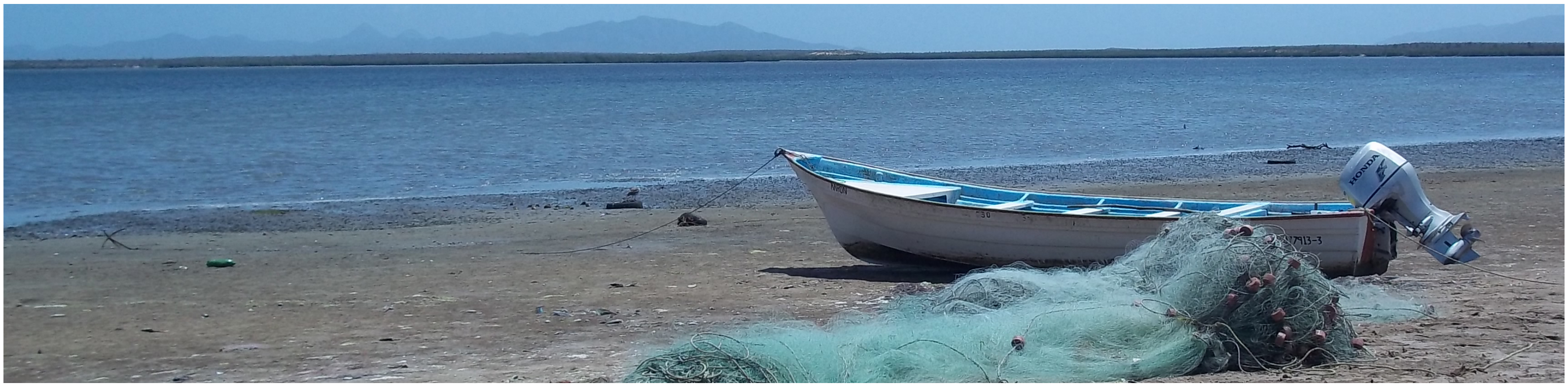

Evaluating the Production of Fish Meal Substitutes from Artisanal Fishery Byproducts in Baja California Sur, Mexico

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

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BREN SCHOOL OF
ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA SANTA BARBARA

OLAZUL
Innovation for Marine Conservation

Evaluating the Economic Viability, Ecological Implications, and Socioeconomic Impacts of Fish meal Substitutes in Baja California Sur (B.C.S.) Mexico

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project 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 Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Abstract

Aquaculture is increasing globally to meet growing demand for animal protein. The majority of aquaculture farms use feed made with fish meal, a protein-rich fish powder that requires high inputs of wild-caught reduction fish like anchovies. However, the global catch of reduction fish has stabilized around 20-30 million tonnes per year. As a result, there is growing interest in producing fish meal from fishery byproducts, though this has occurred largely at the industrial scale. Since over 90% of fishermen fish at the artisanal scale, the byproducts from these fisheries represent an untapped resource that could provide additional economic opportunities for small fishing communities. We conducted an economic analysis in Baja California Sur, Mexico as a first step in assessing the feasibility of producing fish meal substitutes from byproducts in artisanal fishing communities. We find that waste material is highly variable and has declined in recent years from over 20,000 tonnes to less than 5,000 tonnes annually. Furthermore, we reveal that processing practices are changing and byproducts now represent less than 10% by weight of several important species groups. Our feasibility analysis identified 27 locations where the production of fish meal substitutes could be consistently viable. However, low quantities of waste appear to limit economic benefits and significant negative ecological ramifications are possible. Therefore, we recommend that the production of fish meal substitutes from fishery byproducts in Baja California Sur should be considered on a location by location basis and only if ecological implications are well understood and properly managed.

Table of Contents

List of Figures

List of Tables

Executive Summary

Background

With the human population recently reaching 7 billion people and still growing, there has been a significant increase in the demand for animal protein sources. This spike in demand, coupled with unsustainable fishing practices and poor regulation, has had serious negative implications for the health of wild capture fisheries around the globe. In developing nations, this exacerbates issues of poverty in coastal communities that are dependent on marine resources for food and employment (FAO, 2012). In response to the limited supply of wild fish, aquaculture production has grown dramatically since the 1980s. However, it has become apparent that future aquaculture expansion will largely depend on the availability of feed ingredients, including fish meal.

Fish meal is a dried powder traditionally produced from wild harvests of small pelagic species known as reduction fisheries. However, the global supply of reduction fish has stabilized and, coupled with the growing demand from aquaculture, fish meal prices have increased dramatically. In response, feed producers are developing novel alternatives to fish meal, with the production of fish meal from fish byproducts becoming a particularly attractive option. Currently, this production primarily occurs on the industrial scale and fish byproducts from artisanal fisheries remain largely underutilized.

Project Objectives

The goal of this project was to evaluate the production of fish meal substitutes from artisanal fishery byproducts as a means to create sustainable economic opportunities in coastal communities. Specifically, this project sought to:

1. Investigate the quantity, composition, and spatial distribution of artisanal fishery byproducts in Baja California Sur (B.C.S.), Mexico.
2. Evaluate the economic feasibility of producing fish meal substitutes from artisanal fishery byproducts in B.C.S.
3. Examine the important socioeconomic factors to be considered in the implementation of a fish meal substitute program.

Study Site

In Mexico, the FAO defines artisanal fisheries as those using small boats (~6-10 m), known locally as *pangas*, operating close to shore with low capital investment, intensive labor, and limited capacity. Baja California Sur (B.C.S.) is the southernmost state of western Mexico's Baja California Peninsula and accounts for nearly 11% of national landings per year (Bizarro et al. 2009). There are over 11,000 artisanal fishermen in B.C.S. who collectively account for 95% of all reported landings in the state. These fishermen are predominantly located in small fishing communities characterized by low to moderate infrastructure, often without electricity, refrigeration, running water, and access to education (Salas et al., 2011). As a result of increasing effort and poor management, artisanal fishing communities in B.C.S. are now dependent on threatened stocks and in serious need of additional economic opportunities.

Methods and Results

Objective 1: Waste Supply

To examine the supply of artisanal fishery waste in B.C.S., eight years of artisanal-specific landings data were obtained from the Mexican aquaculture and fisheries commission (Comisión Nacional de Aquacultura y Pesca, CONAPESCA). The data we received contained artisanal-level catch data from port communities in B.C.S. from 2005 to 2012. Catch is recorded at the species level and includes monthly live weight, landed weight and monetary value. From this information we calculated waste for each entry as the difference in the recorded live and landed weight. Finally, we obtained coordinate data for each location from several government and academic sources.

The final data set contains 72,625 individual entries from 378 locations during the eight-year period from 2005 to 2012. Total landings were above 70,000 tonnes from 2005 to 2007, when they peaked at 78,116. However, since 2007 landings have not exceeded 60,000 tonnes except for in 2010 when they reached 72,375. There was also a strong seasonal trend observed for landings and waste; reported catches peak at an average of approximately 10,000 tonnes in June and July before dropping to just above 2,000 tonnes from December to February. High quantities of landings were observed in Magdalena Bay, Santa Rosalía, Bahia Asuncion, and Guerrero Negro; this coincides with large amounts of waste, particularly for Santa Rosalía. Though the majority of ports reported fewer than five species in a given month, several locations consistently landed between 20-32 different species.

A dramatic decline in waste was observed in the data series. From 2005 to 2007, between 20,000 and 25,000 tonnes of waste were produced, representing approximately one third of the recorded live weight in each year. Since 2010, however, waste has dropped below 7,000 tonnes and was only 3,484 tonnes in 2012. This decline was primarily the result of low landings from the squid fishery and the more complete utilization of squid, sharks, and rays for human consumption.

Objective 2: Economic Feasibility Analysis

To determine the economic feasibility of fishery waste utilization in artisanal fishing communities in B.C.S., we developed an analytical framework to identify where the production of fish meal substitutes could be profitable. This model first values fishery waste based on its nutritional profile, subtracts costs associated with processing the waste into a sellable product, and determines how far the product can be transported before becoming cost-prohibitive. These distances are compared to the distance to Promotora Industrial Acuasistemas S.A. de C.V. (PIASA), an aquafeed producer in B.C.S., to identify the ports where production is feasible each month. Finally, the model examines the consistency of supply at each port and identifies ports which were feasible suppliers for at least 50% of the study period.

Variable and fixed per-unit costs of production were calculated for two methods of processing artisanal fishery byproducts: fermented fish silage and artisanal fish meal. These products were valued using the price of fish meal, scaled for protein content, as a proxy. This valuation considers both the global commodity price and that paid by PIASA, which is traditionally double the commodity price. Additionally, as some consumers may consider these products to be imperfect substitutes for fish meal, soybean meal is also used as a price proxy.

Six scenarios combining the different production methods and proxy values were evaluated in the model for 209 ports in B.C.S. Due to the low price, production of silage and artisanal fish meal were never feasible if valued by consumers as a substitute for soybean meal. In feeds for livestock, where demand for fish meal is elastic, the additional nutritional benefits of marine-derived protein may warrant a certain degree of inclusion. Of the 143 ports for which we were able to calculate transportation distance, 118 ports could transport products in at least one of the four scenarios. However, from these 118 ports, only 27 could produce and transport products for at least 50% of the study period. Due to higher average protein content and lower transportation costs, production of artisanal fish meal was consistently feasible at more locations than silage (27 and 17 respectively). Notably, artisanal fish meal production was also feasible at several major squid ports, resulting in a far greater amount of waste available for production (81,426 tonnes and 5,050 tonnes respectively).

Objective 3: Socioeconomic Considerations

In addition to the consistent availability of fishery waste, there are important socioeconomic factors that must be considered before implementing a fish meal substitute program. We identified four major categories: economic need, social capital, community structure, and local demand. Because economic opportunities are often limited in B.C.S., the level of unemployment in a fishing community, particularly for women, can indicate the availability of labor. Furthermore, the strength of institutions, relationships, and societal norms in a community will shape the ability of that community to work together. Similarly, the current organization of the fishing community, such as being a cooperative or an aggregation of independent fishermen, has implications for the ability to aggregate and process waste. Finally, the potential value of producing fish meal substitutes should be compared with any existing uses of fishery waste, such as for bait. Taken together, these characteristics can indicate a community's willingness to participate, level of collective effort, effectiveness of production, and potential economic benefit.

Ecological Implications

Two important concerns of any program that creates value from previously undesirable fishery products is whether such a program will incentivize bycatch or increase effort on exploited stocks. For artisanal fisheries, where there is low diversity and selectivity of fishing methods, catches can contain a considerable number of non-target species (FAO, 2011). In B.C.S., the ecological damage of these fishing practices has been acute. A fish meal substitute program that increases the value of bycatch may further entrench the use of destructive and unsustainable fishing practices. Also, due to regulatory limitations, catches below the legal minimum size might be kept rather than returned to the ocean. Furthermore, it will be difficult to monitor which species are included in production, potentially leading protected species and closed fisheries to become more vulnerable to exploitation. These issues are of particular concern in B.C.S., where regulations exist but enforcement is extremely limited. Finally, it is possible that markets for fishery byproducts could have the undesirable effect of diverting marine protein away from direct human consumption.

Conclusion

The results of our analysis suggest that there are significant quantities of unused artisanal fishery waste in Baja California Sur, Mexico. The availability of waste is variable and has declined significantly through time. For those areas identified as feasible by this analysis, the implementation of a fish meal substitute program can bring employment and added value to the community's fisheries. While economic benefits could be significant, such a program has the potential to generate perverse incentives that increase bycatch, concentrate fishing effort, and divert fish away from direct human consumption. Therefore, the production of fish meal substitutes from fishery byproducts in Baja California Sur should be considered only on a location by location basis if the local ecological implications are well understood and can be properly managed.

Significance

Capture fisheries and aquaculture are crucial contributors to global food security, providing 3.0 billion people with almost 20 percent of their intake of animal protein (FAO, 2012) Fisheries also provide employment and income to a large percentage of the world's population. Artisanal fisheries, which are characterized by their small-scale and limited use of technology, employ more than 90 percent of the world's fishermen and play an important role in poverty alleviation in developing countries.

However, poor management of capture fisheries has led to overfishing in many coastal regions. Globally, annual catches of wild fish appear to have plateaued at 90 million tonnes while fishing effort is still increasing, often resulting in lower catches per unit effort. In developing nations, this exacerbates issues of poverty in coastal communities that are dependent on marine resources for food and employment (FAO, 2012). Additionally, the often isolated and remote locations of artisanal fishing communities limit the availability of economic opportunities outside of the fishing sector. Beyond the estimated 34 million people who work as artisanal fishers, 100 million people are involved in the small-scale post-harvest sector, performing jobs like processing and packaging. From these activities, fish byproducts—viscera, bones, heads, skins, and meat scraps—are produced.

These fish byproducts are rich in potentially valuable proteins, fats and minerals that have uses in aquaculture, agriculture, and livestock industries. Aquaculture, in particular, is a rapidly growing industry that has a significant demand for marine protein. The majority of aquaculture farms use feeds made from fish meal, a protein-rich fish powder that requires high inputs of wild-caught reduction fish like anchovies and sardines. However, the global supply of reduction fish has stabilized around 20-30 million tonnes per year, so in order to allow for the predicted expansion of aquaculture, novel alternatives to aquaculture's reliance on traditional fish meal need to be explored (Tacon, Hasan, & Metian, 2011).

Currently, about 25% of global fish meal production is made from fish byproducts (FAO 2012). However, this primarily occurs on the industrial scale, and fish byproducts from artisanal fisheries remain largely underutilized, sometimes even posing a significant waste disposal problem. There is considerable potential to gain more value from artisanal fishery waste, and possible uses include providing protein for livestock and aquaculture feeds and producing fertilizer for agriculture. These and other alternative uses for fish waste could generate significant revenue in fishing communities, but there are commercial and practical hurdles to be overcome before these options become viable. The local and regional conditions in artisanal fishing communities define which options for fish waste repurposing may be economically feasible and ecologically benign.

With more than 2,200 km (23%) of Mexico’s coastline and over 2,000 marine species, Baja California Sur (B.C.S.) is one of the richest fishing regions in Mexico. However, high fishing effort has resulted in the main small-scale fisheries of the Pacific region being fully exploited or exhausted (Salas, Chuenpagdee, Charles, & Seijo, 2011). Approximately 95 percent of fishing activities are conducted by artisanal fishers, who operate out of permanent or temporary fishing camps along the Pacific Ocean and the Gulf of California. As a result of ineffective fishery regulation and resource depletion, artisanal fishers in Mexico often have low average wages, and many fishing communities lack basic services and infrastructure, such as running water, electricity and education (Salas, Chuenpagdee, Charles, & Seijo, 2011). Utilization of fish byproducts in artisanal fishing communities in B.C.S. has the potential to create economic opportunities and add value to these fisheries, while providing aquaculture, agriculture, and livestock industries with a local source of protein and nutrients.

The client for this project, Olazul, is a 501(c)3 non-profit organization based in B.C.S., Mexico with the mission to develop innovative, sustainable economic opportunities in artisanal fishing communities. After identifying fishery waste as an untapped resource in B.C.S., Olazul spearheaded this project in hopes of developing an income stream for fishers that complements their current livelihoods without increasing pressure on marine resources. This analysis will inform Olazul’s implementation phase by highlighting the potential economic and ecological impacts of a fishery waste utilization program in B.C.S.

The findings of this project may be of interest to other stakeholders as well, including aquaculturists and feed producers, non-governmental organizations (NGOs), fishers, coastal communities and government agencies. Our evaluation of the viability of increased use of fisheries waste may inform the aquaculture industry of potential approaches to improving the sustainability, cost-effectiveness and stability of their supply chain. Additionally, the use of byproducts from artisanal fisheries may provide an alternative source of income and employment in coastal communities around the world.

Project Objectives

The goal of this project is to assess the viability of using artisanal fishery waste as a means to create ecologically sustainable economic opportunities in coastal communities. Specifically, this project aims to:

1. Investigate the quantity, composition, and spatial distribution of artisanal fishery byproducts in Baja California Sur (B.C.S.), Mexico.

2. Evaluate the economic feasibility of producing fish meal substitutes from artisanal fishery byproducts in B.C.S.

3. Examine the important socioeconomic factors to be considered in the implementation of a fish meal substitute program.

Background

Global Seafood Demand and Supply

With the human population recently reaching 7 billion people and still growing, there has been a significant increase in the demand for animal protein sources. Additionally, with improved standards of living around the globe, per capita fish consumption has increased from 9.9 kg/year in the 1960s to 17.1 kg/year today, as larger incomes allow from more investment in higher trophic level food sources (Klinger & Naylor, 2012). Globally, fish provide about 3.0 billion people with almost 20 percent of their intake of animal protein, and 4.3 billion people with about 15 percent of such protein (FAO, 2012). Therefore, as a result of both population growth and increased per capita seafood consumption, overall demand for fish and shellfish has skyrocketed.

This spike in demand, coupled with unsustainable fishing practices and ineffective regulation, has had serious negative implications for the health of wild capture fisheries around the globe. Due to high fishing intensity, 53% of the world's fisheries are fully exploited, and 32% are overexploited, depleted, or recovering from depletion (FAO, 2010). Yields from wild fisheries have stagnated over the course of the past fifty years, and since 2006, overall global capture fisheries production appears to have plateaued at 90 million tonnes of fish per year (Campbell & Pauly, 2013) (FAO, 2012).

Aquaculture Fills the Gap

Aquaculture, or the cultivation of aquatic plants or animals as food sources, plays an important role in meeting the demand for seafood (Naylor et al., 2009). Over the past 30 years, the aquaculture industry has grown rapidly in scale and intensity of application, and industry growth is expected to continue in the future. In 2010, aquaculture accounted for 46% of the 128 million tonnes of seafood consumed by humans, totaling nearly 60 million tonnes (Figure 1) (FAO, 2012). Employing over 10.8 million people globally, aquaculture has grown over the past 30 years into a $119.4 billion a year industry (Klinger & Naylor, 2012) (FAO, 2012). It has been estimated that, by 2030, aquaculture will need to supply an additional 23 million tonnes of food to maintain current levels of per-capita consumption (FAO, 2012).

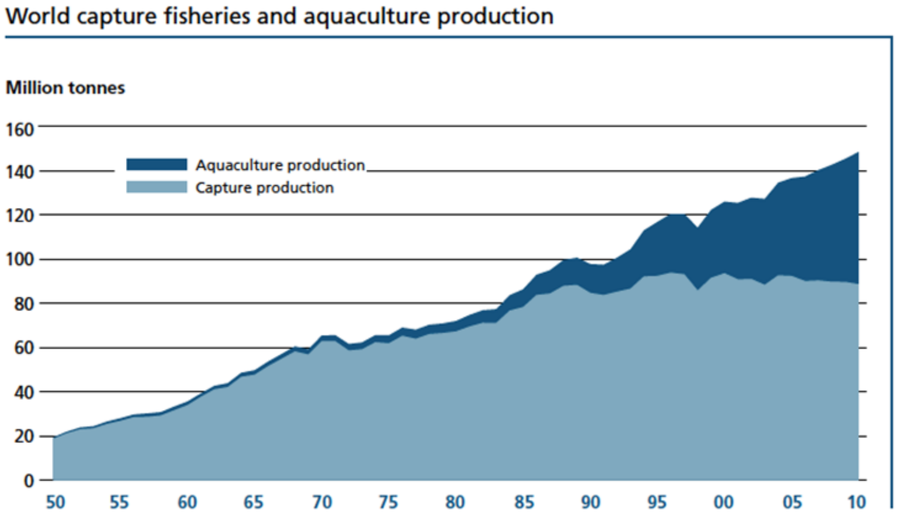

Figure 1: World Capture Fisheries and Aquaculture Production (Source: FAO, 2012)

As the aquaculture industry works towards this goal, it has become apparent that future aquaculture expansion will largely depend on the availability of feeds and feed ingredients (FAO, 2012). Although traditional extensive pond aquaculture tends to rely on naturally available food sources, intensive finfish and crustacean aquaculture often require external nutrient inputs provided by aquafeeds. These feeds can be in the form of fresh feed items, farm-made feeds, or commercially manufactured feeds (Tacon, Hasan, & Metian, 2011).

While the composition of aquafeeds tends to vary based on fluctuations in ingredient prices, all feeds are comprised of fairly similar dietary nutrients, including specific proteins and amino acids, carbohydrates and sugars, lipids and fatty acids, vitamins, and minerals (Tacon, Hasan, & Metian, 2011). Intensive farming of marine finfish and upper trophic-level species has increased over the past few decades, a phenomenon known as "farming up the food chain". This trend has increased the demand for high-protein feeds, as carnivorous and omnivorous fish species require greater concentrations of specific vital proteins and lipids (Campbell & Pauly, 2013). Thus far, the primary protein source for these feeds has been fish meal.

Fish meal

Fish meal is a dried powder produced through a process of cooking, press drying, and milling fishery products (FAO, 2011). Fish meal provides a high quality dietary ingredient in animal feed that is easily digested and metabolized by a variety of farmed aquatic and terrestrial species. Livestock feeds have typically contained 1-10% fish meal while fed aquaculture diets often include between 20-30% (Hasan, Halwart, & Food and Agriculture Organization of the United Nations, 2009). Rich in protein, essential fatty acids, and vitamins, dietary fish meal inclusion can help improve feed efficiency, reduce disease, promote health, and generate environmental benefits (Pike, 1999).

The majority of fish meal is made from whole, small, low-value, wild-caught pelagic species like sardines and anchoveta. Fisheries for these species are often referred to as "reduction fisheries" because the catch is primarily reduced to fish meal and fish oil. Harvests from reduction fisheries have remained between 20-30 million tonnes for over 30 years (FAO 2012). Approximately 4-5 kilograms of wet fish will yield around one kilogram of fish meal (approximately 65% crude protein). Fish meal production comes predominantly from large-scale, capital-intensive commercial operations. Latin America is the world's largest producer of fish meal, accounting for around 44% of total fish meal and fish oil production in 2010(Tacon & Metian, 2008).

Historically, fish meal has been a staple ingredient in swine, poultry, and cattle diets as well as being used for pet food (Figure 2). The use of fish meal by these sectors improves feed conversion efficiency (FCE) and growth rate, promotes livestock health, and reduces mortality (Pike, 1999). While the nutritional benefits of fish meal, particularly long-chain omega-3 fatty acids, are highly desirable in livestock production, demand is relatively elastic due to the availability of substitutes.

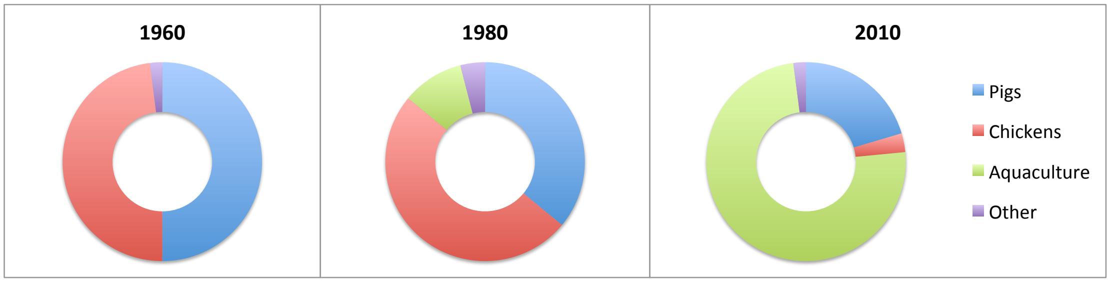

Figure 2: IFFO Estimates of Fish meal Demand by Sector (1960-2010)

In recent years, there have been significant changes in the fish meal industry. The overexploitation of certain fisheries, tightening of quotas in others, El Niño effects, and increased control over unregulated fishing have all contributed to lower reduction fishery harvests (FAO, 2012). Fish meal and fish oil inclusion in aquaculture diets has fallen 6% since 2006, likely because of inconsistency in supply, improvements in feed efficiency, and the increased use of more cost-effective fish meal substitutes (FAO, 2012). It is projected that over the course of the next 10-12 years, fish meal inclusion will continue to be reduced by 10-22% for upper trophic level carnivorous fish and 2-5% from omnivorous species (FAO, 2012). Although the relative amount of fish meal that is included in farmed fish diets' is declining, total use of fish meal and fish oil in aquaculture has increased as output of the industry has grown. Fish meal demand by aquaculture is projected to continue to grow given industry expansion and the reduction of fish meal usage in terrestrial animal production (FAO, 2012).

As a result of changes in supply and demand, the world price for fish meal varied between $500 and $700 per tonne from 2000 to 2005. However, as a result of a drastic increase in aquaculture activity and overall increase in fish meal demand, prices rose 55% to $1220 per tonne in 2008. As a result, feed costs are estimated to account for nearly 75% of total aquaculture expenditures. Ultimately, the reduction in fish meal supply has caused many sectors to substitute away from fish meal to more cost-effective dietary ingredients (Tacon et al., 2011).

In the future, as more pressure is put on reduction fisheries and fish meal prices continue to rise, the growth of aquaculture may be constrained if novel solutions cannot be found. It was reported that in 2008, while feed prices increased by over 30%, the value of farmed fish species remained relatively static, which had a significant negative economic impact on the majority of small-scale producers (Tacon et al., 2011). In the long term, practical, sustainable, affordable fish meal substitutes will need to be developed to support the anticipated expansion in the aquaculture industry.

Fish meal Substitutes and Artisanal Production

As fish meal prices increase, protein substitutes have become more common in feed production. Small and large-scale feed producers have turned to cereals, seed by-products and alternative animal products, including both terrestrial and aquatic fauna sources, in order to reduce costs (Rana, Siriwardena, Hasan, & Food and Agriculture Organization of the United Nations, 2009).

Oil-bearing seed by-products have been used as a protein replacement for fish meal in many feeds, with soybean meal being the most common. Other vegetable oils (e.g. palm and coconut oils) have lower protein contents than soybean oil, and high crude fiber levels, and contain other growth inhibiting factors. Carbohydrate rich ingredients from grains, fodder plants, grasses, legumes and root crops are essential in feeds for livestock since terrestrial animals use the sugars as an energy source (DeSilva & Sena, 1995). Animal products such as blood, liver and bone meals are higher in protein but lack the rich lipids of fish meal. In general, vegetable feeds contain fewer vitamins and essential amino acids than animal feedstuffs (Hertrampf & Piedad-Pascual, 2000).

Since fish meal and marine-derived inputs are nutritionally superior, their use in feed formulation is highly desirable. The limited supply of reduction fish has motivated the industry to seek suitable alternative marine-based protein sources to include in aquafeeds (Klinger & Naylor, 2012). Meanwhile, the processing of commercial fish species is annually generating millions of tonnes of byproducts and, in recent years, increasing quantities of fish meal have originated from these materials. The International Fish meal and Fish Oil Organization (IFFO) estimate that, currently, about 25 percent of fish meal production comes from the byproducts of fisheries and aquaculture operations (FAO, 2012). However, there is still a large amount of processing waste that is unused, especially from artisanal fisheries that lack the infrastructure and technology to produce fish meal.

The definition of artisanal fisheries is often region-specific, which makes global characterization difficult. The FAO describes artisanal fisheries broadly as "a dynamic and evolving sector employing labor intensive harvesting, processing and distribution technologies to exploit marine and inland water fishery resources" (FAO, 2005). Artisanal fisheries are generally considered to be small-scale and lack advanced technology. Over 90 percent of the world's capture fishermen are active in artisanal fisheries, with women largely involved in processing and marketing (FAO, 2012). These fisheries are crucial for satisfying the protein requirements of the poor and, as a result, the influence of artisanal fisheries on food security, poverty alleviation and poverty prevention is significant. The FAO has identified product diversification and value addition as avenues for improved standards of living for artisanal fishermen, and the production of fish meal substitutes represents one such opportunity. Although conventional fish meal production is a complex and capital-intensive process, alternative methods exist for utilizing fishery waste to produce marine-based fish meal substitutes (Akande & Simpa, 1992).

Artisanal Silage Production

Fish silage is a nutritious source of protein produced from whole or partial fish byproducts through self-degradation of material in acidic environments (DeSilva & Sena, 1995). Many industrial and academic procedures acidify mixtures by adding folic acid. A less dangerous and more economical procedure, known as biological silage, decreases pH through fermentation of wastes with the addition of bacteria *(Lactobacillus sp.)* and a sugar source (Vidotti & Viegas, 2002). Since the bacteria require a sugar source, addition of molasses can dilute the product compared to acid ensilage. Due to the mildness of the bacteria, proteins are not digested as fully as with acids, resulting in a more nutritious feed that can be stored longer with sustained nutrient levels (Hertrampf & Piedad-Pascual, 2000).

The inputs and equipment for biological silage production are relatively inexpensive and accessible compared to alternative methods: the only ingredients needed are fish material, bacteria and sugar source. Additionally, ensiling works to preserve wastes for long-term storage without refrigeration, which further minimizes costs (Vidotti & Viegas, 2002).

Due to the simplicity of the silage formula, fermented fish silage is a nutritious, although dilute, protein product, which can be used in a variety of sectors (Arruda, Borghesi, & Oetterer, 2007). Industrial producers of aquaculture feed can incorporate fish silage into their recipes in place of, or as a supplement to, fish meal. Inclusion in these feeds depends on the protein and moisture content of the silage product, with final feed products ranging from liquid feed attractants to high protein dry pelletized feed (Goddard & Perret, 2005). However, extrusion technology is currently required for the incorporation of silage into dry feeds, which would limit its use by feed producers lacking this specialized equipment (Perez, 1993).

While silage can be processed into a compounded feed, livestock operations can also use silage more directly. When consuming neutralized silage, pigs have been shown to perform as well as or better than when fed traditional feeds, including lower rates of disease. Silage has also been used to supplement grain feeds during seasons when vegetation contains low levels of protein for herbivorous stocks such as sheep and cows (Geron et al., 2007).

Artisanal Fish meal Production

Artisanal fish meal production under the dry-press-grind method is similar to commercial fish meal production, differing only in scale and the inputs needed. Fish wastes are boiled in water to denature the waste's proteins, manually pressed to remove excess moisture, and then set out to dry. While drying can occur anywhere that is exposed to direct sunlight, the use of structures such as polyurethane tunnels to increase ambient temperatures and evaporation rates, as well as to minimize disturbance and contamination by pests, is common. Once dry, the wastes are ground into a final product that closely resembles commercial fish meal in composition and nutritional value (Akande & Simpa, 1992).

The production of artisanal fish meal under the dry-press-grind method requires some additional inputs compared to silage production, such as a stove and drying apparatus. Additionally, while total production occurs over a relatively similar time span, about 3-5 days, more labor is required with dry-press-grind production. Taken together, these factors lead to higher production costs for fish meal compared to silage (Goddard & Perret, 2005; Akande & Simpa, 1992).

However, while associated costs are high with fish meal production, the dry-press-grind method has a number of advantages that increase its competitiveness. First, given its low moisture content, artisanal fish meal can be stored for a similar amount of time compared to silage. Moreover, artisanal fish meal has higher relative protein concentrations by weight, and much lower transportation costs compared to silage. Finally, artisanal fish meal can be used as a direct substitute for commercial fish meal with no additional infrastructure or technology. As a result, artisanal fish meal is a potentially valuable use of waste products (Akande & Simpa, 1992).

Baja California Sur (B.C.S.), Mexico

Baja California Sur (B.C.S.), Mexico's 31st state, is the southernmost state of western Mexico's Baja California Peninsula. Bordered by the Pacific Ocean to the west and the Gulf of California to the east, the majority of settlements in B.C.S. occur along the state's 2,000 km coastline (Angeles, Ivanova, & Gámez, n.d.). La Paz, the state's capital and primary economic center, contains the majority of the population. According to the United Nation's Statistics Department, over 250,000 people live in the central urban area of La Paz. The coastal cities of San Jose del Cabo and Cabo San Lucas to the south are experiencing rapid population growth, with populations climbing from 20,000 in 1980 to 164,000 in 2005 (Angeles et al., n.d.). The remaining 74,000 square kilometers of B.C.S. coastline is relatively undeveloped, with nearly all development related to permanent fishing villages and seasonal or temporary fishing camps (Angeles et al., n.d.).

In Mexico, the FAO defines artisanal fisheries as those using small boats (~6-10 m), known locally as *pangas*, operating close to shore with low capital investment, intensive labor, and limited capacity (Salas, Chuenpagdee, Charles, & Seijo, 2011). Fishing communities in B.C.S. are relatively remote, with most being accessible only by dirt roads. Similarly, most of these settlements are small, each containing an average of only 13-177 people (Sala, Aburto-Oropeza, Reza, Paredes, Lopex-Lemus). Communities are characterized by low to moderate infrastructure (Ramirez-Amaro et al., 2013), with many locations lacking electricity, refrigeration, running water, and access to education (Salas et al., 2011). The increased concentration of population and employment opportunities in urban areas has further marginalized and impoverished these areas. As a result, the majority of the inhabitants of these coastal settlements live below the poverty line (Salas et al., 2011). Artisanal fishing is the primary, if not sole, income source for the nearly all of the small coastal settlements in B.C.S.

Many artisanal fishermen are organized into cooperatives that arose during the 20th century in response to federal fishing policies. These policies attempted to raise standards of living among rural fisherman while simultaneously increasing the national food supply and stimulating economic growth. While subsistence fishermen hold access rights to local fishing grounds, these cooperative members are granted exclusive rights to commercially valuable species in exchange for working collectively, paying dues and assisting the government in monitoring efforts. Unfortunately, overlapping access rights have hindered the incentives necessary for self-enforcement (Young, 2001).

Artisanal Fishing Effort in Baja California Sur

Artisanal fisheries are extremely important in Mexico, supplying about 40% of the total national catch and representing an important source of employment (Sanchez, Hernandez-Herrera, Ramirez-Rodriguez, & Perez-Espana, 2004). The fisheries of B.C.S. make an important contribution to Mexico's total catch, accounting for nearly 11% of national landings per year (Bizzarro, Smith, Hueter, & Villavicencio-Garayzar, 2009); 95% of the B.C.S. catch is reported by artisanal fisherman (Young, 2001). Artisanal fisheries employ over 11,000 people full time in B.C.S., or 5.21% of the state's overall population, with many more partially employed (Salas et al., 2011). In 2011, there were 2,936 registered artisanal vessels in B.C.S. (Comisión Nacional de Acuacultura y Pesca (CONAPESCA), 2011). Despite significant fishing effort, however, incomes remain relatively low, with average monthly incomes derived from fisheries in the region estimated to be around $2,714 Mexican pesos, or $209 USD (Salas et al., 2011).

Artisanal fishing effort in B.C.S. is highly dynamic and opportunistic. Effort is frequently shifted to adjust for closures for specific species, changes in stock abundance, and changes in relative prices of harvested species. These factors contribute to high seasonal variability in the artisanal fisheries of Baja (Salas et al., 2011). Artisanal fisherman in B.C.S. use a variety of gear types, including monofilament nets, traps, hook-and-line, and diving gear, to target a large variety of different species (Young, 2001). Once landed, distribution systems for fish products are highly diffuse, with a large number of fisherman landing small volumes at a multitude of locations along the coast (Schorr, 2005). Catches are mainly sold fresh, iced, or frozen and, in very limited cases, processed. Additionally, artisanal catches generally contain a considerable amount of bycatch due to the low selectivity of fishing gear and diverse effort. Notably, however, most bycatch from artisanal fisheries is sold or consumed rather than discarded, in contrast to most industrial fisheries (Salas et al., 2011).

Status of B.C.S. Fisheries

Migration of unemployed fieldworkers from surrounding areas to coastal regions in B.C.S. and continued population growth in the region have increased pressure on the region's fisheries (Sala, Aburto-Oropeza, Reza, Paredes, & López-Lemus, 2004).

Similarly, poor fisheries management, corrupt fishing inspectors, growing foreign involvement, and increased economic disparity in the region have contributed to diminished fish stocks (Young, 2001), such that 82% of all fisheries in Mexico are fully-exploited or over-exploited (Sala et al., 2004). While overall fishing effort has expanded in B.C.S. steadily since 1950, catch-per-unit-effort (CPUS) has steadily decreased since 1980, as have the average trophic level and size of targeted fish species (Sala et al., 2004). As a result, the main small-scale fisheries of the Pacific region of Mexico are either fully-exploited or exhausted, and six marine fish species are at risk of extinction in the Gulf of California (Salas et al., 2011). With Baja fisheries under such stress, and with expectations that effort will continue to increase in the future, the artisanal fishing sector of B.C.S. appears to be on an unsustainable course.

Fishery Byproducts as an Economic Opportunity in B.C.S.

Given the dependence of artisanal fishing communities in B.C.S. on threatened stocks, the ability for these stocks to persist and sustain current levels of income and employment is in doubt. At the same time, while most of the high-grade fillets and fish products are either sold to generate income or consumed directly, byproducts are typically disposed of. As a result, there are nutritionally and (potentially) economically valuable waste products that are not being utilized in B.C.S.

Currently, the wastes resulting from the industrial processing of sardines and tuna in major port locations such as San Carlos and La Paz serve as an input to commercial fish meal production in B.C.S. Similarly, one known small-scale fish meal plant exists in B.C.S. that is currently collecting and processing a wider variety of waste products, including artisanal fishery byproducts, for the production of a high-quality fish meal product. However, participation in these systems is only feasible for artisanal fishermen in the immediate vicinity due to rapid spoilage of raw waste products. Thus, fishery wastes are for the most part not being exploited in B.C.S.

Methods & Results

Approach

The quantitative analysis of this report was done to address the first two project objectives:

1. Investigate the quantity, composition, and spatial distribution of artisanal fishery byproducts in B.C.S.
2. Evaluate the economic feasibility of producing fish meal substitutes from artisanal fishery byproducts in B.C.S.
3. Examine the important socioeconomic factors to be considered in the implementation of a fish meal substitute program

Objective 1: Waste Supply

Methods

To examine the supply of byproducts in B.C.S., landings data from 2005 to 2012 were obtained from the Mexican aquaculture and fisheries commission (Comisión Nacional de Aquacultura y Pesca, CONAPESCA). The data we received contained artisanal-level catch data for port communities in B.C.S. from 2005 to 2012 (Sanchez et al., 2004). For a complete description of the dataset and sources see Appendix 1: Data Acquisition, Processing, and Example Data Set.

From this data set we calculated waste for each entry as the difference in the recorded live and landed weight. Finally, we obtained coordinate data for each fishing location from government and academic sources and assigned coordinates to the landings.

$$Waste\ Weight\ (kg) = Live\ Weight\ (kg) - Landed\ Weight\ (kg)$$

Results

The final data set contains 72,625 individual entries from 378 locations during the eight-year period from 2005 to 2012. Reported landing sites were equally distributed along the coasts of both the Pacific and Gulf of California, with higher densities observed around Magdalena Bay, Bahia Asuncion, Santa Rosalía, La Paz, and Guerrero Negro (Figure 3). During this time interval, a total of 491,750 tonnes of landings were reported by artisanal fishermen in B.C.S. From these landings, we estimate that approximately 96,404 tonnes of waste were produced. High average annual quantities of landings were observed in Magdalena Bay, Santa Rosalía, Bahia Asuncion, and Guerrero Negro, with coinciding large amounts of waste, particularly for Santa Rosalía (Figure 3).

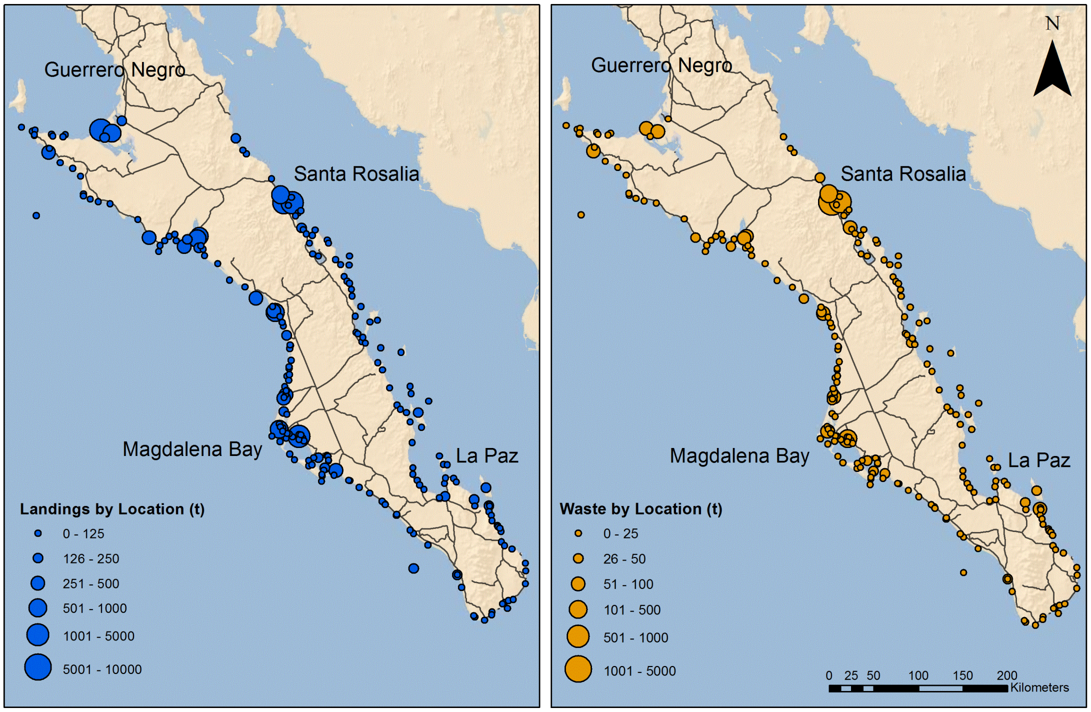

Figure 3: Map of Average Annual Landings and Waste from Artisanal Fisheries in B.C.S. (2005-2012)

While Figure 3 is illustrative of the overall spatial distribution of landings and waste, it does not reveal the relative distribution of different fisheries. In the dataset, landings are classified both at the species level as well as under 16 broadly defined species groups. Of these 16 groups, squid, finfish, shark, ray, and clams were the most common. Figure 4 shows the spatial distribution of landings for the squid, finfish, shark, and clam fisheries in B.C.S. The circle’s size in the figure is relative to that location’s percent contribution to the total landings of that species group in the dataset. For finfish and sharks, landings were relatively evenly distributed around B.C.S., while squid and clam landings were more concentrated. The importance of Magdalena Bay, located in on the southwestern coast of B.C.S., is illustrated by the high proportion of finfish, shark, and clam landings reported there.

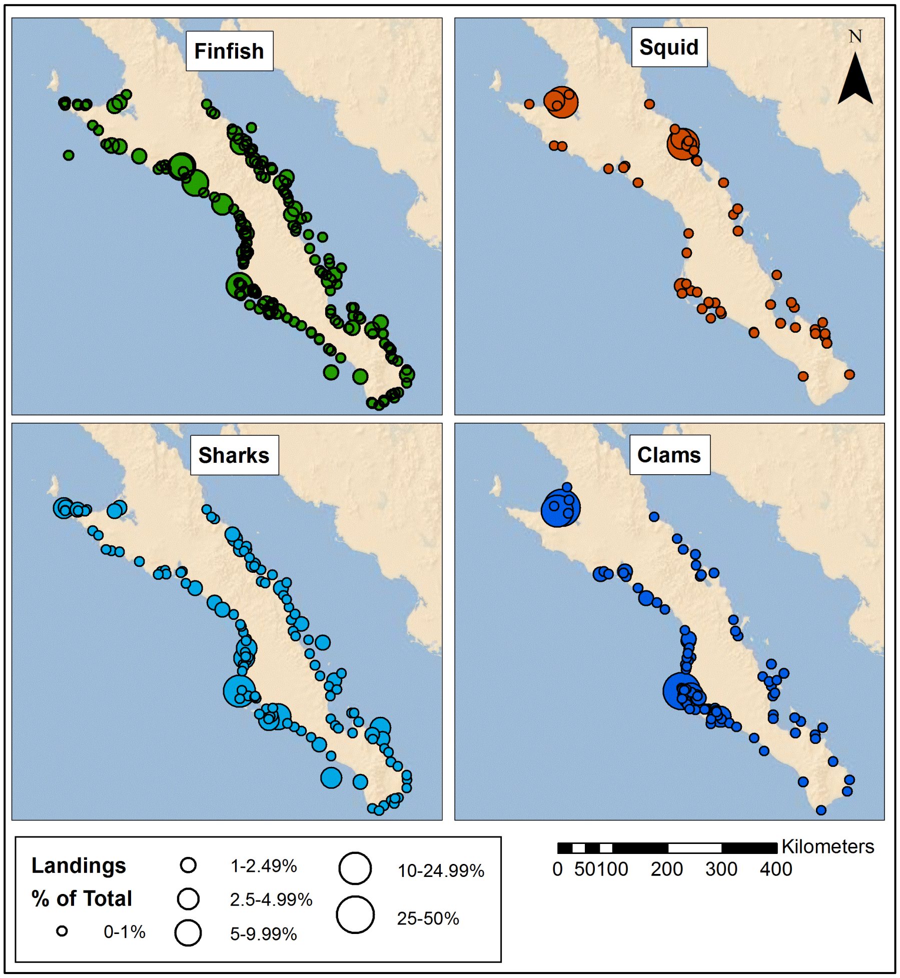

Figure 4: Relative distribution of landings for major species groups in B.C.S. (2005-2012)

Similarly, Santa Rosalía and Guerrero Negro in northern B.C.S. are the primary locations for artisanal squid landings, with Guerrero Negro also being the location of a major clam fishery (Figure 4). Finally, Bahia Asuncion, on the northern Pacific coast hosts a significant finfish fishery (Figure 4).

A potentially important factor in the quantity of waste available at a given artisanal fishing port is the number of species being landed, as the amount and quality of waste will differ between species. As shown in Figure 4, some areas, such as Magdalena Bay, have landings from a variety of species groups while others, like Guerrero Negro, are more specialized.

To examine catch diversity, we calculated the mean number of species reported per month at each fishing port in B.C.S. Figure 5 illustrates that there was a positively skewed distribution of mean monthly landings in B.C.S. during the study period.

Though the majority of ports reported fewer than five species in a given month, several locations consistently landed between 20-32 different species (Figure 5).

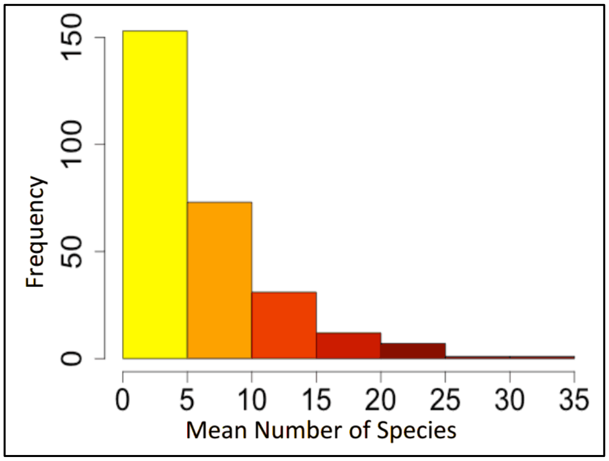

Figure 5: Mean number of species reported per month at artisanal fishing ports

During the eight-year study period, Calamari gigante, or Humboldt squid (*Dosidicus gigas*), was the largest contributor to both landings and waste, at 40% and 70% respectively. Clams were the second largest fishery by weight, comprising 25% of landings and 13% of waste (Figure 6). The majority of clams are shelled and thus the significant contribution to waste is predominantly in the form of shells and not biomass. Comparable to clams, finfish represented 22% of landings but only 6% of waste. A significant amount of waste (8%) is generated from a combination of other sources, such as crabs, oysters, and unclassified landings (Figure 6).

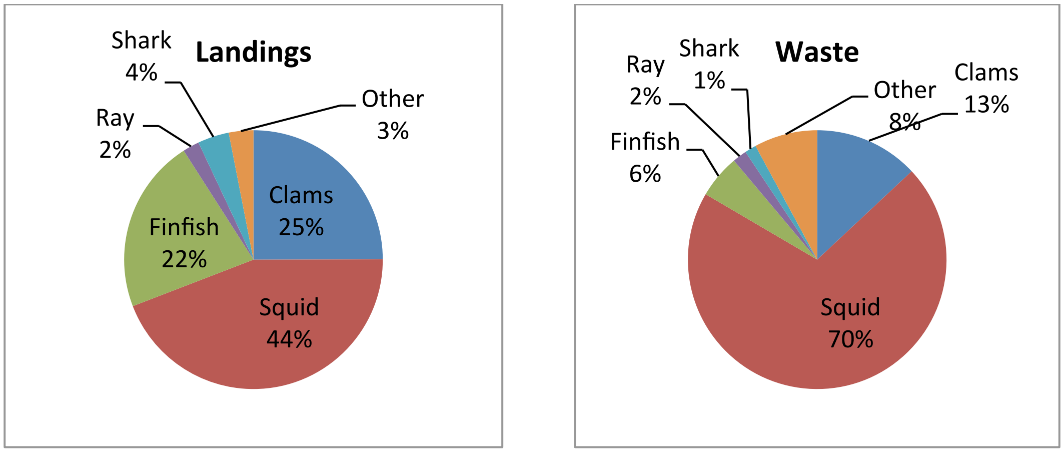

Figure 6: Composition of landings and waste in B.C.S. (2005-2012)

Figure 7 shows the annual variation in quantity and composition of landings in B.C.S. from 2005 to 2012. Total landings were above 70,000 tonnes from 2005 to 2007, when they peaked at 78,116 tonnes. However, since 2007 landings have not exceeded 60,000 tonnes, except in 2010 when they reached 72,375 tonnes. Landings exhibited a strong seasonal trend, with reported catches peaking at an average of approximately 10,000 tonnes in June and July while dropping to just above 2,000 tonnes from December to February. The fluctuations observed in Figure 7 demonstrate the highly variable nature of the squid fishery; while squid accounted for over 50% of landings in four of the eight years, its contribution was as low as 18% in 2011, 26% in 2012 and 28% in 2008. Concurrently, finfish landings have risen from an average of 11,000 tonnes in 2005-2008 to 15,700 tonnes in 2009-2012. As a result, finfish's share of the total annual catch has doubled from 16% in 2005 to 35.5% in 2012 (Figure 7).

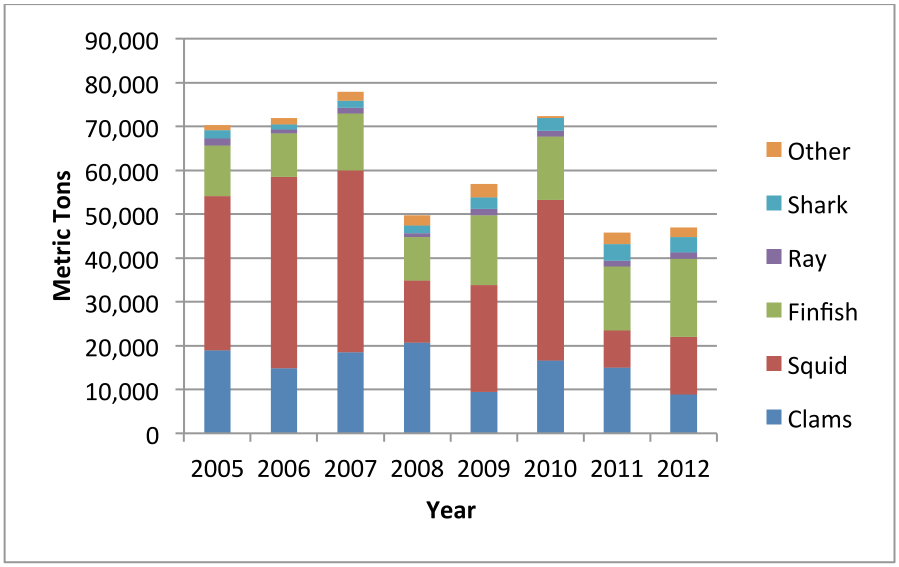

Figure 7: Annual composition of artisanal landings in B.C.S. (2005-2012)

In addition to fluctuations in landings, a dramatic decline in waste was observed in the data series (Figure 8). From 2005 to 2007, between 20,000 and 25,000 tonnes of waste were produced, representing approximately one third of the recorded live weight in each year. Since 2010, however, waste has dropped below 7,000 tonnes and was only 3,484 tonnes in 2012.

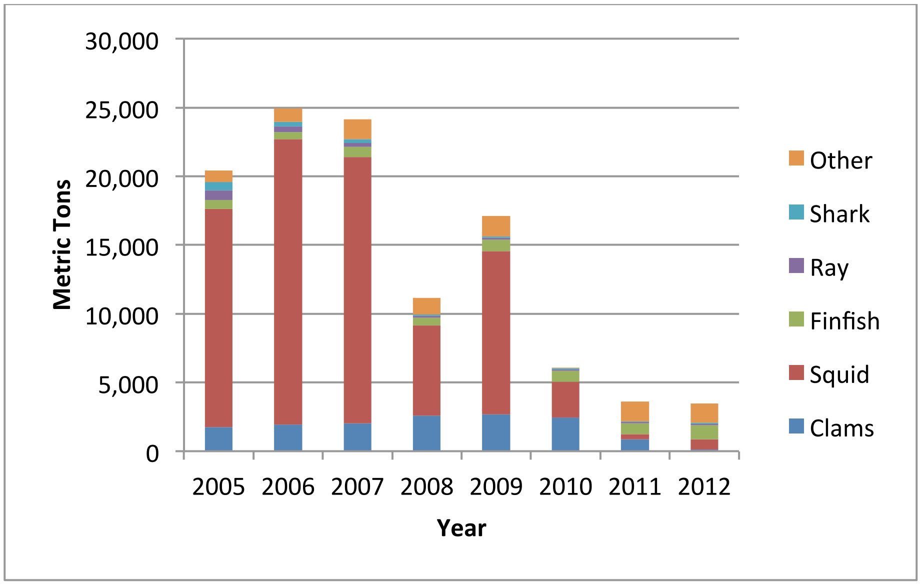

Figure 8: Annual composition of waste from artisanal fisheries in B.C.S. (2005-2012)

In conjunction with low squid landings, it appears that changes in processing practices are contributing to the substantial reductions in waste from artisanal fisheries in B.C.S. Figure 9 shows the ratio of waste-to-landings for each species group throughout the study period. The most striking trend in this figure is the dramatic decrease in waste produced from squid between 2009 and 2010, when waste dropped from a yearly average of nearly 50% to less than 10% (Figure 9). This finding corresponds well with anecdotal evidence obtained from interviews with fishermen and commercial processors in B.C.S. suggesting recent changes in squid processing practices and the opening of markets in Asia for unconventional parts of squid. In addition to reduced waste from squid processing, both the shark and ray fisheries showed a steady decline in waste and now both operate below 10%. No changes were observed in finfish waste ratios (Figure 9).

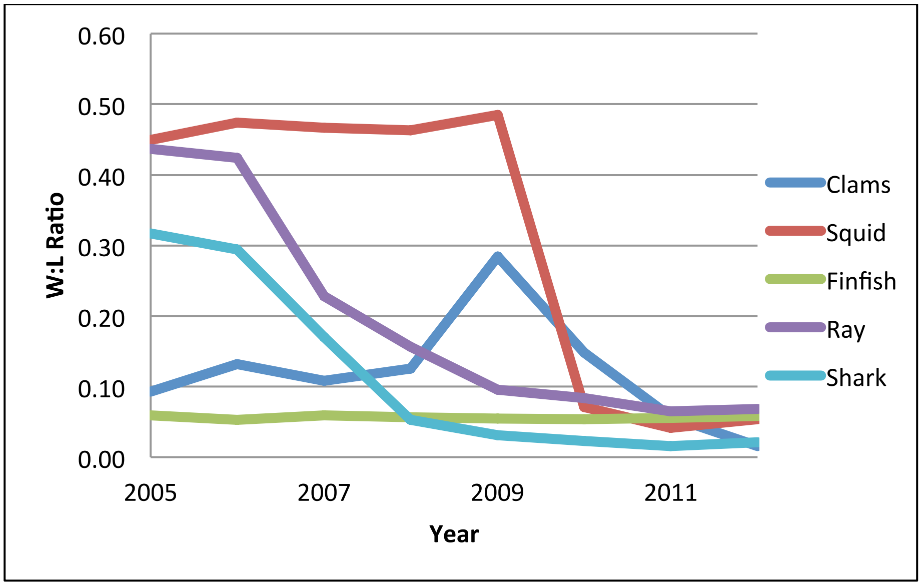

Figure 9: Ratios of waste to landings of selected species groups in B.C.S. (2005-2012)

This review of the data reveals several trends in artisanal fishing in B.C.S. with implications for the supply of waste available for producing fish meal substitutes. First, artisanal fishing effort is widely distributed along both coasts of B.C.S. The total productivity of these fishing communities is largely dependent on the squid fishery and experiences strong seasonal variation. While reported landings have fluctuated, due primarily to the variable squid fishery, changing processing practices and the opening of new markets have resulted in drastically reduced quantities of waste in artisanal fishing communities.

Objective 2: Economic Feasibility Analysis

To determine the economic feasibility of waste utilization in artisanal fishing communities in Baja California Sur, Mexico, we developed an analytical framework to calculate potential profits. This model values fishery waste based on its nutritional profile, subtracts costs associated with processing the waste into a sellable product, and determines how far the product can be transported before it becomes cost-prohibitive. Our model assumes constant returns-to-scale, as no data are available to assess potential efficiency gains that might accompany higher production levels. The constant returns-to-scale assumption implies that the unit cost of processing fish waste is the same regardless of the total amount processed.

The goals of our quantitative economic analysis are threefold:

1. Determine if *processing* artisanal fishery waste for use as a protein source in feeds is economically feasible in B.C.S.
2. Evaluate if *transporting* processed artisanal fishery waste to a potential buyer is economically feasible in B.C.S.
3. Assess the relative *consistency of supply* of product from each fishing port over the study period

Data Preparation

Using the spatial data described previously, we are able to connect GPS coordinates to the landings data from 251 ports. For this analysis, we were only interested in evaluating the economic potential of waste from finfish, sharks, rays and squid, because discards from these species are most amenable to processing. Waste from these species was generated in at least one month of the study period at 209 of the 251 ports. Landings data do not exist for every port in every month from 2005 to 2012. Therefore, we assessed production potential for each port individually on a monthly basis. See Appendix 1: Data Acquisition, Processing, and Example Data Set for more details.

Part 1: Evaluating Economic Feasibility of Waste Processing

Part 1 Methods

To assess the economic feasibility of processing artisanal fishery waste and transporting it to a potential buyer, we:

1. Estimate the quantity of processed fishery waste that could be produced at each port under two different artisanal processing methods

2. Estimate the potential value of processed fishery waste when used as a protein source in feeds
3. Calculate the costs associated with processing and determine potential profits before transportation costs

Quantity of Processed Fishery Waste

Given the limited availability of ice and refrigeration, coupled with warm temperatures year-round, artisanal fishery waste in B.C.S. needs to be processed quickly to prevent spoilage. For our analysis, we evaluated two small-scale processing methods: fermented fish silage and artisanal fish meal. While both of these methods are relatively simple and technically feasible on a small scale, they have different equipment requirements and production costs.

Fermented Fish Silage

Through experimental trials conducted between July 2013 and September 2013, we determined that successful fermentation of fish discards can be achieved with silage composed of 80% raw waste, 10% bacterial culture, and 10% sugar. We applied this ratio to the quantity of raw waste in a port to estimate the amount of silage:

$$Waste\ Weight\ (kg) \div 0.8 = Silage\ Weight\ (kg)$$

Artisanal Fish meal

Artisanal fish meal production involves removing most of the moisture from raw fish discards. Therefore, we used the concentration of dry matter in raw fish discards to estimate the quantity of artisanal fish meal that could be produced. Industrial fish meal is usually about 90% dry matter. However, because small-scale processing under local conditions is less efficient than industrial production, we assumed artisanal fish meal to be 80% dry matter (Hertrampf & Piedad-Pascual, 2003).

Dry matter concentration varies among species (Table 1), which we account for in deriving the total quantity of artisanal fish meal.

$$Waste\ Weight\ (kg) \times \frac{\%\ Dry\ Matter}{0.8} = Artisanal\ Fishmeal\ Weight\ (kg)$$

Table 1: Dry matter concentrations of raw waste. Values are the average across sources.

Species Group	% DM Raw Waste	Source
Finfish	27.8%	(Geron et al., 2007)(Vidotti & Viegas, 2002)(Bechtel, 2003)
Sharks	28.82%	(Vázquez et al., 2011)(UN FAO: Fishery Industries Division, 1986) (Mowbray, Rossi, & Chai, 1988)
Rays	24.75%	(Vázquez et al., 2011)(Poernomo & Buckle, 2002)
Squid	17.03%	(Nithin, 2013)(Hertrampf & Piedad-Pascual, 2003)(Lian, Lee, & Park, 2005)

Estimated Substitution Value

Because there is no market data on byproducts from artisanal fisheries, we estimate their value by the price of potential substitutes, such as fish meal and soybean meal. When serving as an input for aquaculture or livestock feeds, we assumed that processed waste would be solely a source of protein; therefore, its value is based entirely on crude protein content. Again, because the protein content of fish byproducts varies among species, we evaluated the protein content of each species group separately and summed them to determine total nutritional content and value.

Nutritional Composition

We obtained estimates of crude protein concentrations of raw fishery waste from published literature. Multiple sources were consulted, and for each species group the average protein concentration across sources was used (Table 2).

From these concentrations, we calculated the weight of crude protein present in a given quantity of raw waste. We assumed that all protein would be conserved through processing and storage (see Appendix 4: Quantitative Economic Analysis Assumptions). Therefore, the quantity of crude protein in raw waste is equivalent to the quantity of crude protein in silage or artisanal fish meal.

$$Crude\ Protein_{Total}(kg) = \sum Waste\ Weight_{Species\ Group}\ (kg) \times \%\ Crude\ Protein\ _{Species\ Group}$$

Table 2: Crude protein concentrations of raw waste. Values are the average across sources.

Species Group	% Crude Protein Raw Waste	Sources
Finfish	16.1%	(Geron et al., 2007)(Bechtel, 2003)(Vidotti & Viegas, 2002)
Sharks	20.61%	(Vázquez et al., 2011)(UN FAO: Fishery Industries Division, 1986)(Mowbray et al., 1988)
Rays	20.18%	(Vázquez et al., 2011)(Poernomo & Buckle, 2002)
Squid	13.63%	(Nithin, 2013)(Hertrampf & Piedad-Pascual, 2003)(Lian et al., 2005)

Price Proxies

The price one could expect to receive for processed fishery waste is uncertain, so we calculated the value of silage or artisanal fish meal using three different price proxies (Table 3). For each proxy we determined the value of one kilogram of protein, and then applied this value to the protein content of the silage or artisanal fish meal to determine the total value of the product.

We evaluated two different price scenarios for traditional fish meal. In one, we used the commodity price of fish meal in Mexico as of December 2013. In the other, we used the price that Promotora Industrial Acuasistemas S.A. de C.V. (PIASA), a small-scale aquafeed producer in La Paz, pays for fish meal. PIASA’s fish meal price is nearly double that of commodity fish meal.

We also calculated the value of silage or artisanal fish meal serving as a substitute for soybean meal.

$$Value_{Feed\ Input} = Crude\ Protein_{Total}(kg) \times Price\ Per\ Kg\ Protein(USD)$$

Table 3: Price proxies used in the analysis to calculate value.

Substitutable Product	Protein Concentration	Price (USD/tonne)	Price (USD/kg protein)	Source
Commodity Fish Meal	65%	$1,525.90	$2.35	(World Bank, 2013a)
PIASA Fish Meal	65%	$3,012.55	$4.63	(Alejandro Flores Márquez, PIASA, 2013)
Commodity Soybean Meal	48%	$485.08	$1.01	(World Bank, 2013b)

Production Costs

We calculated per unit costs of production for two methods of processing artisanal fishery waste: fermented fish silage and artisanal fish meal.

Producing fermented fish silage involves collecting fisheries byproducts, grinding them to a finer consistency using an electric meat grinder, transferring them to a 200L plastic barrel, and adding 10% sugar and 10% lactic acid-producing bacterial culture to stimulate fermentation. This solution then sits for up to 5 days until the pH drops to a level where the acidity prevents spoilage, thus allowing for unrefrigerated storage of the material (Arruda et al., 2007). We calculated the costs associated with producing fermented fish silage using a vegetable fermentation starter culture as the source of lactic acid-producing bacteria. The vegetable culture is prepared by combining vegetable culture starter packets, water, and shredded cabbage in order to raise a viable bacterial culture.

The production of artisanal fish meal involves collecting fisheries byproducts, cooking them in 55 gallon steel drums over a high output propane stove, manually pressing the waste material in burlap sacks using wooden planks and two heavy items, drying the waste in a polyurethane solar tunnel for about three days, and then the grinding and bagging the final fish meal product.

For each production method, we considered fixed costs and variable costs. Fixed costs are one-time expenditures that are not directly related to production volume, while variable costs are a function of the amount of the products produced. As noted above, the major assumption in determining costs is that there are constant returns-to-scale, implying constant per unit costs regardless of the volume of waste processed. All fixed and variable costs were first calculated on both a unit-of-sale (200L drums for silage and 55kg sacks for fish meal) basis, and then converted to a per-kg basis for integration into the model. The costs for all equipment and supplies were marked up 20% to account for the costs of delivering these goods to remote fishing camp locations. For a detailed breakdown of the fixed and variable costs and citations for cost data sources see Appendix 2: Production Costs and Appendix 3: Transportation Costs and Cost Data Sources.

Fixed Costs

For each component of fixed costs, the monetary cost, the average lifespan, and the maximum production capacity over that time period were determined. Dividing costs by the lifetime production potential of a piece of equipment yielded the fixed cost per unit of product. Additionally, dividing the cost per unit of sale by the weight of the unit of sale yielded the cost per kg of waste produced.

$$Fixed\ Costs\ Per\ Unit\ of\ Sale = \frac{Total\ Fixed\ Cost}{Production\ Capacity\ over\ Lifespan}$$

$$Fixed\ Cost\ per\ kg = \frac{Fixed\ Cost\ Per\ Unit\ of\ Sale}{Unit\ of\ Sale}$$

A major assumption of this cost determination was that the lifespans of each of these fixed costs were determined by use rather than by time. For instance, the lifespan of an electric meat grinder was determined by the overall amount of fish waste that was run through it, rather than the number of years it had been in operation. As a result, it is assumed that months of high waste availability would be met with the purchase of additional equipment during these periods such that all available waste resources would be utilized. During these times, fixed costs rise, though fixed costs per unit of sale or weight remain the same. During periods of low landings, all unneeded equipment is idled, extending its lifespan through time and eliminating the need to purchase additional equipment in the future. As a result, during these periods of low production, this underutilization of equipment would not be reflected in higher per-unit production costs given that these costs are spread over future production. The result of this assumption is that unit costs are constant and dependent solely on the amount of fisheries waste being processed. On a per-unit basis, fixed costs are the same for each port and through time (see Appendix 4: Quantitative Economic Analysis Assumptions).

Variable Costs

Following the procedure used with fixed costs, all variable production costs of silage and fish meal were calculated per unit-of-sale, as well as per-kg of final product.

$$Variable\ Cost\ per\ Unit\ of\ Sale = Sale\ Cost\ x\ Inclusion\ Per\ Unit\ of\ Sale$$

$$Variable\ Cost\ per\ kg = \frac{Variable\ Cost\ per\ Unit\ of\ Sale}{Unit\ of\ Sale}$$

Total Production Costs by Method

Total costs are the sum of all fixed and variable costs.

$$Total\ Cost = Fixed\ Costs + Variable\ Costs$$

For silage, the costs of production are $50.20 per 200kg drum or $0.25 per kg of silage (Table 4). For artisanal fish meal, production costs are $33.68 per 50kg bag or $0.67 per kg of fish meal (Table 5).

Table 4: Production costs for silage.

Product	Cost Type	Production Input	Cost Per Unit Of Sale ($/200kg Drum)	Cost per Kg
Silage	Fixed	Grinder	$0.93	$0.00467
		200 L Barrel	$0.30	$0.00150
	Variable	Veggie Culture	$15.44	$0.07722
		Cabbage	$7.44	$0.03720
		Sugar	$17.76	$0.08880
		Labor	$7.81	$0.03906
		Gasoline	$0.51	$0.00254
	Total		**$50.20**	**$0.25100**

Table 5: Production costs for artisanal fish meal.

Product	Cost Type	Production Input	Cost Per Unit Of Sale ($/50kg Bag)	Cost per Kg
Artisanal Fish meal	Fixed	Grinder	$0.29	$0.00584
		55 Gallon Drum	$0.02	$0.00038
		High Output Stove	$0.04	$0.00350
		Poly Tunnel	$0.36	$0.00724
		Burlap Sack	$1.65	$0.03300
	Variable	Labor	$16.02	$0.32031
		Water	$11.09	$0.2218
		Propane	$4.02	$0.08031
		Gasoline	$0.16	$0.00317
		50 kg Fish meal Bags	$0.06	$0.00120
	Total		**$33.68**	**$0.6737**

Profit Before Transportation Costs

To evaluate the conditions under which processing artisanal fishery waste is economically feasible in B.C.S., we use the production cost results in Table 4 and Table 5 to calculate profits for six scenarios defined by prices and product type (Table 6). Potential profits for silage and artisanal fish meal production were calculated using three value proxies: fish meal at PIASA's price, commodity fish meal, and commodity soybean meal (Table 3).

$$Profits\ Before\ Transportation = Value - Production\ Costs$$

Table 6: Scenarios evaluated in economic model that consider the three price proxies and two potential products.

Scenario	Product	Value Proxy
1	Silage	PIASA FM
2	Silage	Commodity FM
3	Silage	Commodity SM
4	Artisanal Fish meal	PIASA FM
5	Artisanal Fish meal	Commodity FM
6	Artisanal Fish meal	Commodity SM

Part 1 Results

We evaluated the economic feasibility of processing artisanal fishery waste into silage or artisanal fish meal at 209 ports in B.C.S. When considering only the delivered price less production costs (without taking into account the cost to transport the product to a buyer) we found that processing artisanal fishery waste has the potential to be profitable in all ports across all months in four of the six scenarios (

Table 7). In the two scenarios where soybean meal was used as the price proxy, the production costs outweighed the potential value, indicating that it is not economically feasible to process fishery waste as a substitute for soybean meal. In

Table 7, potential profit per kilogram of waste represents the potential value minus the processing costs for a kilogram of waste under each scenario. The range of potential profits is indicative of a range of protein concentrations, which dictate the relative value of a kilogram of waste.

Table 7: Economic feasibility of processing artisanal fishery waste (does not include transportation costs)

Scenario	Product	Value Proxy	Frequency of Profitability Across Ports and Months	Potential Profit Per Kilogram of Waste (USD)
1	Silage	PIASA FM	100%	\$0.32 – \$0.64
2	Artisanal FM	PIASA FM	100%	\$0.49 – \$0.73
3	Silage	Commodity FM	100%	\$0.01 – 0.17
4	Artisanal FM	Commodity FM	100%	\$0.14 – \$0.27

5	Silage	Commodity SM	0%	-$0.18 – -$0.11
6	Artisanal FM	Commodity SM	0%	-$0.07 – $0.00

Part 2: Evaluating Economic Feasibility of Transportation

Part 2 Methods

Although it may be profitable to *process* artisanal fishery waste under a range of price and cost scenarios, in order to receive the estimated price that we used in our profit calculations, the product needs to be transported to the buyer. Transportation can be especially cost-prohibitive for silage, which is a liquid and has a high volume and weight relative to its protein concentration. In this part of our analysis, we:

1. Estimate transportation costs for silage and artisanal fish meal in B.C.S.
2. Determine if the product can be cost-effectively transported to a potential buyer in B.C.S.

Transportation Costs

We estimated transportation costs by calculating the costs associated with moving one kilogram of product one kilometer by truck in B.C.S. Fuel costs, labor costs for a transport driver, and vehicle depreciation costs are the components of total transportation costs (Table 8). The major assumptions adopted for these calculations are that all vehicles travel at full capacity, carry their maximum payload (4 barrels of silage or 16 bags of fish meal) from port to end user, and then return empty. As a result, all transportation costs were calculated on a cost per kilogram per kilometer basis, and then doubled to include the cost of the return trip.

$$\frac{Fuel\ Cost}{kg \times km} = Fuel\ Cost \times \frac{Fuel\ Economy}{Max\ Payload}$$

$$\frac{Labor\ Cost}{kg \times km} = \frac{Wage}{hour} \div \frac{Average\ mileage}{hour} \div Max\ Payload$$

$$Depreciation\ Costs = \frac{Vehicle\ Depreciation\ Costs\ per\ km}{Max\ Payload}$$

$$\frac{Total\ Transportation\ Cost}{kg \times km} = \frac{Fuel\ Costs + Labor\ Costs + Depreciation\ Costs}{kg \times km} \times 2$$

Table 8: Transportation costs per kilogram of product per kilometer traveled.

Cost Type	Cost Per Kilogram Per Kilometer
Fuel	$0.0002651
Labor	$0.0000977
Depreciation	$0.00031986
Total	**$0.001365**

Multiplying these costs by the load of product in kilograms will yield the overall cost to transport a given load one kilometer.

$$Transportation\ Costs\ Per\ Km\ = Load\ (kg) \times Cost\ per\ kg * km$$

The explicit method for the determination of cost parameters from data sources, citations for this data, as well a list of all assumptions used in determining cost parameters are included in Appendix 3: Transportation Costs and Cost Data Sources.

Transportation Distance

The maximum distance that a product can be transported is calculated by dividing the profits before transportation costs by the transportation costs per kilometer. This distance represents the break-even point where profits would then be equal to zero.

$$Maximum\ Transportation\ Distance\ (km) = \frac{Profits\ Before\ Transportation (USD)}{Transportation\ Costs\ Per\ Km\ (USD/km)}$$

Mapping Distance to Buyer

After determining the maximum distance that a product can travel, an estimate of the actual transportation distance between fishing communities and buyers in B.C.S. was needed. We identified two potential buyer locations: La Paz and Ciudad Constitución (Figure 10). La Paz is the largest city in B.C.S. It serves as an important commercial center and is home to PIASA and one other small-scale feed producer. Ciudad Constitución is located 125 miles north of La Paz and is the second largest city in B.C.S. It has a large commercial center and is situated on the main highway along one of PIASA's existing transportation routes to an industrial fish meal supplier in Puerto San Carlos.

The coordinates of La Paz and Ciudad Constitución were used to calculate total distances between each port and each potential buyer using the “routes” function in the R ggmap package, which bases its distance estimates on the roads data contained in Google Maps. In R, the route function divides the route from starting point to end point into individual legs and sums the segments to determine total distance. We used this function to calculate the distance from each port to La Paz and Ciudad Constitución.

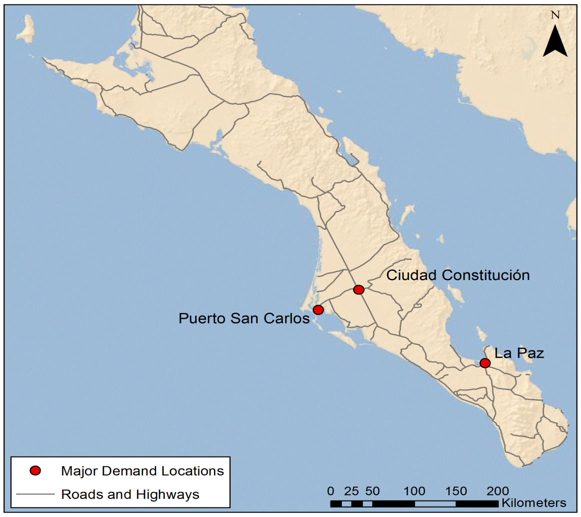

Figure 10: Current demand locations for fish meal substitutes in B.C.S.

Of the 209 ports that we had GPS coordinates for, we were able to map distances for 143 ports.

Economic Feasibility of Transportation to Buyer

In order to determine if it is economically feasible to transport silage or artisanal fish meal from a port to either La Paz or Ciudad Constitución, we compared the maximum transportation distance at each location to the distance to a buyer.

We first eliminated months in which total production was less than 200 kilograms of silage or 50 kilograms of fish meal under the assumption that it would be impractical to transport processed waste from a port that was not able to produce one unit of sale per month. Then, for each port, we determined if La Paz or Ciudad Constitución was closer, and designated that as the delivery location. Finally, we assessed for each month if the maximum transportation distance is equal to or greater than the distance to a buyer, and designated those months as feasible.

$$Maximum\ Transporation\ Distance\ \geq Distance\ to\ Buyer = Feasible$$

In the determination of feasibility at the port level, several assumptions were made (Table 9). For a more detailed discussion of the analysis assumptions see Appendix 4: Quantitative Economic Analysis Assumptions.

Table 9: Quantitative economic analysis assumptions.

	Assumptions

1	All available waste at a port is utilized
2	Protein concentrations in literature are reflective of protein concentrations of fishery waste in Baja California Sur
3	Protein is conserved during processing and storage
4	Silage and artisanal fish meal are perfect substitutes for proxy products with the same protein concentration
5	Funds for initial capital investment are available
6	The price proxy for the products is fixed
7	Constant returns to scale in production
8	No discounting of costs
9	Input costs are increased by 25% to account for delivery to remote locations
10	Uniform transportation costs per kilogram of product per kilogram traveled

Part 2 Results

For each scenario in which production was deemed profitable, we evaluated the economic feasibility of transporting the product to either La Paz or Ciudad Constitución. This was evaluated on a monthly basis, and we first examined which ports could feasibly transport products in at least one month of the study period (96 total months in study period). Of the 143 ports for which we were able to calculate transportation distance, 118 ports could feasibly transport products in at least one of the four scenarios (Figure 11). The most ports (118) could feasibly transport artisanal fish meal to a buyer in Ciudad Constitución or La Paz at PIASA's fish meal price (Table 10). Only 31 ports could feasibly transport silage to a buyer in Ciudad Constitución or La Paz at the commodity fish meal price (Table 10).

Table 10: Number of ports that could feasibly transport either artisanal fish meal or silage to Ciudad Constitución or La Paz

Scenario	Product	Value Proxy	Number of Ports with Feasible Transportation
1	Silage	PIASA FM	76
2	Artisanal FM	PIASA FM	118
3	Silage	Commodity FM	31
4	Artisanal FM	Commodity FM	95

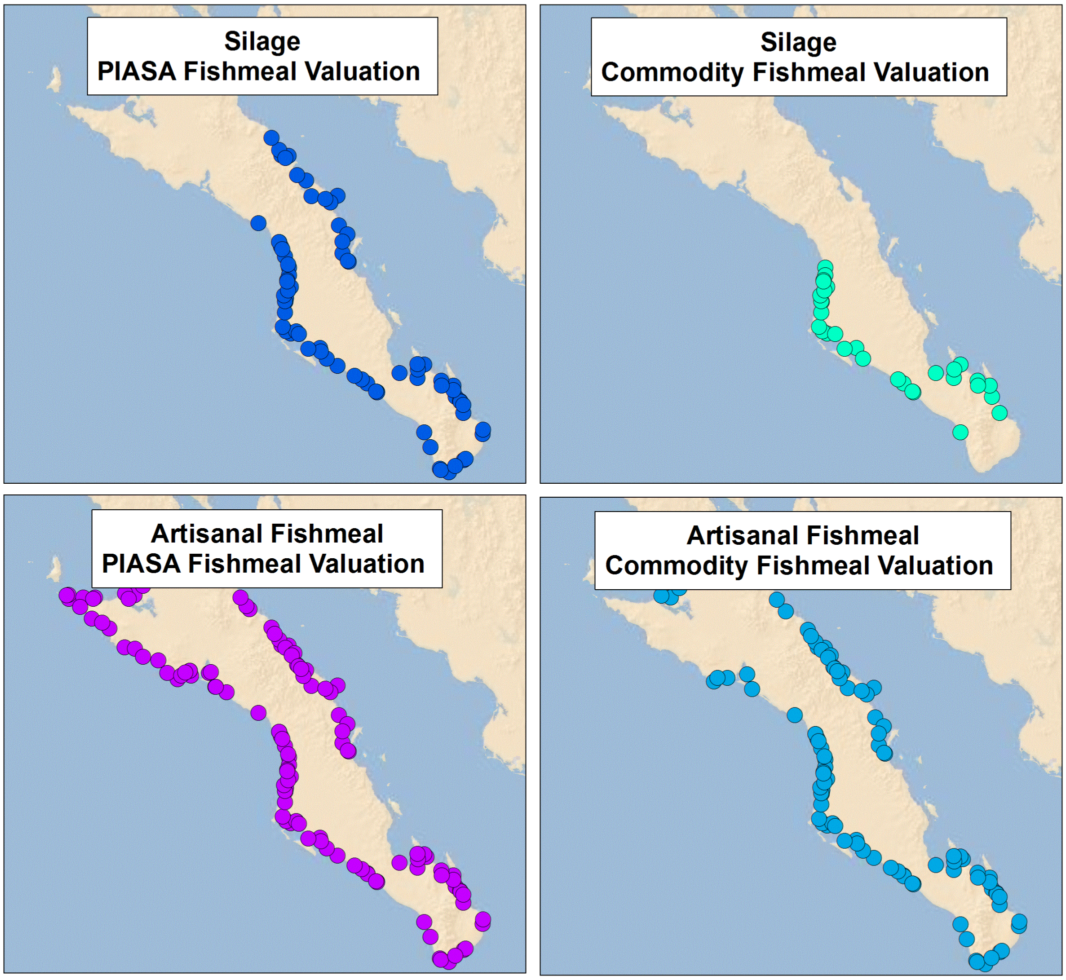

Figure 11: Ports that could feasibly transport either artisanal fish meal or silage to Ciudad Constitución or La Paz.

Part 3: Assessing Consistency of Supply

Part 3 Methods

A key concern of buyers of silage or artisanal fish meal is the supply consistency of both the quantity and quality of feed inputs. To determine consistency of supply for each port, we divided the total number of months in which transportation of a product was deemed economically feasible by the total number of months in the study period (8 years x 12 months/year=96 months). Then, we isolated ports that could feasibly transport silage or artisanal fish meal to a buyer at least 50% of the study period (48 out of 96 months). These are termed “consistently feasible ports.”

Part 3 Results

A total of 27 ports could feasibly transport products for at least 50% of the study period (48 out of 96 months) in at least one of the four scenarios (Figure 12). Production of artisanal fish meal allowed the most ports (27) to consistently transport product to a buyer in Ciudad Constitución or La Paz at PIASA's fish meal price (Table 11). Only 3 ports could consistently transport silage to a buyer in Ciudad Constitución or La Paz at the commodity fish meal price (Table 11).

Table 11: Number of ports that could consistently transport either artisanal fish meal or silage to Ciudad Constitución or La Paz.

Scenario	Product	Value Proxy	Number of Ports with Consistently Feasible Transportation (50% of Study Period)
1	Silage	PIASA FM	17
2	Artisanal FM	PIASA FM	27
3	Silage	Commodity FM	3
4	Artisanal FM	Commodity FM	20

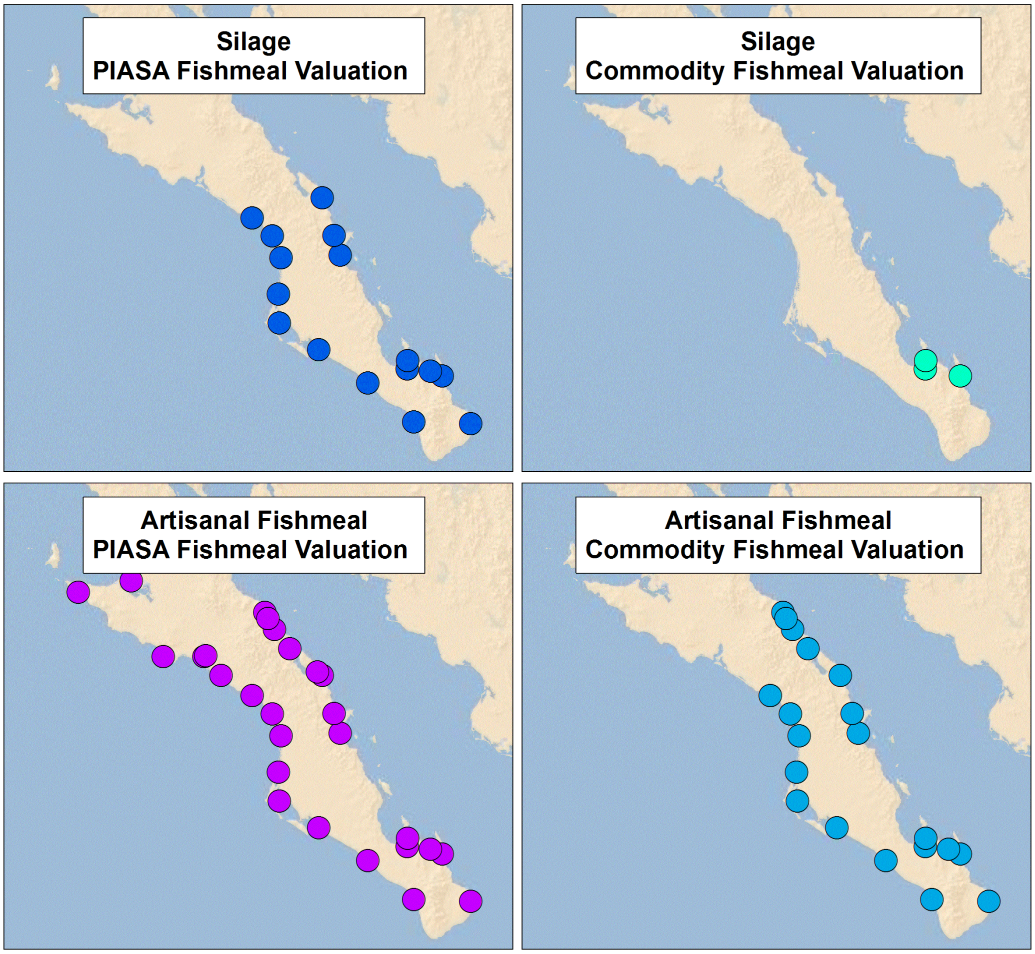

Figure 12: Ports that could consistently transport artisanal fish meal or silage to a Ciudad Constitución or La Paz

When silage is valued at the commodity price of fish meal (scenario 3), production is only consistently feasible at a few locations near La Paz (Figure 12). Furthermore, potential profits and labor generated by silage production are low, indicating that, although feasible, the economic benefits to these areas are limited (Table 12).

Table 12: Average monthly profits and labor hours for scenario 3 (silage at commodity FM price)

Port	Avg. Monthly Profit ($US dollars)	Avg. Monthly Labor Hours for Processing all Waste
PUNTA ARENAS	205	98
LA PAZ	110	34
PICHILINGUE	34	17

Monthly profits are higher under scenario 1 where the increased value of silage generates larger profit margins at each port. However, while profits are higher, monthly labor hours are unchanged as the same quantity of waste is being processed (Table 12 and Table 13). Profits were calculated as a monthly average where unfeasible months yield negative profits due to the sunk costs of producing products with low protein concentrations. For Mulege, average monthly profits were actually negative, indicating that significant volumes of low quality waste were processed during unfeasible months (Table 13). The results for artisanal fish meal scenarios (2 and 4) are not included here but can be found in Appendix 5: Profits and Employment for Artisanal Fish meal Scenarios.

Table 13: Average monthly profits and labor hours for scenario 1 (silage at PIASA FM price)

Port	Avg. Monthly Profit ($US dollars)	Avg. Monthly Labor Hours for Processing all Waste
ADOLFO LOPEZ MATEOS	2,767	150
PUNTA ARENAS	2,232	98
LAS BARRANCAS	1,405	130
PUNTA BENTONITA	204	11
SAN CARLOS	3,635	221
PUERTO CHALE	1,835	86
ENSENADA BLANCA	141	9
LOS FRAILES	178	13
SAN JUANICO PACIFICO	445	74
PUNTA LOBOS	683	58
LORETO	340	37
MULEGE	-353	111
NICOLAS SAN	66	12
LA PAZ	716	34
PICHILINGUE	354	17
SANTA ROSA PACIFICO	430	26
EL SARGENTO	901	63

In Figure 13, the average annual protein content of each port is plotted against that port's distance to the closest buyer. For each scenario, consistently feasible ports are plotted in color. The results show clustering of feasible ports with average annual protein concentrations of 16-19% and distance from the closest buyer less than 300 km (Figure 13). For every scenario there are numerous ports close to a buyer and with a high average protein content that are were not identified as being consistently feasible. This result reflects the disparity between the findings in Figure 11 and Figure 12; many locations could occasionally produce a viable product but only a small subset could do so consistently.

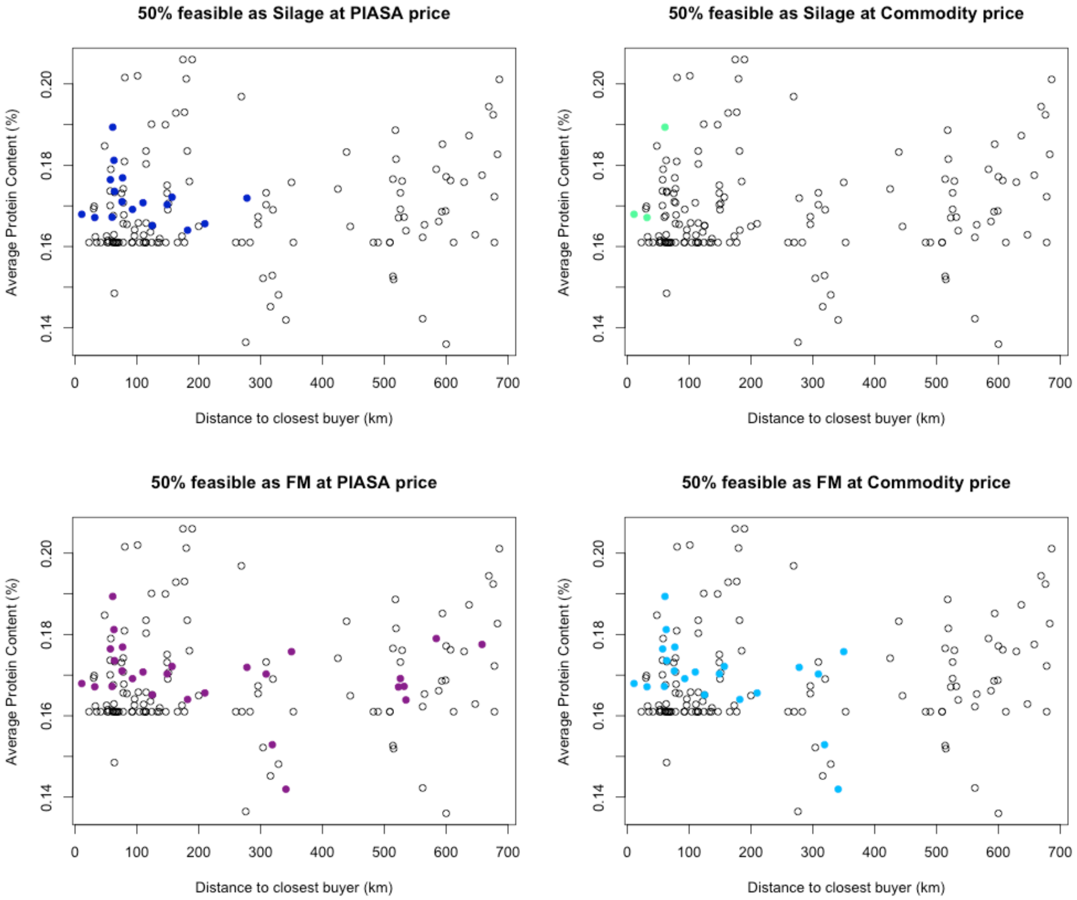

Figure 13: Comparison of annual average protein content and distance to closest buyer for feasible and non-feasible ports

Sensitivity Analysis

Methods

As with all models, the results depend on the underlying assumptions. We tested the sensitivity of the model to each of our input parameters. The relative effect on output and maximum transportation distances were assessed and graphed for comparison. We performed a simple one-factor-at-a-time (OFAT) analysis to determine which input values had the most effect on the output.

Silage protein content was varied over the range of possible concentrations (5% - 25%) to assess how this factor might affect the maximum distance that a product can be transported from a port. The price of fish meal was varied since the price of fish meal that PIASA pays is much higher than the commodity price for fish meal, and the price that would be received for silage or artisanal fish meal is uncertain. Price of the substituted product was tested over a range from just below commodity price to just over the price in B.C.S. ($2.00/kg - $5.00/kg).

Production costs were the most uncertain parameters since prices for, and access to, equipment are likely to vary greatly based on location. Therefore we varied these over a wide range of values: from less than half the estimated cost to more than double it ($0.05/kg - $0.60/kg). Additionally, we tested how increasing the estimated per-unit transportation cost by three fold might affect possible travel distances ($0.001/kg×km – $0.003/kg×km)

We visualized these results in two ways. First, we created heat-labeled matrices of the output to compare the relative importance of each parameter. Second, once the most important variables had been identified, we plotted threshold graphs varying these key parameters against the output distances to determine at what values each product type becomes unprofitable (maximum distance < 0).

Results

Of the four parameters we tested in our sensitivity analysis (protein content, price of substituted product, production costs, and transportation costs), transportation costs and protein content had the largest impact on maximum transportation distance. Protein concentration dictates the value of a product. Since this parameter depends on the species composition of the landings, a change in catch diversity could impact feasibility. Transportation costs also had a large impact on feasibility and in reality are likely to vary depending on local road conditions. Proxy prices of fish meal also had a lower but still substantial influence on output. Given the significant difference in price between commodity fish meal and PIASA fish meal, the number of feasible ports varied significantly between these scenarios. Costs of production showed the least impact on output compared to the other parameters, despite being varied over a wide range. See Appendix 6: Sensitivity Analysis for output tables.

In Figure 14, we graph the potential maximum transportation distances based on varying protein concentrations of silage product given four different costs of transportation (the vertical dotted line highlights differences in distances at 15% protein). At all levels of transportation cost, production becomes unprofitable at a protein content of 7%, but maximum distances vary greatly. For example, if a location produces silage at a protein content of 15%, under our base assumptions they should be able to transport their product about 250km; if the transportation were to become more efficient, this distance could quickly increase to over 500km. If the cost of transportation increases transportation distances would decrease significantly, to less than 100km.

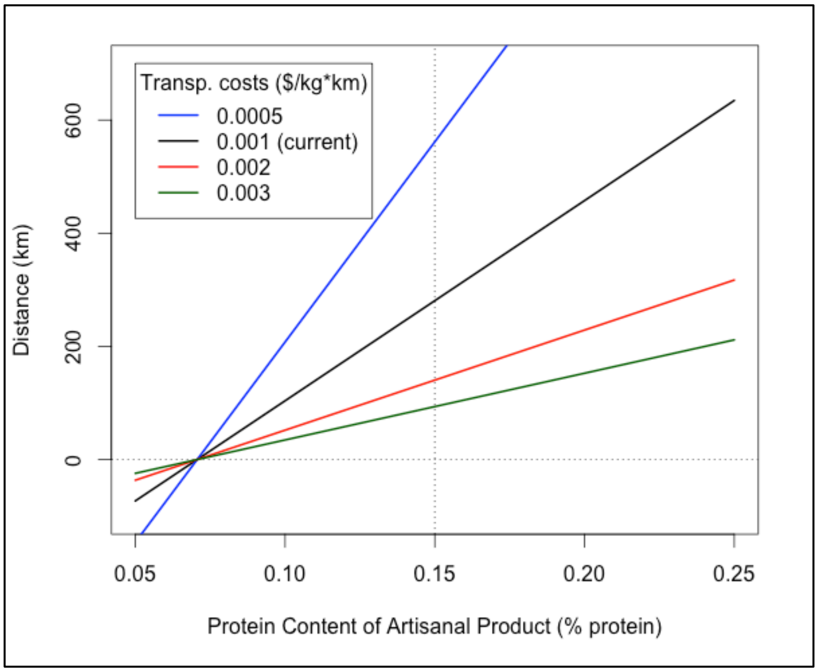

Figure 14: Maximum transportation distance based on silage protein content for four potential costs of transportation.

Limitations

While landings data from CONAPESCA represent the best available estimates of artisanal-scale landings in Baja California Sur, these data have several shortcomings. First, these data sets are self-reported by fishermen and are not confirmed by fishery officials. Though every effort was made to correct errors identified by the authors, it was necessary to omit numerous data entries that could not be resolved. Furthermore, as a self-reported dataset, and in the absence of effective monitoring and enforcement, the landings analyzed in this report represent a very conservative estimate of the actual total landings in B.C.S. A recent study estimated that, after accounting for illegal, unreported, and underreported (IUU) fishing, landings in Mexico were nearly twice the official report.

Additionally, while we could base our estimates of the supply of fishery waste in Baja California Sur on landings data, we were unable to find reliable data to estimate the total demand and willingness to pay of potential buyers of silage or artisanal fish meal. In the absence of these data, we assumed that ports would be able to sell their product at the same price as fish meal or soybean meal. This assumption was supported by communications with personnel at PIASA, who indicated that they would be willing to pay a price comparable to fish meal assuming protein contents are equivalent. However, large volumes of available fish meal substitutes could exceed PIASA's capacity in the short term. Furthermore, if marginal costs rise as larger volumes of fish meal substitutes are incorporated, PIASA may offer a lower price in order to remain profitable.

Finally, our analysis was limited by our assumptions, many of which are supported in the literature but have not been verified in practice. For a discussion of these assumptions, see Appendix 4: Quantitative Economic Analysis Assumptions.

Objective 3: Socioeconomic Considerations

The economic model identifies feasible locations based on the supply of waste and the demand for protein sources, as reflected in the proxy prices considered. However, there is an array of site-specific socioeconomic factors that have the potential to serve as both catalysts and barriers to potential implementation. During the summer of 2013 we spoke with potential stakeholders in B.C.S. to assess the practical feasibility of implementing a program to collect and process fishery waste.

From July 2013 to September 2013 we visited fishing communities in B.C.S. and interviewed fishermen, community leaders, fishing cooperative managers, fish processors, feed producers, farmers, government officials, and scientists. We strove to gain a better understanding of the organizational structure of artisanal fishing communities and current fishery waste disposal practices. Additionally, we sought to examine communities' economic need and relative interest in opportunities for income generation through fisheries waste processing. Through conversations with feed producers and farmers we worked to identify important demand considerations. Finally, we sought to elucidate institutional and technical barriers to implementation through conversations with government officials and scientists. This time on the ground helped inform assumptions of our quantitative analysis and brought to light potential barriers to implementation.

Informed by our time in B.C.S. and the relevant literature, we identified four major classes of socioeconomic considerations that will dictate the success of a waste utilization program:

1. Economic need
2. Social capital
3. Fishing community structure
4. Local demand

These social factors are important to determine a community's willingness to participate, capacity for collective effort, ability to collect and process waste, and distribution of economic benefits (Figure 15). In B.C.S., artisanal fishing communities are idiosyncratic, and the socioeconomic conditions and cultural climate vary among locations (Sanchez et al., 2004). Therefore, while each factor should not be viewed as a mandatory requirement for implementation, when considered together they can help ensure continued success through time.

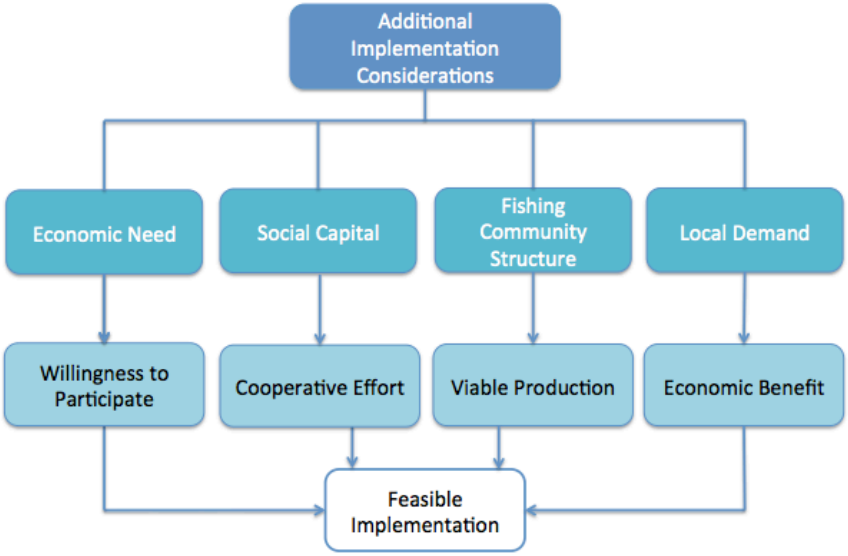

Figure 15: Important socioeconomic considerations for successful implementation of an artisanal fishery waste utilization program.

Economic Need

An assumption of our quantitative analysis is that all available waste at a port is utilized. This requires 100% participation by fishermen and an adequate supply of labor to process the waste. A community's employment demographics are important to consider when assessing willingness to participate and available labor force. The majority of these ports possess very little if any other economic opportunities outside of fishing (Young, 2001), although larger cities, like La Paz have thriving commercial centers.

The presence or absence of other potential employment and income sources, such as seasonal farm labor, government programs, or a growing ecotourism industry, will be a major driver in determining whether or not the production of fish meal alternatives could be an attractive means of employment for the individuals of a community. During our interviews, we found that it is unlikely that the majority of fisherman would be willing to assume the additional work and responsibility of processing wastes. Instead, we found that unemployment rates among women are especially high in the communities of B.C.S., as there are even fewer employment opportunities for women. As a result, women could be a major component of a labor force dedicated to processing fisheries wastes.

Additionally, it is possible that markets for fishery waste could divert marine protein away from direct human consumption. The processing of low-value fisheries products and waste has been shown to threaten the food security of the lowest-income members of a community whom rely on low-value fish and waste products as a major source of animal protein (Kabahenda and Hüsken 2009). As seen in Figure 9, changing fish processing practices have resulted in a more complete use of harvested seafood in B.C.S. This result implies a trend towards more efficient practices and the use of previously neglected material for human consumption. Furthermore, bycatch harvested by the artisanal sector in B.C.S. is often used for subsistence consumption or sold to offset travel costs (Salas et al., 2011). By increasing their value, there is the potential for diversion of byproducts and bycatch away from direct consumption. While there would be some return to these communities in the sale of value-added fish meal alternative products, benefits will not necessarily be realized by those negatively affected by the program. Direct human consumption of resources is both socioeconomically and ecologically preferable to the generation of fish meal alternatives products (FAO, 2012). Therefore, the impact of a program on direct consumption should be monitored closely, though such efforts would likely prove difficult.

Social Capital

Social capital refers to the institutions, relationships, and norms that shape a community's social interactions. Four main factors are commonly used to define social capital: presence of trust, reciprocity and exchanges, common rules and norms, and connectedness in networks and groups (Sawatsky, 2008).

Assessing social capital is important when considering how to strategically utilize and manage a resource such a fishery waste. Efficient processing and transportation of waste is achieved when a community can pool the waste in a centralized location and use shared equipment and resources for processing and transportation. However, fishery waste is produced and owned by individual fishermen and fishing cooperatives in the community. Therefore, communities with high "bonding" social capital will be more likely to cooperate and collaborate internally, which may facilitate community-wide aggregation of waste. Additionally, relations of trust among community members reduce transaction costs between people as waste changes hands during collection, processing, transporting, and selling (Sawatsky, 2008).

Social capital not only encompasses a community's interconnectedness but also its ties to outside organizations and institutions, sometimes referred to as "bridging" social capital. This is important because isolated fishing communities will need to access materials like bacterial cultures and electric grinders, which may be difficult to acquire without connections outside of the community.

It is significant to note that each fishing community in B.C.S. has its own unique form of social capital that may or may not be conducive to a fishery waste utilization program. For example, a study conducted in Magdalena Bay in 2008 found that Puerto Magdalena, a small and isolated fishing community, has high “bonding” but low “bridging” social capital (Sawatsky, 2008). This indicates that while this community may excel at working together to aggregate and process waste, they may face challenges in acquiring materials and connecting with buyers. In contrast, Puerto San Carlos, the largest town along the Bay and a regional port, has low “bonding” and medium “bridging” social capital (Sawatsky, 2008). Members of Puerto San Carlos tend to work more independently and to organize in smaller groups such as the family unit, so a community-wide waste utilization program that requires significant cooperation may be unsuccessful.

Fishing Community Structure

There are a number of features of fishing community structure that may affect whether production of a fish meal substitute would be technically viable. The most important of these is the residency of a port location. Many of the ports included in the analysis are temporary fishing camps, occupied either seasonally or for only a few days a week, with fisherman primarily living in the larger towns or cities around the state (Bizzarro et al., 2009). It is unlikely that the production of either product is viable in these locations, where populations are only present sporadically or change regularly.

Similarly, the leadership structure of a port location can influence whether or not a fish meal alternative can be produced consistently and efficiently. It is common practice in B.C.S. for fishermen to work under a *permisionario*, who provides boats, equipment, and fuel to fishermen in exchange for a portion of the total catch or earnings. During interviews, we learned that despite the fact that a portion of the catch is owed to a *permisionario* in exchange for his services, all of the waste generated is still “owned” by the fisherman. However, it is possible that if a market for alternative products were to materialize, the rights to fisheries waste could change. Additionally, fishing cooperatives are a common leadership structure in the state, and exist in nearly all port locations. It is likely that these cooperatives could provide the management and organization necessary for the success of a project by obtaining necessary inputs for production, mobilizing and overseeing the work force, ensuring consistency in quality of products, and coordinating transportation and sale of final products.

Finally it is important to consider the availability of necessary production inputs at each location. Some of the ports considered in the analysis are geographically remote, and the supply of even basic items such as ice or food can be irregular or absent. As a result, being able to consistently obtain necessary inputs such as vegetable culture in these places could potentially be problematic. Similarly, given the arid climate of B.C.S. and lack of groundwater resources, many port locations are highly water-limited, with some towns paying premium prices to have water trucked in. As a result, the water necessary for the production of artisanal fish meal in particular may not be consistently available, which would limit economically feasible.

Local Demand

The last important consideration is of current demand for fisheries waste as well as the potential demand for alternative products from each port location. Currently, some demand does already exist for waste and processing scraps. Major commercial operations exist in locations such as San Carlos that are utilizing the wastes from the industrial tuna and sardine fisheries as inputs for large-scale fish meal production. Additionally, a small-scale fish meal production plant recently began operations in San Carlos, where artisanal wastes are collected from nearby port locations for fish meal production. Similarly, waste is currently used as trap bait or as bait for sport fishing in a few select locations. Thus, if the value of waste used to produce a fish meal substitute is lower than the value of an existing local use like bait, production will not be viable.

Of similar importance is the consideration of potential local demands for alternative products. In the economic analysis, only the demand by PIASA is considered, and we see that the high transportation distances between many port locations and PIASA make production infeasible. As a result, viable uses of fishery waste may exist at ports not found to be feasible in the model. For this reason, it is important to explore a wider array of alternative and local uses, as discussed previously. The existence of the uses in geographic proximity to a port location could significantly reduce transportation costs and provide a sufficiently consistent demand source to incentivize production at many locations around the state not found to be feasible under the assumptions of our model.

Considering both these current local demands as well as a wider array of potential uses that are specific to a given location is a necessary step in assessing the full potential for fish waste utilization. However, more importantly, it is also a vital means to maximize the overall utilization of waste, maximize the economic potential of a program, and generate the most social good for these participating communities in B.C.S.

Discussion

Aquaculture Production Potential of Fishery Waste

While unfit for direct human consumption, fishery waste has great food production potential if transformed into a feed ingredient. A protein conversion ratio (PCR) is the ratio of protein applied in feed to the biomass of aquatic animal production. PCRs can be used to estimate the biomass of farmed aquatic animals that could be produced from the crude protein in fishery waste. Atlantic salmon, blue tilapia, and black tiger prawn are three common aquaculture species with PCRs ranging from 0.43 to 0.7 (Table 14)

Table 14: Protein conversion ratios for common aquaculture species

Species	Protein Conversion Ratio	Source
Atlantic Salmon	0.43	(Boyd, Tucker, Mcnevin, Bostick, & Clay, 2007)
Blue Tilapia	0.58	(Boyd et al., 2007)
Black Tiger Prawn	0.7	(Boyd et al., 2007)

Annually, an average of 10,953,340 kg of byproducts from the processing of finfish, sharks, rays, and squid are produced by artisanal fisheries in B.C.S. Given the species composition of the waste and the protein concentrations in Table 2, this yields approximately 1,538,643 kg of unused protein per year. Aquaculture feeds are generally 20-50% protein, depending on the species, and protein is generally the most expensive component of aquaculture feeds (Boyd et al., 2007). Using the PCRs in Table 14, we estimate in Table 15 the annual aquaculture production that could be supported by 1,538,643 kg of protein from artisanal fishery waste (Table 15 represents the total production of each species if *all waste-derived protein is used to produce only that species*).

Table 15: Potential annual aquaculture production, given the average annual protein content of fish byproducts in Baja California Sur and protein conversion ratios in Table 14.

Species	Total Annual Production (kg)
Atlantic Salmon	3,578,239
Blue Tilapia	2,652,832
Black Tiger Prawn	2,198,061

In 2011, total aquaculture production in Baja California Sur was 5,859,000 kg (Comisión Nacional de Acuacultura y Pesca (CONAPESCA), 2011). Therefore, full utilization of artisanal fishery waste as protein for aquaculture feeds could support a 48% increase in total aquaculture production on average, depending on which species is cultured. Meeting the protein requirements for this amount of aquaculture production without the use of fishery waste would require harvesting 4,216,615 kg of soybean seeds or 6,259,735 kg of wild Pacific Sardines.

Trends in Waste Availability and Economic Feasibility

The results of our analysis suggest that there are significant quantities of unused and nutritionally valuable byproducts from artisanal fisheries in B.C.S. Although the availability of waste is variable and has declined significantly through time, it may still be economically feasible for select communities to process their waste into silage or artisanal fish meal to be sold as an ingredient in aquaculture or livestock feeds.

The production method (i.e. silage or artisanal fish meal) and price received greatly impact which ports can consistently process and transport their waste to a buyer. This determines the total quantity of artisanal fishery waste that could potentially be utilized in B.C.S. In Table 16, total waste for each scenario was calculated by summing the total quantity of waste produced from the finfish, squid, shark and ray fisheries from 2005 to 2012 from the ports that were found to be economically feasible at least 50% of the time in each scenario.

Table 16: Summary of results from economic feasibility analysis.

Scenario	Product	Value Proxy	Production Costs	Value	Number of Ports with Consistently Feasible Transportation	Total Waste (tonnes)
2	Artisanal FM	PIASA FM	High	High	27	81,428
4	Artisanal FM	Commodity FM	High	Medium	20	78,857
1	Silage	PIASA FM	Low	High	17	5,050
3	Silage	Commodity FM	Low	Medium	3	655
5	Silage	Commodity SM	Low	Low	0	0
6	Artisanal FM	Commodity SM	High	Low	0	0

When the product is highly valued and consumers are willing to pay a price comparable to PIASA’s fish meal price, such as in scenarios one and two, more ports can feasibly process and transport their waste. If, however, the product is viewed as protein substitute for soybean meal and willingness to pay is much lower, such as in scenarios five and six, it is not feasible to process or transport waste from any port location (Table 16).

Additionally, more ports can process and transport their waste if it is made into artisanal fish meal instead of silage. Although the per unit production costs for artisanal fish meal are higher than for silage, fish meal can be transported longer distances because it is a powder rather than a liquid. This means that protein is more concentrated in fish meal relative to silage and the transportation costs per valuable unit (per unit of protein) are lower. It is important to note that this analysis only considers transportation to potential buyers in La Paz or Ciudad Constitución; therefore, the ports found to be economically feasible are concentrated in the southern part of B.C.S., especially in the silage scenarios where transportation costs are higher.

The concentration of feasible ports in southern B.C.S. has important implications for our analysis due to the spatiotemporal distribution of waste availability, and specifically the distribution of squid waste. As shown in Figure 6, over 50% of artisanal fishery waste produced from 2005 to 2012 came from the squid fishery. The high abundance of squid waste is related to both the population dynamics of squid and the processing practices of fishermen. Squid are known to intermittently appear in the Gulf of California in large numbers, creating a boom-and-bust fishery that is highly variable and unpredictable. Some years the squid fishery is highly productive and other years large schools of squid are completely absent from the region. In the past, it was common practice for fishermen to process these squid at sea, throwing approximately 50% of each squid overboard and bringing boats full of squid mantles to shore to sell. These trends are reflected in the landings data, which showed thousands of tonnes of squid waste being produced from 2005 to 2009 (Figure 8).

The presence or absence of squid has a large impact on a port's relative waste availability, as seen in Figure 3, which highlights Santa Rosalía as the major waste hotspot. Therefore, our results show that when artisanal fish meal is produced, buyers in southern B.C.S. can source the product from farther away, thus capturing the waste from the Santa Rosalía region. In Table 16, the large difference in total waste between the artisanal fish meal scenarios (scenarios two and four) and silage scenarios (scenarios one and three) illustrates the impact of sourcing squid waste from northern B.C.S.

However, as consumption practices have changed, and international markets for squid parts other than the mantle have emerged, fishermen have begun to discard less squid. This shift in processing practices, combined with two years of relatively low squid landings, has led to lower waste availability in recent years. Other species, specifically rays and sharks, show similar trends of declining waste availability through time (Figure 9).

These trends are clear when comparing the available waste from the most recent two years of data to the waste from the preceding years. Table 17 shows these values for the three ports that were found to consistently feasible in all four scenarios. All of the ports show significant decreases in waste availability between these two time intervals, particularly in Punta Arenas where average annual available waste drops from 70 tonnes to only 4 tonnes. If this trend continues, the availability of waste may be too low to make production practical. La Paz, in contrast, retains more than half of their historic waste availability with the new processing trends. However, additional social factors suggest that La Paz may not be conducive to production.

Table 17: Average annual waste for the most consistently feasible ports in 2005-2010 and 2011-2012.

Port	Avg. annual waste 2005 – 2010 (tonnes)	Avg. annual waste 2011 – 2012 (tonnes)
La Paz	20	13
Pichilingue	11	3
Punta Arenas	70	4

In order to identify the best location for implementing a pilot project, we conducted a qualitative analysis based on government records and published papers reporting socioeconomic statistics for La Paz, Pichilingue, and Punta Arenas (Table 18). From these sources we looked at levels of available labor, overall infrastructure and fishing effort. We calculated available labor based on both unemployed (people actively looking for work) and economically inactive individuals, which include people old enough to work that do not have jobs and are not looking for work (removing disabled population from this group). We included the economically inactive individuals because, during our conversations in fishing communities, despite being inactive in the labor market, many women showed the most interest in participating.

Table 18: Socioeconomic data for the most consistently feasible ports.

Port	Pop.	Fishing Status	Available Labor	% Available Labor	Infrastructure	# Pangas
La Paz	215,178	Perm	55,526	26%	Significant	8 to 20
Pichilingue	6	Temp	NA	NA	Moderate	11
Punta Arenas	121	Perm	26	21%	Moderate	3 to 40

Of the three ports, La Paz was the most consistently feasible. This is likely due to the fact that the feed producer is located in La Paz, and so transportation costs are the lowest. The capital of B.C.S., La Paz is a large city with over 200,000 inhabitants and significant infrastructure. The size provides a large available labor force but the relatively small percentage involved in fishing (only 8-20 *pangas*) suggests that utilization of waste would have a minimal effect on the community. Although La Paz seems to have a more consistent supply of waste over time (Table 17), there are likely other alternative employment opportunities that currently exist in this urban setting.

Pichilingue was the second most consistently viable port, however only six people are reported to live in the town itself. Although a significant amount of landings are reported at Pichilingue, it is only a temporary fishing community. This indicates that fishermen likely live in La Paz or other nearby towns and travel to Pichilingue to fish. Punta Arenas is only slightly less viable than Pichilingue and supports year-round fishing efforts. The low population (121 inhabitants), moderate level of infrastructure, and relatively high amount of available labor (21%) suggests that this community is the most amenable to implementation (Table 18). Therefore, we recommend that a pilot study be conducted in Punta Arenas (INEGI, Bizzarro 2009).

Alternative and Local Uses

Our analysis focuses on sale of protein products directly to feed producers, but these products can also be used directly in aquaculture, agriculture and livestock operations (Geron et al., 2007). Further analysis would be required to fully assess the relative benefits of direct application versus use in feeds, but bypassing feed production could lower costs for both buyers and producers. In B.C.S., this type of use could also reduce transportation costs.

Farm-made aquaculture feeds are a significant component of global feed production; the FAO estimates that between 18.7 million and 30.7 million tonnes of farm-made feed were produced in 2006 (FAO, 2012). These feeds are generally produced and consumed on-site by small operations, and could benefit from local silage or artisanal fish meal production. In B.C.S., water availability significantly limits terrestrial aquaculture operations and no small-scale open-ocean aquaculture operations currently exist in the region. While no effective method is currently known for utilizing silage for small-scale open-ocean aquaculture, the direct feed of fish scraps or innovations in feed methods could encourage the development of small-scale aquaculture in B.C.S. in the future.

Livestock (cattle, swine and poultry) require relatively low protein inputs, so fish meal has historically been used to supplement grains in animal diets. Recently, demand for marine derived feeds by aquaculture operations have crowded out land-based uses, but the nutritional benefits remain the same (Pike, 1999). Studies have demonstrated successful application of silage in sheep, chicken, pig and dairy cattle feeds, especially when used strategically to improve grow-out and developmental success. In particular, silage has been used to supplement diets in seasons when protein and grazing sources have been depleted (Penedo, Cisneros, & Sosa, 1988) (IAV, 1994). B.C.S. currently supports about 225,000 animals for livestock, including bovine, swine, caprine, ovine and poultry producers (INEGI). These operations may provide a local outlet for ports unable to transport products to commercial feed producers, especially if these farms already produce their own basic feeds.

In addition to their value as a high-quality protein source, silage and fish meal have been used in agriculture as fertilizers and soil amendments (Abbasi, Conn, & Lazarovits, 2004). For agriculture, the ash content (Nitrogen, Phosphorus, Potassium, Calcium, etc.) of the product is the main concern. Many commercially produced fish fertilizers have an NPK rating of approximately 5-1-1. However, fertilizers produced from byproducts will contain elevated calcium levels if fish bones are included, increasing their ash content and potentially their value. Furthermore, the use of fish silage and fish meal in agriculture has been shown to provide growth hormones, important trace elements, promote rhizobacterial activity, and control diseases (El-Tarabily, Nassar, Hardy, & Sivasithamparam, 2003).

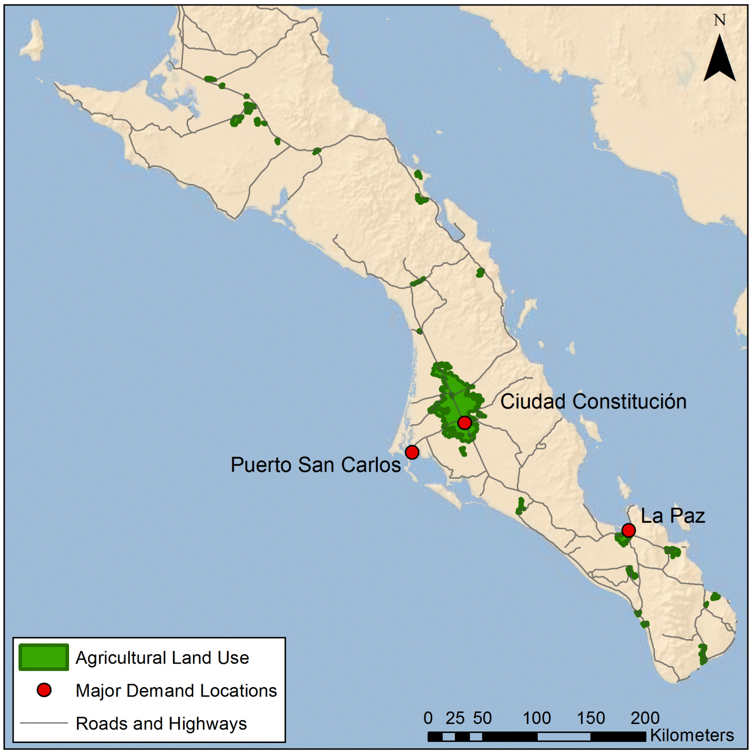

Figure 16: Agricultural land use in B.C.S.

Despite its relatively arid climate, B.C.S. dedicates over 75,000 hectares to agriculture (INEGI). The majority of this agricultural activity occurs in Ciudad Constitución, however, smaller operations are dispersed throughout the state (Figure 16). These locations could provide additional demand for waste products. The state of B.C.S. hopes to expand agricultural production, which would in turn increase demand for fertilizer (SAGARPA). This could increase the market for fishing communities' products while providing local inputs to food production operations.

Ecological Implications

While it may seem as though utilization of fishery waste would have positive ecological impacts by reducing waste and providing a sustainable aquaculture feed ingredient, increasing the value of previously unused fishery products may incentivize ecologically harmful behaviors.

For artisanal fisheries, where there is low diversity and selectivity of fishing methods, catches can contain a considerable number of non-target species (FAO, 2011). In B.C.S., artisanal fisheries showed an increasing trend in catch since 1950. This trend was largely due to a significant increase in the use of motorized *pangas* and gillnets in the region, as shown in Figure 17 (Sala et al., 2004).

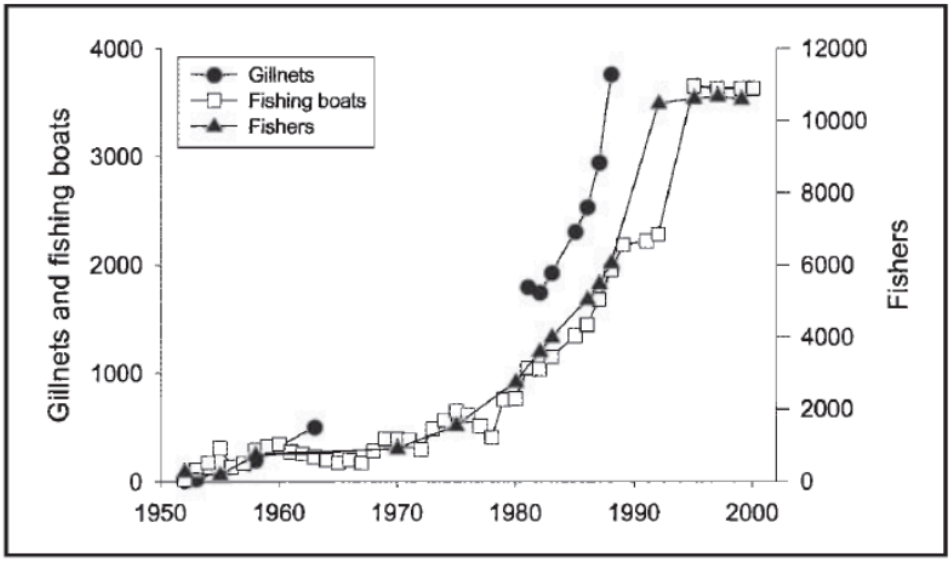

Figure 17: Temporal changes in the number of fishermen, fishing boats, and gillnets in the southern Gulf of California (From Sala et al., 2004)

The expansion of fishing effort, and particularly the use of gillnets, has had major negative effects on marine communities in B.C.S; fishing activities have exhausted many large, high trophic level species and "fished down" to small, lower trophic level species (Sala et al., 2004). This trend may continue or even accelerate if fisheries become more valuable. If fishermen can realize additional income by selling processed waste at a high price to feed producers, they will be incentivized to keep the maximum quantity of waste material, including live bycatch that could be thrown back. Therefore, the use of less selective gear may become further entrenched. Additionally, in areas where more sustainable practices have been introduced, fishermen may revert back to less-selective gear. Due to the limited monitoring capacity in B.C.S., catches that are out of season or below the legal minimum size might be kept rather than returned, and regulating which species are included in each batch of silage will be difficult. As a result, protected species and closed fisheries could become more vulnerable to exploitation.

If the incentives created by a fish meal substitute program are great enough, in addition to keeping non-target species, fishermen might shift their effort in order to target more valuable species for these products. In our research we found that elasmobranchs (sharks and rays) were the most protein rich species group (Table 2) and, therefore, the most valuable in this application. From 1998-1999, Bizzaro et al. identified 83 artisanal fishing camps in B.C.S., many of which were also identified by this analysis. Of these 83 locations, targeted elasmobranch fishing occurred at 40 locations (48.2%). Scalloped hammerhead, *Sphyrna lewini* (IUCN endangered); blue shark, *Prionace glauca* (IUCN near threatened); and Pacific angel shark, *Squatina californica* (IUCN near threatened) were among the primary species observed during the study (Bizzarro et al., 2009). Increasing the value of elasmobranch fisheries could thus have serious implications for important shark populations if other fishing communities start targeting these species more heavily.

Furthermore, the traditional practice of returning the wastes to the shore represents an ecological subsidy, as the waste provides a food source for near shore benthic communities and bird species (Menge et al., 2003). These types of subsidies support important commercial species including crabs and halibut, attracting them to close, accessible areas (Pigott, 1980). Removal of waste would return these near shore environments to a more natural state but will affect any fishery that may have become partially reliant on the subsidy.

Additionally, it is possible that markets for fishery waste could divert marine protein away from direct human consumption. The processing of low-value fisheries products and waste has been shown to threaten the food security of the lowest-income members of a community whom rely on low-value fish and waste products as a major source of animal protein (Kabahenda and Hüsken 2009). As seen in Figure 9, changing fish processing practices have resulted in a more complete use of harvested seafood in B.C.S. This result implies a trend towards more efficient practices and the use of previously neglected material for human consumption. Furthermore, bycatch harvested by the artisanal sector in B.C.S. is often used for subsistence consumption or sold to offset travel costs (Salas et al., 2011). By increasing their value, there is the potential for diversion of byproducts and bycatch away from direct consumption. While there would be some return to these communities in the sale of value-added fish meal alternative products, benefits will not necessarily be realized by those negatively affected by the program. As a result, further equity and justice issues may arise. Direct human consumption of resources is both socioeconomically and ecologically preferable to the generation of fish meal alternatives products. Therefore, the impact of a program on direct consumption should be monitored closely. Unfortunately, detecting the diversion of food resources through reported catch data would be difficult. Instead, this issue should be addressed with the implementation of social nutritional programs, where those whose food security are at risk can be identified and assisted.

Conclusions

Byproducts from artisanal fisheries represent an underutilized resource with the potential to help fill a growing demand for marine protein. With the supply of conventional fish meal limited, processing of this waste material into protein substitutes useable by the animal husbandry industry is increasingly viable. This economic opportunity is particularly significant to Baja California Sur, where the artisanal fishing sector is of critical importance to social welfare. Our results show that the amount of fishery waste in B.C.S. declined from approximately 25,000 tonnes in 2006 to 4,000 tonnes in 2012. This decline was primarily the result of low landings from the squid fishery and the more complete utilization of squid, sharks, and rays for human consumption. Despite these changes, our analysis identified 27 artisanal fishing communities in B.C.S. where the production of fish meal substitutes remains economically feasible, with Punta Arenas representing the best opportunity.

For each fishing community in B.C.S, this analysis determined feasibility by considering variable costs of production, product quantities, nutritional quality, transportation costs, and product value. At any location, feasibility will be greatly affected by transportation costs, with transportation distances over 350 kilometers largely prohibitive. The protein content of the waste will dictate a buyer's willingness to pay, and changes in this factor have a large influence on feasibility. Furthermore, due to the lower protein content of silage and artisanal fish meal relative to conventional sources, production is not viable if these products are only valued as substitutes for soybean meal. Additionally, there are important local conditions that must be considered before program implementation. We identified four major socioeconomic categories: economic need, social capital, community structure, and local demand. Together, these characteristics will dictate a community's willingness to participate, level of collective effort, effectiveness of production, and potential for economic benefit.

For those areas identified by this analysis, the implementation of a fish meal substitute program can bring employment and added value to the community's fisheries. However, adding value to fishery byproducts has the potential to generate perverse incentives that may increase bycatch, concentrate fishing effort, and divert fish away from direct human consumption. These behaviors could be detrimental in the long-run to both the marine environment and artisanal fishing communities. Therefore, the production of fish meal substitutes from fishery byproducts in Baja California Sur should be considered only on a location by location basis if the local ecological implications are well understood and properly managed.

Recommendations

In light of the conclusion of this report, we recommend that a pilot study be carried out in B.C.S. We have identified Punta Arenas as the most feasible location for a pilot study. This trial would serve as an important proof of concept, allowing for the viability of production methods to be tested on the large scale. Similarly, the pilot study would help determine whether the quality, costs, and willingness to pay of end users estimated in this report are accurate. Similarly, the behavioral responses of fishermen and fishing effort could be observed, which could serve as indication of the likely magnitude of identified ecological damages. Training in production of these products should be facilitated by either a non-governmental organization (NGO) or government agency already working within a community. These existing relationships will be necessary to teach the importance of sustainable practices and promote responsible actions after the third party exits.

Once production has been confirmed to be feasible, profitable, and ecologically benign under the pilot project, wider implementation should proceed cautiously. A beneficial next step would be to generate further data regarding potential social and ecological impacts through the application of behavioral surveys in the fishing communities identified as feasible in the analysis. These surveys would be crucial to the determination of overall willingness to participate and could help predict any shifts in fishing effort that may be expected. Similarly, target species that may be subject to increased fishing pressure as the result of program implementation could be identified as species of concern for an NGO manager.

A managing NGO agency would play an important role in coordinating efficient production by disseminating the necessary material inputs and facilitating collection and transportation of final products. More importantly, NGO management and oversight would help promote beneficial ecological and social impacts on a broad scale. NGOs would be able to selectively distribute the necessary equipment and inputs, in effect controlling the entry of participants into the program. This would allow the managing NGO to cap participation, and eliminate the incentive for overall increases in fishing effort. Of equal importance in mitigating ecological impacts will be extensive catch monitoring efforts. NGOs could incentivize better catch reporting if they mandate that only reported catch can be included in the program, improving the transparency of the supply chain in the process. Finally, for ports that are far away from feed producers, options for local use may exist and should be explored; processed fishery waste can be used for farm-made livestock and aquaculture feeds as well as serving as an organic liquid fertilizer in agriculture. These local uses can promote food security, and therefore may represent a significant social and economic benefit to fishing communities.

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Appendices

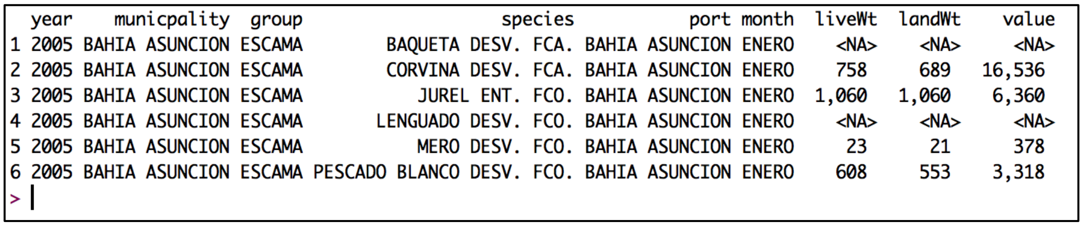
Appendix 1: Data Acquisition, Processing, and Example Data Set

The primary data requirement for this analysis was port-specific landings data for artisanal-scale fisheries in B.C.S. These data were acquired from the Mexican aquaculture and fisheries commission (Comisión Nacional de Aquacultura y Pesca, CONAPESCA) in La Paz who defines “artisanal fishing” as fishing that is conducted from a boat less than 18ft. long.

The data we received contained eight years (2005-2012) of catch data from port communities in B.C.S. Catch is recorded at the species level and includes monthly live weight, landed weight and value. Value was calculated based on prices per species in Mexican pesos (personal communication with CONAPESCA). In addition to being self-reported by fishermen, landings data are not monitored or confirmed by CONAPESCA officials prior to being entered into the database. Due to these rough data collection methods, the data we received were rather inconsistent and disorganized, necessitating extensive organization and formatting prior to analysis. We worked with David (APELLIDO, position from Morgan) from the B.C.S. CONAPESCA office to interpret the data and clarify confusions.

The major issues with the data we received were variable and unintuitive formats between years and inconsistency in names of port locations and reported species. Data were normalized and the specificity and detail of the original data was largely maintained. Reformatting was completed in the statistical computing package R due to its ability to easily manipulate large datasets. Each year was cleaned-up and normalized separately prior to being combined into a single continuous eight-year dataset.

The output table was simplified to a nine-column table with each row representing the catch of an individual, by month, year and port, with reported landed weight, calculated live weight, and value for each entry (Figure 18). The municipality column represents the CONAPESCA office to which the landings were reported. The “species” column also includes processing codes (here, “DESV. FCA.” or eviscerated, and “ENT. FCO.” or whole)(Figure 18). Species names were standardized manually by separating them from processing codes and identifying and relabeling unique species.



```
  year    municpality  group                     species          port month  liveWt  landWt    value
1 2005 BAHIA ASUNCION ESCAMA        BAQUETA DESV. FCA. BAHIA ASUNCION ENERO    <NA>    <NA>     <NA>
2 2005 BAHIA ASUNCION ESCAMA        CORVINA DESV. FCA. BAHIA ASUNCION ENERO     758     689   16,536
3 2005 BAHIA ASUNCION ESCAMA            JUREL ENT. FCO. BAHIA ASUNCION ENERO   1,060   1,060    6,360
4 2005 BAHIA ASUNCION ESCAMA       LENGUADO DESV. FCO. BAHIA ASUNCION ENERO    <NA>    <NA>     <NA>
5 2005 BAHIA ASUNCION ESCAMA            MERO DESV. FCO. BAHIA ASUNCION ENERO      23      21      378
6 2005 BAHIA ASUNCION ESCAMA PESCADO BLANCO DESV. FCO. BAHIA ASUNCION ENERO     608     553    3,318
> 
```

Figure 18: Sample of final CONAPESCA dataset for artisanal fisheries in B.C.S.

In order to examine the data spatially, coordinates were sourced from government records and academic publications. Two studies conducted thorough assessments of the artisanal fishing communities on the Pacific and Gulf Coasts of Baja California Sur, respectively(Ramirez-Amaro et al., 2013) (Bizzarro et al., 2009). These publications contained accurate coordinates that were invaluable in defining locations of reported ports. We supplemented these locations with the CONAPESCA atlas of fishing locations, which included ports and fishing communities as well as offshore landing sites. To ensure that the port locations were inhabited, we supplemented these locations with GPS points of registered localidades (fine scale state registered population sites) from the government geography and population statistics agency (Instituto Nacional de Estadistica y Geografía, INEGI). Finally, since fishermen created the original records, we spoke with local B.C.S. fishermen to identify the whereabouts of mislabeled and unconventionally listed sites.

Table 19: Example data set used in Objective 2: Economic Feasibility Analysis.

Year	Month	Port	Lat	Long	Species Group	Live Weight (kg)	Landed Weight (kg)	Waste Weight (kg)
2005	1	ABREOJOS	26.71	-113.574	ESCAMA	459	417	42
2005	1	ABREOJOS	26.71	-113.574	RAYA	55	50	5
2005	1	ABREOJOS	26.71	-113.574	TIBURON	3131	2157	974
2005	2	ABREOJOS	26.71	-113.574	ESCAMA	119	108	11
2005	2	ABREOJOS	26.71	-113.574	RAYA	11	10	1
2005	2	ABREOJOS	26.71	-113.574	TIBURON	3779	2584	1195
2005	3	ABREOJOS	26.71	-113.574	ESCAMA	267	242	25
2005	3	ABREOJOS	26.71	-113.574	RAYA	339	308	31
2005	3	ABREOJOS	26.71	-113.574	TIBURON	524	412	112
2009	1	SAN CARLOS	24.78	-112.103	ESCAMA	99505	90298	9207
2009	2	SAN CARLOS	24.78	-112.103	ESCAMA	112379	99973	12406
2009	3	SAN CARLOS	24.78	-112.103	ESCAMA	167937	148240	19697
2009	3	SAN CARLOS	24.78	-112.103	TIBURON	376	301	75

Year	Month	Port	Lat	Long	Species Group	Live Weight (kg)	Landed Weight (kg)	Waste Weight (kg)
2009	4	SAN CARLOS	24.78	-112.103	ESCAMA	128302	111360	16942
2009	5	SAN CARLOS	24.78	-112.103	CALAMAR	8600	4300	4300
2009	5	SAN CARLOS	24.78	-112.103	ESCAMA	164878	144083	20795
2009	6	SAN CARLOS	24.78	-112.103	ESCAMA	151361	136944	14417
2009	7	SAN CARLOS	24.78	-112.103	ESCAMA	250575	219097	31478
2009	7	SAN CARLOS	24.78	-112.103	TIBURON	327	218	109
2009	8	SAN CARLOS	24.78	-112.103	ESCAMA	316850	285107	31743
2009	8	SAN CARLOS	24.78	-112.103	TIBURON	21600	9000	12600
2009	9	SAN CARLOS	24.78	-112.103	ESCAMA	126343	114004	12339
2009	10	SAN CARLOS	24.78	-112.103	ESCAMA	81119	73033	8086
2009	10	SAN CARLOS	24.78	-112.103	RAYA	26	24	2
2009	11	SAN CARLOS	24.78	-112.103	ESCAMA	111186	98378	12808
2009	12	SAN CARLOS	24.78	-112.103	ESCAMA	68858	62380	6478
2009	12	SAN CARLOS	24.78	-112.103	TIBURON	133	110	23

Appendix 2: Production Costs

All cited assumptions come from the literature; assumptions made by analysts are denoted by *

General Assumptions

1. The stated fixed and variable costs are the only costs considered in the model (all costs are assumed to be known and constant over time)
2. There is assumed to be a constant return to scale, with costs fixed regardless of the volume of waste processed. As a result, all costs are represented as $ cost per unit of production
3. Given there is little to no access to credit markets by fisherman, costs are not discounted through time (it is also assumed there is no time preference for consumption)
4. All production equipment functions perfectly through its lifetime (no repair or replacement costs)
5. All costs are marked up 20% to account for transportation of goods to remote fishing locations
6. When Mexico specific costs figures are not available, American prices stand as substitutes
7. The density of silage is assumed to be 1 kg/L, so volume and mass figures are equivalent.
8. The quality of silage is believed to be consistent and dependent only on protein concentration
9. Given inclusion rates of 80% waste and 20% additives, the amount of waste in each drum of silage is 160 kg
10. The conversion efficiency for artisanal fish meal production is 5:1 waste to final product[1]
11. The life time of equipment is dependent on total usage rather than time since purchase
12. Increased waste volume by port is assumed to be met with purchasing of additional equipment and increases in capacity to process all available resources (all available waste is converted to product leaving no unutilized waste)
13. One work day is 8 consecutive hours and one work year consists of 350 days

Fixed Costs

Electric Meat Grinder (Silage)

Assumptions

- Can grind 400 lbs an hour[2]

- Lifetime of the grinder is 6 months*

$$Lifetime\ Capcity = \frac{400lbs}{hour} = \frac{3200lbs}{8\ hour\ day} = \frac{1451.9\ kg}{8\ hour\ day} \div \frac{160kg}{barrel} = \frac{9.07\ Barrels}{8\ hour\ day}$$

$$\times 175\ days = \frac{1588.02\ Barrels}{6\ months}$$

Electric Meat Grinder (Silage)					
Cost	**Adjusted Cost**	**Lifetime**	**Lifetime Capacity**	**Cost per Barrel**	**Cost per Kg Silage**
$1237.10[2]	$1,484	6 months*	1588.02 Barrels	$0.93	$0.00467

Electric Meat Grinder (Fish meal)

Assumptions

- Can grind 400 lbs an hour
- Lifespan of 1 year*

$$Lifetime\ Capcity = \frac{400lbs}{hour} = \frac{3200lbs}{8\ hour\ day} = \frac{1451.9\ kg}{8\ hour\ day} \div 50kg =$$

$$\frac{29.038\ \ Bags}{8\ hour\ day} \times 175\ days = \frac{5081.65\ Bags}{6\ months}$$

Electric Meat Grinder (Fish meal)					
Cost	**Adjusted Cost**	**Lifetime**	**Lifetime Capacity**	**Cost per Bag**	**Cost per Kg Fish meal**
$1237.10[2]	$1,484	6 months*	5081.65 Bags	$0.29	$0.00584

200L Poly Barrel

Assumptions

- Can be filled 4 times per month*
- Lifespan of 6 years*

$$Lifetime\ Capacity = \frac{4\ Uses}{Month} \times \frac{12\ months}{1\ Year} \times 6\ years = 288\ Drums$$

200L Poly Barrel					
Cost	**Adjusted Cost**	**Lifetime**	**Lifetime Capacity**	**Cost per Barrel**	**Cost per Kg Silage**
\$72.00[3]	\$86	6 Years*	288 Barrels	\$0.30	\$0.00150

High-Output Propane Stove and 55 Gallon Drum

Assumptions

- Stove output=25,000 BTU/hour[5]
- Average temperature in Baja is 27^{O} C
- It requires 4 BTU's to Heat 1 L of water 1 ^{O} C
- Ideal mixing ratio of water to waste for filling is 60kg waste : 15L water[1]
- Capacity of the steel drums used for boiling is 85L
- Fish waste must be cooked for 30 minutes at full heat to denature proteins[1]
- Steel drums are purchased used

$$Ideal\ Mixing\ Ratio\ for\ Boiling = 60kg\ waste{:}\ 15L\ water$$

$$60kg\ waste = 12\ kg\ fishmeal$$

$$100\ {}^{o}C - 27\ {}^{o}C = 73\ {}^{o}C$$

$$73\ {}^{o}C \times 15\ L \times 4\ \frac{BTU}{{}^{o}C * L} = 4{,}380\ BTU's$$

$$Time\ to\ boil = \frac{Necessary\ Heat}{Stove\ Output} = \frac{4{,}380\ BTU's}{25{,}000\,\frac{BTU's}{hr}} \approx .2\ hour$$

$$Total\ Cook\ Time = 12\ mins + 30\ mins = 0.7\ hours$$

$$Lifetime\ Capacity = \frac{60\ kg\ waste}{0.7\ hours} = \frac{12\ kg\ fishmeal}{0.7\ hours}$$

$$= \frac{137.14\ kg\ fishmeal}{8\ hour\ day} \div 50\ kg = \frac{2.74\ Bags}{8\ hour\ day} \times 350\ days$$

$$= 960\frac{Bags}{Year} \times 3\ years = 2880\ Bags$$

High-Output Propane Stove					
Cost	**Adjusted Cost**	**Lifetime**	**Lifetime Capacity**	**Cost per Bag**	**Cost per Kg Fish meal**
$92.53[5]	$111	3 Years*	2880 Bags	$0.039	$0.000771

55 Gallon Steel Drum					
Cost	**Adjusted Cost**	**Lifetime**	**Lifetime Capacity**	**Cost per Bag**	**Cost per Kg Fish meal**
$10.00[4]	$12	3 Years*	2880 Bags	$0.0042	$0.00008

Solar Drying Poly Tunnel

Assumptions

- A 1x1m area is needed to dry 50 kg fish waste*
- Solar tunnel dimensions are 10mx30m* = 15,000m^2
- Fish meal must be dried for 3 days to remove majority of moisture[1]
- A poly-tunnel will increase ambient air temps enough so that adequate drying occurs
- Spoilage and bug infestations will be prevented completed by the poly tunnel
- The lifetime of a poly tunnel is 1 year at full capacity

Tunnel Component	Cost ($)
10mx30m Poly Tarp (Floor)[6]	$667.00
16mx30m Poly Tarp (Exterior)[7]	$833.00
1 x 30m Segment 1.5" PVC Pipe[8]	$90.00
22 x 8m Segment 1.5" PVC Pipe[8]	$176.00
22 x 2ft .5" Rebar [9]	$13.97
	Total = $2100.47

$$\frac{15{,}000\ m^2}{Poly\ Tunnel} = \frac{15{,}000\ kg\ waste}{Drying\ Session} \div 5 = \frac{3000\ kg\ fishmeal}{Drying\ Session} \div 50$$

$$= 60\ Bags\ Fishmeal$$

$$\frac{350\ Days}{3\ Day\ Drying\ Session} = 116\ \frac{Drying\ Sessions}{Year}$$

$$Lifetime\ Capacity = 60\ bags\ fishmeal \times 116\ Drying\ Sessions$$

$$= 6960\ bags\ fishmeal$$

Solar Drying Poly Tunnel					
Cost	Adjusted Cost	Lifetime	Lifetime Capacity	Cost per Bag	Cost per Kg Fish meal
$2100.47[6789]	$2,520	1 Year*	6,960 Bags	$0.36	$0.0072

Burlap Sack

Assumptions

- 48” x 72”
- Capacity is 50kg of fish waste*
- Lifespan is 20 uses*

$$Lifespan\ Capacity = \frac{50kg\ waste}{use} = \frac{10\ kg\ fishmeal}{use} \times 20\ uses$$

$$= 200\ kg\ fishmeal = 4\ bags\ fishmeal$$

Burlap Sack					
Cost	Adjusted Cost	Lifetime	Lifetime Capacity	Cost per Bag	Cost per Kg Fish meal
$5.48[10]	$7.00	20 Uses*	4 Bags	$1.75	$0.035

Variable Costs

Yogurt Starter

Assumptions

- 1 gram of yogurt starter will yield 5L of culture with sugar and milk[11]
- 1 gram of yogurt starter will yield 2L of culture with only sugar and water*
- 20 L culture per barrel*

$$\frac{\$26.99}{30\ grams} = \frac{\$0.90}{gram}$$

Yogurt Starter				
Price	Adjusted Price	Inclusion Per Barrel	Cost Per Barrel	Cost per kg Silage
$0.90/gram	$1.08/gram	10 grams	$10.80	$0.054

Vegetable Culture Starter

Assumptions

- 1 packet = 0.5 grams[12]
- Sold in sets of 6 packets[12]
- Culture can be recultured from 1L of the previous culture*
- Can recultured a total of 6 times without effects on culture potency*
- 1 packet of yogurt starter will yield 1L of culture with cabbage, sugar, and water[12]

$$Price\ Adjusted\ For\ Reculturing:$$

$$1\ packet = 1L\ culture$$

$$6\ packets = 6L\ culture$$

$$(1\ L\ saved\ for\ next\ culture\ with\ 5\ L\ culture\ yielded)\ x5\ culturings + 6th\ culture\ of\ full\ 6\ L$$

$$= 5(5) + 6 = 31\ L\ per\ 6 - packets$$

$$\frac{\$19.95^{12}}{31\ L\ culutre} = \frac{\$0.64}{1\ L\ culture} = \frac{\$0.64}{0.5\ g} = \frac{\$1.29}{g}$$

Vegetable Culture Starter				
Price	**Adjusted Price**	**Inclusion Per Barrel**	**Cost Per Barrel**	**Cost per kg Silage**
$1.29/gram[12]	$1.54/gram	10 grams	$15.44	$0.07722

Commodity Sugar

Assumptions

- 20 kg sugar per barrel*

$$\frac{\$0.3341}{pound} \times 2.204 = \frac{\$0.736}{kg}$$

Commodity Sugar				
Price	**Adjusted Price**	**Inclusion Per Barrel**	**Cost Per Barrel**	**Cost per kg Silage**
$0.736/kg[12]	$0.89	20 kg*	$15.44	$0.07722

Cabbage

Assumptions

- 2 cups of cabbage are needed for each 1L of vegetable culture[12]
- 1 pound cabbage = 4 cups[15]

$$Inclusion = 40cups = 10\ pounds$$

Cabbage				
Price	**Adjusted Price**	**Inclusion Per Barrel**	**Cost Per Barrel**	**Cost per kg Silage**
\$0.62/pound[14]	\$0.74	10 pounds	\$7.44	\$0.03720

Propane

Assumptions

- All camps have access to propane
- The stove can burn at full output for 20 hours using 8 gallons fuel[5]

$$\frac{20\ hours}{8\ gallons} = \frac{0.4\ gallons}{hour}$$

$$50\ kg\ fishmeal = 250\ kg\ waste$$

$$\frac{250\ kg\ waste}{60\ kg\ batches} = 4.17\ batches\ x\ 0.7\ hours = 2.92\ hours$$

$$2.92\ hours\ \frac{0.4\ gallons}{hour} = 1.17\ gallons$$

Propane				
Price	**Adjusted Price**	**Inclusion Per Bag**	**Cost Per Bag**	**Cost per kg Fish meal**
\$2.86/gallon[17]	\$3.43	1.17 gallons	\$4.01	\$0.08

Gasoline (Silage)

Assumptions

- All camps have functioning generators that can be used to provide electricity for grinders
- Runs for 8.5 hrs on 1.2 gallons[21]

$$\frac{\$3.43^{16}}{gal} = \frac{\$0.906}{L}$$

$$\frac{8.5\ hours}{1.2\ gallons} = \frac{8.5\ hours}{4.54\ L} = \frac{0.53L}{hour}$$

$$Inclusion\ per\ barrel\colon \frac{9.07\ barrels}{8\ hour\ day} = \frac{0.88\ hours}{Barrel} \times 0.901\frac{\$}{L} = \frac{0.4675\ L}{Barrel}$$

Gasoline (Silage)				
Price	**Adjusted Price**	**Inclusion Per Barrel**	**Cost Per Barrel**	**Cost per kg Silage**
$0.906/L[16]	$1.09	0.4675L	$0.51	$0.00254

Gasoline (Fish meal)

Assumptions

- All camps have functioning generators that can be used to provide electricity for grinders
- Runs for 8.5 hrs on 1.2 gallons[21]

$$Inclusion\ per\ bag\colon \frac{29.038\ \ Bags}{8\ hour\ day} = \frac{0.2755\ hours}{Bag} = \frac{0.146\ L}{Bag}$$

Gasoline (Fish meal)				
Price	**Adjusted Price**	**Inclusion Per Bag**	**Cost Per Bag**	**Cost per kg Fish meal**
$0.906/L[16]	$1.09	0.146 L	$0.16	$0.00317

Water (Fish meal)

Assumptions

- Water is assumed to be on average 100% more expensive in fishing ports than the average of city prices

$$Inclusion\ per\ Bag\colon 4.17\ batches\ x\ 15L\ water = 63\ L$$

Water (Fish meal)				
Price	**Adjusted Price**	**Inclusion Per Bag**	**Cost Per Bag**	**Cost per kg Fish meal**
$0.088/L[18]	$0.176	63 L	$11.10	$0.22

Labor (Silage)

Assumptions

- Adequate compensation for labor is \$25/day*
- Total time to produce silage is 2 hours (0.8 hours grinding in addition to prepping and mixing)
- It takes 1 hour to load and unload a truck at pickup and drop-off locations
- Maximum payload of a truck is 800 pounds (4 Barrels)

$$\frac{\$25}{8\ hour\ day} = \frac{\$3.125}{hour}$$

$$Loading\ Labor = \frac{2\ hours}{4\ Barrels} = 0.5\ \frac{hours}{Barrel}$$

$$Processing\ Labor = 2\ \frac{hours}{Barrel}$$

$$Total\ Labor = Loading\ Labor + Processing\ Labor = 2.5\ \frac{hours}{Barrel}$$

Labor (Silage)			
Price	**Inclusion Per Barrel**	**Cost Per Barrel**	**Cost per kg Silage**
\$3.13/hour*	2.5 hours*	\$7.8125	\$0.039063

Labor (Artisanal Fish meal)

Assumptions

- Adequate compensation for labor is \$25/day*
- For each 60kg batch of fish waste being cooked 0.7 hours of labor are required to oversee each batch (mixing, occasional monitoring, and draining)
- Total production labor per bag is 5 hours, with 3 hours for cooking, .5 hours for grinding, and 1.5 hour for prepping and pressing.
- It takes 1 hour to load and unload a truck at pickup and drop-off locations
- Maximum payload of a truck is 800 pounds (16 bags)

$$\frac{\$25}{8\ hour\ day} = \frac{\$3.125}{hour}$$

$$Processing\ Labor = 5.0\ \frac{hours}{Bag}$$

$$Loading\ Labor = \frac{2\ hours}{16\ Bags} = 0.125\ \frac{hours}{Bag}$$

$$Total\ Labor = Loading\ Labor + Processing\ Labor = 5.125\ \frac{hours}{bag}$$

Labor (Fish meal)			
Price	**Inclusion Per Bag**	**Cost Per Bag**	**Cost per kg Fish meal**
$3.13/hour*	5.125 hours*	$16.04	$0.32

Fish meal Bags

Assumptions

- Bags are single use*
- Bag capacity is 50kg[18]

50kg Fish meal Bags				
Price	**Adjusted Price**	**Inclusion Per Bag**	**Cost Per Bag**	**Cost per kg Fish meal**
*$0.05[18]	$0.06	1 bag	$0.06	$0.00100

Appendix 3: Transportation Costs and Cost Data Sources

Transportation Costs

Assumptions

- All fishermen have access to pickup trucks or other equivalent vehicles used for the transportation of final product to end users
- All of these vehicles have a fuel economy and maximum payload similar to a midsize truck such as 2000 Chevrolet Silverado
- All trips to end users are with the truck at full capacity
- Maximum payload of the vehicles are 800 pounds (4 Barrels, or 16 Bags)
- Fuel economy is rounded down to account for decreased fuel economy of full load
- Labor costs per mile are based on $25 a day wages and 40 km/hour average speed
- Vehicle depreciation costs were estimated to be $0.159/mile[22]
- Loading and unloading labor costs are incorporated into production costs
- Together fuel costs, labor costs, and vehicle depreciation costs make up overall transportation costs
- Transportation costs are doubled to account for a vehicles return trip from end user back to port

$$Fuel\ Economy = 10\frac{miles}{gallon} = 2.64\frac{miles}{L} = 4.249\ \frac{km}{L}\ 0.2354\frac{L}{km}$$

$$Fuel\ Cost\ per\ kg * km = Fuel\ Cost \times \frac{Fuel\ Economy}{Max\ Payload}$$

$$Fuel\ Cost\ per\ kg * km = \$0.901 \times \frac{0.2354\ L/km}{800\ kg} = \frac{\$0.00026512}{kg * km}$$

$$Labor\ Cost\ per\ kg * km = \frac{Wage}{hour} \div \frac{Average\ mileage}{hour} \div Max\ Payload$$

$$Labor\ Cost\ per\ kg * km = \frac{\$3.125}{1\ hour} \div \frac{40km}{1\ hour} \div 800kg = \frac{\$0.0000977}{kg * km}$$

$$Vehicle\ Depreciation\ Costs = \frac{\$0.159}{mile} = \frac{\$0.25589}{km}$$

$$Vehicle\ Depreciation\ Costs\ per\ kg * km = \frac{Vehicle\ Depreciation\ Costs\ per\ km}{Max\ Payload}$$

$$Vehicle\ Depreciation\ Costs\ per\ kg * km = \frac{\$0.25589/km}{800\ kg} = \frac{\$0.00031986}{kg * km}$$

$$Transportation\ Cost = \frac{Fuel\ Costs + Labor\ Costs + Depreciation\ Costs}{kg * km} \times 2$$

$$Transportation\ Cost = \frac{\$0.0013655}{kg * km}$$

Transportation Costs			
Fuel Cost/kg*km	Labor Cost/kg*km	Depreciation Cost/kg*km	Total Cost/kg*km
$0.0002651/kg*km	$0.0000977/kg*km	$0.00031986/kg*km	$0.001365 /kg*km

	Cost/Data Description	**Source**	**Source Location**
1	Cottage Fish meal Production	Akande & Simpa	“Cottage Level Production of Fish meal”, 1992, ISBN 978-2345-085
2	Electric Meat Grinder	Katom	http://www.katom.com/248-PSE12.html
3	200 L Plastic Barrel	ULINE	http://es.uline.mx/BL_8154/Plastic-Drums
4	55 Gallon Steel Drum	Ebay	http://www.ebay.com/itm/55-gallon-open-head-drums-/271251363289
5	High Output Propane Stove	Sure Marine Service	http://www.suremarineservice.com/PS65-0000.aspx?gclid=CJP1kJTYkLwCFUiGfgodGg8A0g
6	10x30 m Poly Tarp	Tarp Surplus	http://www.tarpsurplus.com/clear-tarps.html
7	16x30 m Poly Tarp	Tarp Surplus	http://www.tarpsurplus.com/clear-tarps.html
8	1.5in PVC Tube	U.S. Plastic Corp.	http://www.usplastic.com/catalog/item.aspx?itemid=23979&

			catid=727
9	0.5in x 20 ft. Rebar	Home Depot	homedepot.com/p/Unbranded-1-2-in-x-20-ft-Rebar-REB-4-615G4-20/202532809#
10	48”72” Burlap Sack	ULINE	http://www.uline.com/BL_227/Burlap-Bags
11	Yogurt Starter		http://bacillusbulgaricus.com/order.php
12	Vegetable Culture Starter	Wilderness Family Naturals	http://www.wildernessfamilynaturals.com/category/culturing-products-veggie-culture-starter.php
13	Commodity Sugar	Index Mundi	http://www.indexmundi.com/commodities/?commodity=sugar-us-import-price&months=360
14	Cabbage	USDA	http://www.ers.usda.gov/media/133287/eib71.pdf
15	Cabbage Density	About.com	http://southernfood.about.com/library/info/blequivc.htm
16	Average Gasoline Mexico	Bloomberg	http://www.bloomberg.com/visual-data/gas-prices/20133:Mexico:USD:g
17	U.S. Commodity Propane (As of 1/5/13)	U.S. Energy Information Administration	http://www.eia.gov/petroleum/heatingoilpropane/
18	Water Costs	Estrada y Associados	http://www.estradayasociados.com.mx/area-information/baja-california/utilities
19	50 kg Fish meal Bags	Alibaba	http://hcstbz.en.alibaba.com/product/918809185-200143803/white_pp_woven_bag_sack_for_50KG_fish meal.html
20	Average Mid-Sized Pickup Fuel Economy	U.S. Department of Energy	http://www.nadaguides.com/Cars/2000/Chevrolet/SILVERADO-1500-PICKUP-1-2-Ton-V8/Regular-Cab-2WD/Specs
21	Average Mid-Sized Pickup Max Payload	NADA Guides	http://www.nadaguides.com/Cars/2000/Chevrolet/SILVERADO-1500-PICKUP-1-2-Ton-V8/Regular-Cab-2WD/Specs
22	Average generator Fuel Economy	All Power America	http://www.allpoweramerica.com/#!APG3004A/c1yvl
23	Average Vehicle Depreciation	Automotive Fleet	http://www.automotive-fleet.com/statistics/statsviewer.aspx?file=http%3a%2f%2fwww.automotive-fleet.com%2ffc_resources%2fstats%2fAUTOF-36-39-1.pdf&channel=

Appendix 4: Quantitative Economic Analysis Assumptions

In our quantitative analysis, we made several key assumptions.

1. *All available waste is utilized.*
   Our model assumes that all available waste in a port is collected, processed, and sold together. Given that this waste is generated by a variety of fishing cooperatives, families, and individual fishermen, fulfilling this assumption would require 100% participation and significant cooperation among community members. In actuality, cooperative collection and processing would most likely need to be coordinated by a community leader or third party to ensure that there is a fair distribution of benefits to participants. Additionally, we assume that there is enough available labor in each fishing community to process all of the waste.
2. *Protein concentrations in literature are reflective of protein concentrations of fishery waste in Baja California Sur.*
   We used values from proximate analyses in published literature to estimate the protein concentration of raw fishery waste in Baja California Sur. This posed some limitations because most of the available literature focused on marine species from temperate regions, which differ from those found in B.C.S. Additionally, most of the studies conducted proximate analyses in which nitrogen concentrations were used to extrapolate crude protein content. However, some marine by-products—specifically dogfish, shark, and ray waste—contain significant levels of non-protein nitrogen, such as urea, which can significantly alter the accuracy of protein levels determined in this way (Marki, 1990). It is recommended that a nutrient analysis of waste samples from the study region be conducted to confirm actual protein concentrations of the waste.
3. *Protein is conserved during processing and storage.*
   We assumed that all of the protein present in the raw waste would be conserved during processing and storage. However, inefficient processing may result in some protein loss. Additionally, if silage fermentation is not properly controlled, natural enzymes present in the raw waste can break down proteins too far, leading to an overall loss in digestible protein (Backhoff, 1976).
4. *Silage and artisanal fish meal are perfect substitutes for proxy products with the same protein concentration.*
   The price of proxy products was scaled by protein concentration to account for the lower protein content of waste-derived silage and artisanal fish meal compared to industrially produced fish meal or soybean meal. However, even with comparable protein concentrations, silage and artisanal fish meal are more likely to have inconsistent quality and be prone to issues like mold growth.

Therefore, in reality, they may receive a lower price, or in some cases be unsellable due to contamination issues. Additionally, because silage is a liquid, is it not a suitable fish meal substitute in all situations. For example, if a feed producer uses a pelletizer rather than an extruder to produce feed, it is much more difficult to incorporate liquid ingredients into production.

5. *Funds for initial capital investment are available.*
   We assumed that each port would be able to afford the initial capital investment to begin silage or artisanal fish meal production. In reality, a non-governmental organization or government agency will most likely need to subsidize production at the start, especially to fund expensive equipment like electric grinders.
6. *Price proxy for the products is fixed.*
   In this analysis, one price was used for each price proxy. However, in reality, the price of fish meal and soybean meal is highly variable and subject to market conditions.
7. *Constant returns to scale in production.*
   The production processes of silage and artisanal fish meal have not been tested at the community-level scale considered in this analysis, and the cost estimates used in this report were based on extrapolations of small batch experiments. As a result, the cost savings associated with economies of scale cannot be accurately estimated. Second, assuming constant returns to scale allows our approach to avoid estimating feasibility/profitability as a function of total landings. In doing so, we buffer against the unreliability of the data and the assumption that all fishermen landing at a given port will participate.
8. *No discounting of costs.*
9. *Input costs increased by 25% to account for delivery to remote locations.*
   Many fishing communities are located on remote stretches of coastline accessible only by dirt roads or boat. Acquiring the materials for silage or artisanal fish meal production may prove difficult, especially for inputs that are not widely available, like bacterial cultures. Therefore, we increased input costs by 25% to account for the additional costs associated with getting equipment and materials to remote locations.
10. *Uniform transportation costs per kilogram of product per kilometer traveled.*
    In reality, transportation costs will vary based on the local road conditions and existing transportation networks in the area. Some very remote locations may have higher transportation costs due to poor road infrastructure. Other locations may be able to “piggy back” on existing transportation routes and incur lower transportation costs.

Appendix 5: Profits and Employment for Artisanal Fish meal Scenarios

Table 20: Average monthly profits and labor hours for scenario 4

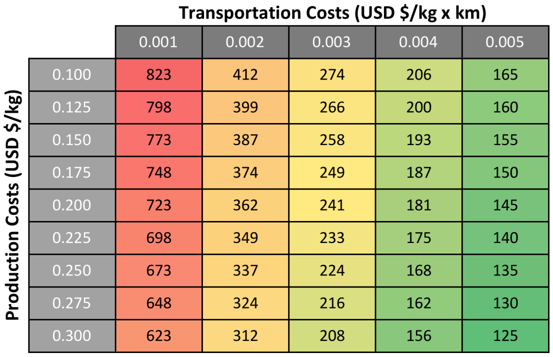
Port	Avg. Monthly Profit ($US dollars)	Avg. Monthly Labor Hours for Processing all Waste
ADOLFO LOPEZ MATEOS	1141	140
PUNTA ARENAS	1022	92
LAS BARRANCAS	558	122
PUNTA BENTONITA	80	10
SAN BRUNO SANTA ROSALIA	8896	2224
SAN CARLOS	1340	207
PUERTO CHALE	728	81
ENSENADA BLANCA	60	9
LOS FRAILES	92	13
SAN JUANICO PACIFICO	212	70
PUNTA LOBOS	406	55
LORETO	204	34
SANTA MARIA GOLFO	215	65
MULEGE	449	104
SAN NICOLAS	37	12
LA PAZ	261	32
PICHILINGUE	133	16
SANTA ROSA PACIFICO	186	24
SANTA ROSALIA	50429	13487
EL SARGENTO	465	59

Table 21: Average monthly profits and labor hours for scenario 2

Port	Avg. Monthly Profit ($US dollars)	Avg. Monthly Labor Hours for Processing all Waste
ADOLFO LOPEZ MATEOS	1141	140
PUNTA ARENAS	1022	92
LAS BARRANCAS	558	122
PUNTA BENTONITA	80	10
SAN BRUNO SANTA ROSALIA	8896	2224
SAN CARLOS	1340	207
PUERTO CHALE	728	81
ENSENADA BLANCA	60	9
LOS FRAILES	92	13
SAN JUANICO PACIFICO	212	70
PUNTA LOBOS	406	55
LORETO	204	34
SANTA MARIA GOLFO	215	65
MULEGE	449	104
SAN NICOLAS	37	12
LA PAZ	261	32
PICHILINGUE	133	16
SANTA ROSA PACIFICO	186	24
SANTA ROSALIA	50429	13487
EL SARGENTO	465	59

Appendix 6: Sensitivity Analysis

Table 22: Sensitivity of transportation costs (in $/km, horizontal) vs cost of production (in $/kg, vertical)



Production Costs (USD $/kg)	Transportation Costs (USD $/kg x km) 0.001	0.002	0.003	0.004	0.005
0.100	823	412	274	206	165
0.125	798	399	266	200	160
0.150	773	387	258	193	155
0.175	748	374	249	187	150
0.200	723	362	241	181	145
0.225	698	349	233	175	140
0.250	673	337	224	168	135
0.275	648	324	216	162	130
0.300	623	312	208	156	125

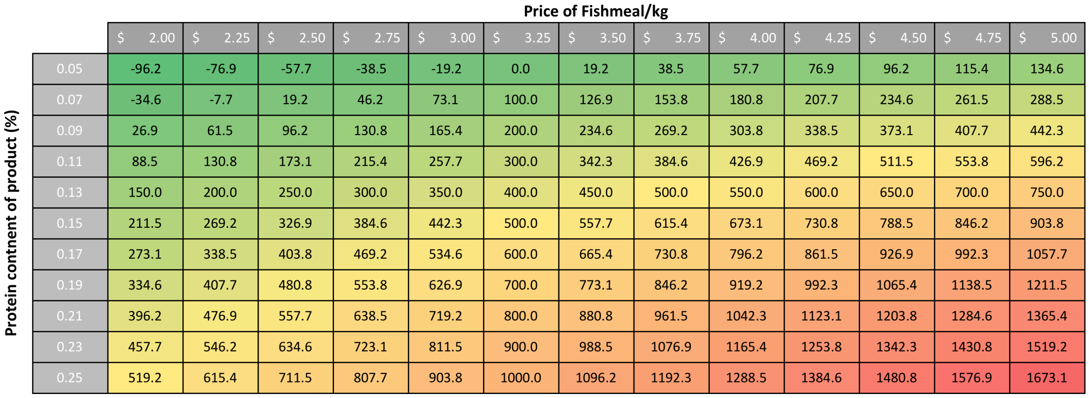
Output in Table 22 shows how potential distances (km) change with variation in each parameter. The color gradient highlights the changes in output with highest values in red and lowest values in green.

Table 23: sensitivity of transportation costs (in $/km, horizontal) vs price of fish meal (in $/kg,vertical)

Transportation Costs (USD $/kg x km)	Price of Fishmeal/kg $ 2.00	$ 2.25	$ 2.50	$ 2.75	$ 3.00	$ 3.25	$ 3.50	$ 3.75	$ 4.00	$ 4.25
0.0010	-135	-19	96	212	327	442	558	673	788	904
0.0015	-90	-13	64	141	218	295	372	449	526	603
0.0020	-67	-10	48	106	163	221	279	337	394	452
0.0025	-54	-8	38	85	131	177	223	269	315	362
0.0030	-45	-6	32	71	109	147	186	224	263	301
0.0035	-38	-5	27	60	93	126	159	192	225	258
0.0040	-34	-5	24	53	82	111	139	168	197	226
0.0045	-30	-4	21	47	73	98	124	150	175	201
0.0050	-27	-4	19	42	65	88	112	135	158	181

Output shows how potential distances (km) change with variation in each parameter. The color gradient highlights the changes in output with highest values in red and lowest values in green

Table 24: Sensitivity of Price of Fish meal (in $/kg, horizontal) vs protein content of product (in g/kg, vertical)



	Price of Fishmeal/kg												
Protein contnent of product (%)	$ 2.00	$ 2.25	$ 2.50	$ 2.75	$ 3.00	$ 3.25	$ 3.50	$ 3.75	$ 4.00	$ 4.25	$ 4.50	$ 4.75	$ 5.00
0.05	-96.2	-76.9	-57.7	-38.5	-19.2	0.0	19.2	38.5	57.7	76.9	96.2	115.4	134.6
0.07	-34.6	-7.7	19.2	46.2	73.1	100.0	126.9	153.8	180.8	207.7	234.6	261.5	288.5
0.09	26.9	61.5	96.2	130.8	165.4	200.0	234.6	269.2	303.8	338.5	373.1	407.7	442.3
0.11	88.5	130.8	173.1	215.4	257.7	300.0	342.3	384.6	426.9	469.2	511.5	553.8	596.2
0.13	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0	550.0	600.0	650.0	700.0	750.0
0.15	211.5	269.2	326.9	384.6	442.3	500.0	557.7	615.4	673.1	730.8	788.5	846.2	903.8
0.17	273.1	338.5	403.8	469.2	534.6	600.0	665.4	730.8	796.2	861.5	926.9	992.3	1057.7
0.19	334.6	407.7	480.8	553.8	626.9	700.0	773.1	846.2	919.2	992.3	1065.4	1138.5	1211.5
0.21	396.2	476.9	557.7	638.5	719.2	800.0	880.8	961.5	1042.3	1123.1	1203.8	1284.6	1365.4
0.23	457.7	546.2	634.6	723.1	811.5	900.0	988.5	1076.9	1165.4	1253.8	1342.3	1430.8	1519.2
0.25	519.2	615.4	711.5	807.7	903.8	1000.0	1096.2	1192.3	1288.5	1384.6	1480.8	1576.9	1673.1

Output shows how potential distances (km) change with variation in each parameter. The color gradient highlights the changes in output with highest values in red and lowest values in green.