Effects of Fuel Costs and Market Product Price on Catch of Small Pelagic Fish

Market Study of the Sardine Fishery in the Gulf of California

By Esteban Arenas

Masters project in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment of
Duke University

Dr. Martin Smith, Adviser
April 2017

Table of Contents

Figures

Tables

Abstract

From a management perspective, what is the best use of forage fish? Global landings of forage fish comprise approximately 16% of the global wild marine fish catch. Forage fish provide livelihoods and a protein source for millions of people worldwide. Also, forage fish are a critical food source for transferring energy from plankton to higher trophic levels in marine ecosystems. Knowing their significance, should forage fish be made into fish meal and used in agriculture, canned for domestic human consumption, frozen fresh as feed for blue fin tuna mariculture, or left in the ocean to serve ecological functions? Recognizing that this is a complex topic, this projects aims to analyze the sardine Mexican fishery solely from an economic standpoint and identify externalities or relationships in the market that, if managed differently, could have significant effects on economic incentives for the use of sardines. Fuel subsidies are analyzed as a potential tool to influence fishing behavior. It's found that higher fuel prices and differences between high and low quality market sardine prices, incentivize a greater percent catch of high quality sardines. This implies higher production of canned sardine products and thus potentially addressing food security concerns. This economic analysis of the use of the sardine resource in Mexico can consequently be complemented by social, environmental, or other tailored analyses.

Keywords: Sardine, Fisheries, Baja California, Fishing Behavior, Fuel Subsidies, Food security

1. Introduction

Fisheries of small pelagic fish provide livelihoods and a protein source for billions of people worldwide, particularly in low income countries (Beveridge et al., 2013). In 2014, it's estimated that over 16% of global marine landings were small pelagic landings (FAO, 2017). Human use of pelagic fish ranges but generally can be categorized into canning, fish meal, or fresh use. These products can be used in aquaculture, mariculture, agriculture, sport fishing, or for direct human consumption.

In addition to their social and economic benefits, small pelagic fish are a critical food source for a variety of species in different ecosystems. Being of a low trophic level, they feed on plankton and then form a significant part of the diet of predatory fish, pinnipeds, seabirds, as well as pelagic oceanic predators such as tuna and sharks (Konstantinos, 2014).

Small pelagics typically travel in schools, and due to improving technology, it's becoming an increasingly cost efficient fishery. Boats can head out only when a school has been spotted instead of having to look for it. Purse seining gear allows fishermen to catch the entire school all at once. Additionally, spawning aggregations at particular times of the year can result in large portions of the population congregating in a minuscule fraction of its home range (Erisman et al., 2012). School behavior, spawning aggregations, and purse seine fishing can all lead to the illusion of plenty because catches might not decline year after year. However, often catches of small pelagic fish can be surpassing the capacity of a population to recover, eventually leading to a collapse (Essingtona et al., 2015).

Given the economic and ecological significance of small pelagic fish, it's becoming increasingly important to invest in sustainable fishing practices. However, sustainable practices go beyond ensuring small pelagic stocks are maintained at MSY levels. MSY levels are usually based on market oriented strategies which often put a price tag on ecosystem services (Burkhard et al., 2012). What's often left out is the importance of reserving natural resources to increase ocean productivity and indirectly maximize economic benefits. Some work on assessing ecological benefits of forage fish has been carried out, but much remains to be done (Lenfest, 2012).

Externalities, monopolies, or subsidies can all be distortions in the market that could lead to a suboptimal use of small pelagics. Using the sardine fishery in Baja California and the Gulf of California as a case study, this Masters Project will focus on analyzing the different uses of sardines from an economic perspective.

From a social perspective, there are also food security concerns in the sourcing of small pelagics. Where fish are sourced from, could have effects on food security and nutrition of local populations. Data has indicated that China, for example, extracts the largest percentage of its yearly catch from African waters (Pauly et al., 2014). There have been other studies linking the importance of fish trading to food security, particularly in developing countries (Fabinyi et al., 2016). Therefore, there are concerns of declining fish catch affecting human health (Golden et al., 2016) and efforts to consider the relationship between fish and food security in marine conservation (Darling, 2014).

Another social consideration is the use of small pelagic catch, whether it be for human or non-human consumption. Fish meal or fresh small pelagics are often used as feed for livestock or aquaculture. It is estimated that as many as 90% of fish destined for non-direct human consumption (such as fish meal or oil) are of human consumption quality (Cashion et al., 2017). It's worth considering whether there is an economic failure in the sense that high quality small pelagics are being used to produce low grade final products, such as fish meal. From an ethical perspective, should small pelagics be consumed directly to feed more people or should they be used to fatten farmed animals that then provide less and more expensive total amount of protein for human consumption?

Objective

The objective of this study is to understand the sardine fishery in Baja California and the Gulf of California as well as test the hypothesis that the sardine fishery is not being utilized in an economically optimal manner.

Of course "optimal" use is subjective and can be described from social, economic, ecological, or a variety of other perspectives. Considerations by governments when deciding how to manage a resource such as small pelagics include domestic employment, food security, national economic gain, foreign investment, tourism, and ecological sustainability. Therefore, depending on what priorities are, "optimal" utilization of sardines in Mexico could mean very different things. What would a comprehensive approach to this question look like and what would be some of the tradeoffs?

Recognizing that this is a complex topic, this projects aims to analyze the sardine Mexican fishery solely from an economic standpoint and identify externalities or relationships in the market that, if managed differently, could have significant effects on economic incentives for the use of sardines. This economic analysis of the use of the sardine resource in Mexico can consequently be complemented by social, environmental, or other tailored analyses.

To test this hypothesis, canning, fish meal, and fresh uses of sardine are evaluated from an economic standpoint. Potential market failures are subsidies that misallocate fishing effort across product types and fishing areas, externalities on the environment not being accounted for in the market (e.g. setting quotas that fail to account for the stock dynamics appropriately), or market power in certain industries that influence landings. The first of these issues, the influence of subsidies, can be explored with the data that are available. Through regression analysis, this project examines market benefits and costs of the three uses of sardine and evaluates key variables that significantly impact resource allocation. If any externalities are found to have significant impact on resource allocation, it could be the case that sardine economic use in Mexico is not optimal.

2. Introduction to the Small Pelagics Fishery of Baja California and the Gulf of California

The sardine fishery takes place primarily north of the 20th parallel north on both sides of the Baja California peninsula, the Pacific Ocean and Gulf of California. There are 10 species that make up the fishery, listed in

Table *1*.

Up until 2010, the fishery was divided into four zones with similar fishing units. However, starting in 2011 Isla de Cedros fishing zone was rehabilitated, resulting in the final distinct fisheries shown in Table 2 (INAPESCA, 2011).

Figure *1* is a visual representation of where the different fishing zones are located.

Table 1. Target species listed for management under NOM-0003 for the small pelagic species fishery in Baja California Mexico.
(CONAPESCA, 1993)

Common Name (Spanish)	**Common name (English)**	**Scientific Name**
Sardina Monterrey	Pacific Sardine	Sardinops sagax caerulea
Anchoveta	California Anchovy	Engraulis mordax
Sardina Crinuda	Pacific Thread Herring	Opisthonema libertate
Sardina Crinuda Azul	Slender Thread Herring	Opisthonema bulleri
Sardina Crinuda Machete	Middling Thread Herring	Opisthonema medirastre
Macarela	Chub Mackerel	Scomber japonicus
Sardina Bocona	Pacific Anchoveta	Cetengraulis mysticetus
Sardina Japonesa	Red-eye round herring	Etrumeus teres
Charrito	Pacific jack mackerel	Trachurus symmetricus
Sardina Piña	Shortjaw Leatherjacket	Oligoplites refulgens

Table 2. States and corresponding ports for the small pelagics fishery of the Gulf of California and Pacific Ocean west of the Baja California peninsula (INAPESCA, 2011)

Zone	States/Distinct Fisheries	Ports
West Coast of Baja California (Pacific Ocean)	Baja California	Ensenada
		Isla de Cedros
	Southern Baja California	San Carlos Lopes Mateos in Bahia Magdalena
Gulf of California	Sonora	Guaymas
		Yavaros
	Sinaloa	Mazatlan

Figure 1. Map of states and corresponding ports from which the Mexican Small Pelagics Fishery takes place. This map is original and created through GIS for this report.

Fishing Zones and Ports of the Mexican Small Pelagics Fishery

Esteban Arenas
March 2017
Projection:
GCS_Mexican_Datum_of_1993

According to the FMP and data analyzed previous to its 2011 publication, main uses of small pelagic catch from the fishery are:

1.) Production of fish meal and oil (84%), which is used in the fabrication of balanced feed for poultry, livestock, and aquaculture
2.) Canned product for human consumption (15%)
3.) Fresh and/or frozen (1%)

However, fresh and/or frozen product production has increased since then due primarily to the installation of mariculture tuna farms near Ensenada. In fact, in 2008 fresh/frozen use had increased to 4% and it was estimated that by 2012 that number would increase to 10% (SAGARPA, 2012b). Tuna ranches have increased since then and the government is in the process of granting more mariculture permits (INAPESCA, 2016), suggesting that this number is currently even higher and will continue to grow.

Although all ports have processing capacities for at least two of these uses, proportion of resources allocated to each use varies by port. This is due to nearby market demands as well as species composition in areas near each port. Table 3 lists ports and percentage of resources allocated to each use (SAGARPA, 2012b). Species composition by port, as listed in NOM 003 is the following:

- Ensenada: Monterrey, Anchoveta, Macarela, Charrito, and Bonito
- Guaymas and Yavaros: Monterrey, Crinuda, Macarela, Bocona, Anchoveta, Japonesa, and Piña
- Mazatlan: Crinuda and bocona
- Bahia Magdalena: Monterrey, Crinuda, Macarela, and Bocona

Additional information was obtained from an interview with Armando Coppel, general director of the sardine division of the Pinza group. Pinza is one of the groups with the most participation in the Mexican sardine industry. He said the type of sardine matters for what product you can generate. Monterrey is known to be of the highest quality and is used for high quality canned products and fresh/frozen uses. Macarela and Japonesa are mentioned as potential candidates for human consumption as well. Crinuda can be used for either canned products or for fish meal/oil production. However, if used in cans it will be a lower quality product and cannot have a "premium" label. Bocona, anchoveta, and anchoa are exclusively used for fish meal and oil (Coppel, 2017).

Table 3. Ports and percentage of small pelagic fish resource allocated to the three main uses. Values are not known for spaces without a percentage (SAGARPA, 2012b)

Ports	Fresh/Frozen	Fish Meal and Oil	Canned
Ensenada	85%	-	-
San Carlos Lopes Mateos in Bahia Magdalena	~1%	80-85%	15-20%
Guaymas and Yavaros	~1%	80-85%	15-20%
Mazatlan	0%	100%	0%

In relation to total national landings, 36.72% are from sardines, 10.66% correspond to tuna, and 2.64% are wild shrimp. This puts the small pelagic fishery as the most important nationally in terms of volume, followed by tuna, and in seventh place the shrimp fishery. On the other hand, in terms of monetary value, the order is inverted putting in first place the shrimp fishery, followed by tuna, and in fifth place small pelagics (CIB, 2007).

3. ENSO Effects on the Sardine Stock

El Niño Southern Oscillation (known as ENSO) is a phenomenon that causes significant changes in wind patterns and inter-annual fluctuations in temperature. El Niño typically brings about warmer temperatures while La Niña causes temperatures to decrease.

Particularly for small pelagics in Baja California and the Gulf of California, ENSO events can have significant effects on their population densities and recruitment. Warm surface waters can stop the flow of nutrients that serve as a food source for phytoplankton, which are in turn the food source of small pelagics (Konstantinos, 2014). Penetration of warm water can cause spawning and nursing grounds for small pelagics to be confined towards the cooler northern areas of the Gulf or Baja California (SCS, 2016). Some studies show that the large midriff islands of the Gulf of California is an area where cool water from tidal currents creates a type of refuge in adverse conditions (Nevarez-Martinez et al 2001). Likewise, a different study showed that there was a probability of 5% or less of finding small pelagic eggs in waters warmer than 24°C (Hammann et al., 1998).

A recent el Niño event causing significant positive sea surface temperature anomalies in June 2014, was referenced by INAPESCA small pelagics staff as the cause of low catch (SCS, 2016). Using data collected from fisheries independent biomass detection cruises, INAPESCA stated that most pelagics were at this time scattered and in low abundance deeper in the water column, which reflected the low availability to the fishery (Alvarez-Trasviña et al 2015). The expectation is for the abundance of the Monterrey sardine to continue at low levels until the 2020's (Nevarez-Martinez et al., 2015b).

However, despite recent declining catch in the Monterrey sardine, the relationship between ENSO effects and small pelagics abundance is varied and uncertain. Gulf of California

Monterrey catch data analysis done by INAPESCA show a mild positive correlation with sea surface temperature in the short term (Zuñiga-Flores et al. 2015). Furthermore, other studies have concluded that environment variability and its impact on small pelagics is disperse. In addition to ENSO, abundance is governed by ocean climate processes that are species specific and not well defined (Parada et al., 2013). It's been shown that recruitment does not have a clear correlation with ENSO events, indicating that factors other than primary production, such as predator and fishing pressure, are important in determining juvenile small pelagic survival (Laws, 2000).

4. Methods

4.1 Data

Data for this analysis was obtained from INAPESCA. INAPESCA is a decentralized body of the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) in Mexico. INAPESCA is a fisheries and aquaculture researching institution that provides authorities scientific statements and data to manage fisheries and aquaculture sectors in Mexico.

The data is for vessels in the small pelagics fishery of Mexico and includes total catch, value of catch, species caught, economic entity to which catch is sold, month and year of catch (from 2000 to 2016), and to an extent the quality of the catch. Through additional research, data is complemented with metric ton boat capacity for some of the vessels.

ENSO data is obtained from NOAA as the Multivariate ENSO Index (MEI) (NOAA, 2017). The index is based on the observations of six variables over the tropical Pacific: sea level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. The index is calculated bimonthly for each of the twelve season, starting with Dec/Jan and ending with Nov/Dec. The general idea is that a higher index corresponds to abnormal warmer water temperatures while a negative index corresponds to abnormal cold water temperatures. More information on MEI can be found on the NOAA website (NOAA, 2017).

Mexican diesel prices are combined using data from the World Bank (Banco Mundial, 2016), the Mexican National Index of Consumer Prices (INPC) (AMEGAS, 2017), a paper on diesel prices by the Mexican university Metropolitana Unidad (Taboada et al., 2009), and another paper on fuel prices in Mexico by an economist from the University of Guanajuato (Ramírez, 2014).

Diesel prices obtained from the World Bank are for every other year from 2000 to 2009. This data is yearly averages for those years. Data for 2010 to 2016 is from INPC. These are monthly diesel price values for each of those years. Data for 2001, 2003, and 2005 is from a Mexican peer reviewed paper (Taboada et al., 2009). These are yearly averages. Finally, 2007 and 2009 data is from another Mexican peer reviewed paper (Ramírez, 2014). This is yearly average values as well.

4.2 Data Cleaning

Mexican Diesel Prices

As explained above, prices for different years are obtained from different sources. Since the fisheries data set is from 2000 to 2016, only those values are used. Some values were found as a yearly value while others included the price each month for the given year. Therefore, to combine them all, monthly fuel prices are kept as such. Yearly values are assigned to each month within that particular year (all monthly values in that year are the same). The end result is a fuel prices data set with prices for all months for the years 2000 to 2016.

Furthermore, all prices are deflated using the CPI with base year 2010 from Banco de Mexico (Banco, 2017).

ENSO

ENSO data came in bimonthly values for 2000 to 2016. Final ENSO data set used in analysis is derived by finding the average of two consecutive bimonthly values and assigning the outcome to the middle month. For example, Jan/Feb and Feb/March values are averaged and the outcomes is assigned to the month of February. The end result is ENSO data set with values for all months for the years 2000 to 2016.

Original Data Set

Cleaning of the data is based on inconsistencies noted in the data. INAPESCA contacts are consulted prior to any of the decisions being made. The recorded price for which the catch is sold, appears as $0 for some entries. Entries that had a positive catch by weight but $0 recorded value are deleted as errors in the data. An INAPESCA contact corroborated this decision. INAPESCA said data is recorded in a way that all catch should have a positive monetary value associated to it. As recorded length in days of fishing trips, anything above 20 days is deleted as an error. INAPESCA likewise corroborated, saying that a trip is not allowed to be more than 15 days. 20 days is used as an acceptable error margin.

Once data on the metric ton capacity of ships was obtained, INAPESCA data is likewise filtered for any recorded catch that goes above this known capacity for each individual ship. However, INAPESCA mentioned that before 2007 it was not required to report catch within any particular time frame. From 2007 on, it became mandatory to report catch within a maximum of three days after returning to land. Thus, it could be the case that recorded catch before 2007 is actually multiple trips recorded as one. Therefore, it was decided to keep all recorded catch before 2007 and catch from 2007 onward was only kept if the recorded catch did not exceed the vessel capacity by more than 3 metric tons. 3 metric tons is picked, again, as an acceptable margin of error.

There are some vessels reporting catch in the data for which there is no vessel capacity information. Recorded information for these vessels is filtered by the greatest metric ton vessel capacity on record. Again, all values before 2007 are kept and values from 2007 onward are deleted if recorded catch weight is greater than the maximum vessel capacity on record.

Finally, only sardine data is extracted from the entire data set, given that the entire data set contains information on all small pelagics caught. This filtering removes mackerel and anchovy information.

Once the original data is cleaned, ENSO, and diesel prices are matched by year and incorporated into the final data set.

Then the data is parsed by state into the separately managed fishing zones as well as into fresh and whole and industrialized quality catch within each of those zones. Fresh and whole and industrialized are picked as the two quality categories because all other categories (bait, fresh, non-packaging, and fresh and industrialized) comprised less than 1% of the total catch for the fishery. Fresh and whole quality sardines are treated as raw material to produce fresh and whole sardines as well as some canned products. Industrial quality sardines are treated as raw material to produce fish meal.

Finally, price is further trimmed by removing less than .1% of the data. The highest value before trimming was $26310/MT while the average is $79.57/MT. Trimming less than 1% of the data corresponded to removing all price values above $800/MT. Anything above $800/MT was skewing results heavily and it was agreed they are errors, perhaps someone simply forgetting to type in a decimal.

4.3 Summary Statistics

After cleaning of the data summary statistics on variables of importance for this analyses, are shown in **Table *4***. Note that data is organized by trip and specifically species landed in that trip. Furthermore, species are subdivided according to their quality. Therefore, one entry of data corresponds to landings from one trip for a specific quality of one species.

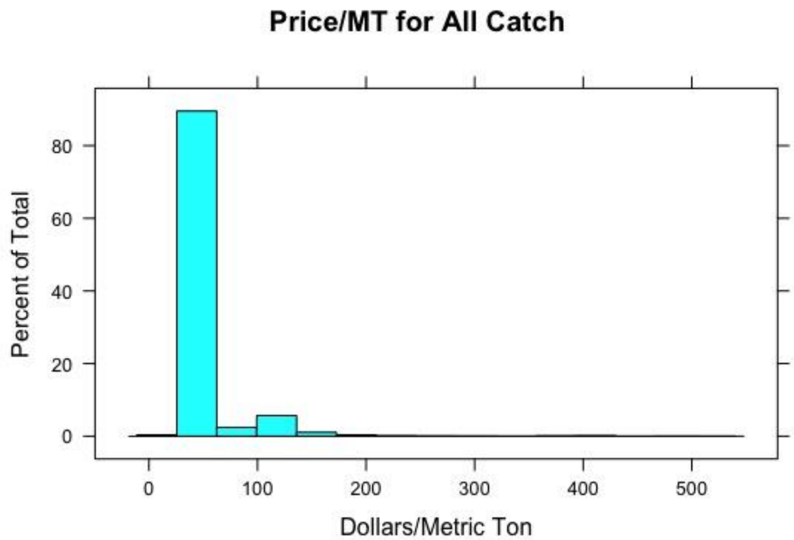
Table 4. Summary statistics from INAPESCA used for analysis
Information shown is after cleaning of the data.

	Enso (MEI Index)	Real Diesel Prices (Pesos Per Liter)	Price ($/MT)	Landings (MT)	Total Value of Landings ($)
Min	-1.882	5.44	9.36	0.001	0.05
1st Quarter	-0.331	6.67	52	25.48	1430
Median	0.14	7.02	52	51.15	2860
Mean	0.1558	8.21	58.55	67.782	3893.07
3rd Quarter	0.725	9.76	52	94.218	5196.93
Max	2.448	12.17	520	771.254	188861.92
SD	0.788	1.99	29.17	60.3	4772.42
N	16113	16113	16113	16113	16113

Some of these variables are heavily skewed, and their distributions are shown visually in the following figures.

Figure 2 shows the distribution of the price variable for the entire data set. This includes all sardine species and all qualities of such.

Figure 2. Price per Landing of the sardine fishery in the Gulf of California (Dollars/Metric Ton)

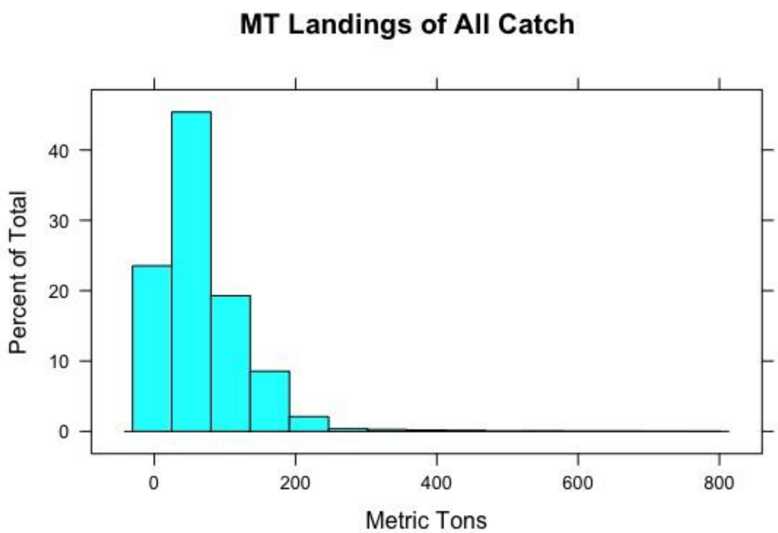


As can be seen in

Figure 2, price data is heavily skewed, with the majority of observations being $52/MT. This is something that called into question the validity of the data. One explanation is that due to vertical integration, true prices are not reported the majority of the time. Approximately just over half of vessels in the fleet are owned by processing plants themselves. In these instances, reported price become an internal transaction and a seemingly aleatory number is reported (in this case $52/MT). For improved data collection, it seems this issue should be addressed. However, lack of enforcement could be an important reason this is occurring and this leads the question of what other data in the fishery might be being misreported.

Figure 3 shows the landings by weight (metric tons) for all sardine species and all qualities of such.

Figure 3. Metric Ton Landings of the sardine fishery in the Gulf of California (Metric Tons)



Landings are skewed as well, with some very high outlier catches reported. As was discussed in the cleaning of the data section, a possible explanation for high reported catch is that previous to 2007 it was not required to report catch in any timely fashion. Therefore, it could be that the catch of multiple trips was reported as the catch of one trip. Furthermore, there might have been errors in data recording.

Likewise, there are several values of just a few Kg of landings reported. Because individual data entries are by species per trip, it could be that they are simply estimates of a few individuals. Perhaps as the landings were being unloaded a few individuals of a different species were seen and therefore reported as part of the catch, in their own separate data entry. It would be valuable to know criteria on exactly how these values are recorded, in order to make informed decisions of what might be a data error and what isn't. Again, if there are no criteria or criteria are not enforced, enforcement would improve the quality of the data.

As can be expected right tail skewed prices and landings by weight lead to right skewed total value of landings as well. The Enso index and diesel prices are shown below in results as functions of time.

4.4. Manipulating Data for Final Regression

In analyzing the economics of the fishery and different tools the government has at its disposal for managing the fishery, fuel subsidies seemed the most interesting to explore further. Given the three different uses for sardine in this fishery (fish meal, canned, or fresh), the question became whether the fuel subsidy impacts the use of sardines. Does the fuel subsidy influence the quality of catch and therefore the use of the catch (fish meal, can, or fresh)?

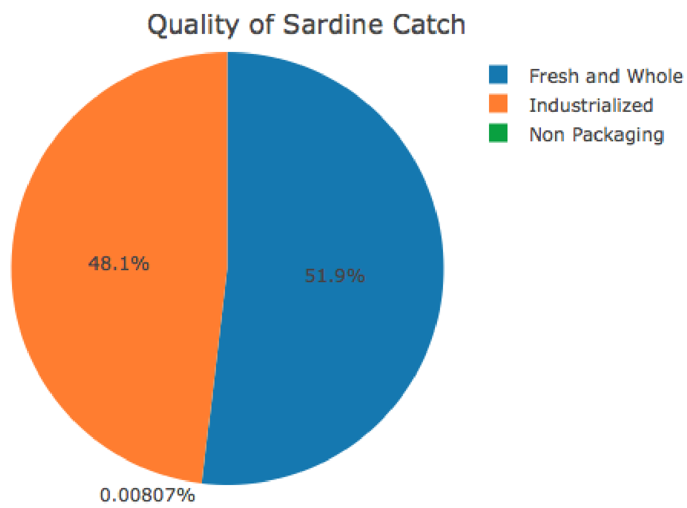
It's worth keeping in mind that there are tradeoffs with the different uses of sardine. Fish meal usually benefits agriculture and aquaculture as feed or protein supplements. Canned products benefit mostly low income human populations as an important source of protein. Lastly, fresh sardines benefit tuna mariculture farms as fresh feed. More sardine resources being allocated to any of these three sectors means less resources get allocated to the other two. As a result, through fuel subsidies the government could influence the use of the sardine resource and therefore favor the beneficiaries of that particular use of the resource.

To test the effect of fuel subsidies on catch, a fresh catch ratio variable and quality difference in price variable are generated from the data. Fresh quality catch is designated to either fresh sardines or for canned products while industrial quality sardine is designated for fish meal.

Data is aggregated by fishing trip and quality, with the mean of catch and price. One trip might have recorded catch for multiple species of either fresh or industrial quality. Aggregating by trip generates the mean metric ton catch as well as mean price per ton, separated by quality, for that trip. Only “Fresh and Whole” and “Industrialized” quality data was extracted from these results.

“Fresh and Whole” and “Industrialized” quality are extracted because, as figure 6 shows, the vast majority of catch in the fishery is one of those two qualities. There are miscellaneous “Non Packaging” and “Bait” qualities. But since they make up such a small percentage of the whole, these are simply excluded from the analysis. “Fresh and Whole” quality corresponds to high quality and this is typically the catch that gets produced into fresh or canned sardine product. On the other hand, “industrialized” quality is low quality and these are typically the sardines that get turned into a fish meal product.

Figure 4. Quality of Sardine Catch in the Gulf of Mexico
Fresh and Whole represents high quality and Industrial represents low quality



Once this is done, through a loop, only trips that recorded both “Industrial” and “Fresh and Whole” catch are selected for. This is important when calculating the price difference of qualities, given that no price will be recorded if a trip had no catch of a given quality. However, this does not mean the price is zero. For the purposes of this study, only vessels that had both “Fresh and Whole” and “Industrialized” quality catch are used in the analysis.

After this organizing process, the results are two entries per vessel trip, one for “Fresh and Whole” and the other for “Industrialized”. Both have associated mean catch by weight and mean price.

Through a series of more loops, our final fresh ratio of catch and difference in price variables are calculated. The fresh ratio is the percent of the catch that is fresh, meaning fresh/fresh + industrialized. Having the mean catch of fresh and industrialized for each trip, fresh catch is simply divided by the total. This assigns that particular trip a Fresh ratio value. Difference in price is the price of fresh minus the price of industrial. Having the mean price of fresh and industrialized for each trip, industrial price is simply subtracted from fresh price. This assigns each trip a difference in price value, corresponding to dollars/metric ton.

Regression results are presented and discussed in the results and discussion sections.

5. Results

Changes in the data through time are shown below, particularly for prices and landings by weight.

Figure 5 shows prices through time by all sardine species. Notice that there is still the problem of price mentioned in the summary statistics section of methods. Most prices recorded are static at around $52/MT, only noticeably deviating from 2010 onward. These seem like aleatory prices recorded perhaps due to lack of enforcement and/or vertical integration.

Figure 5. Price Through Time by Species for all sardines in the Gulf of California

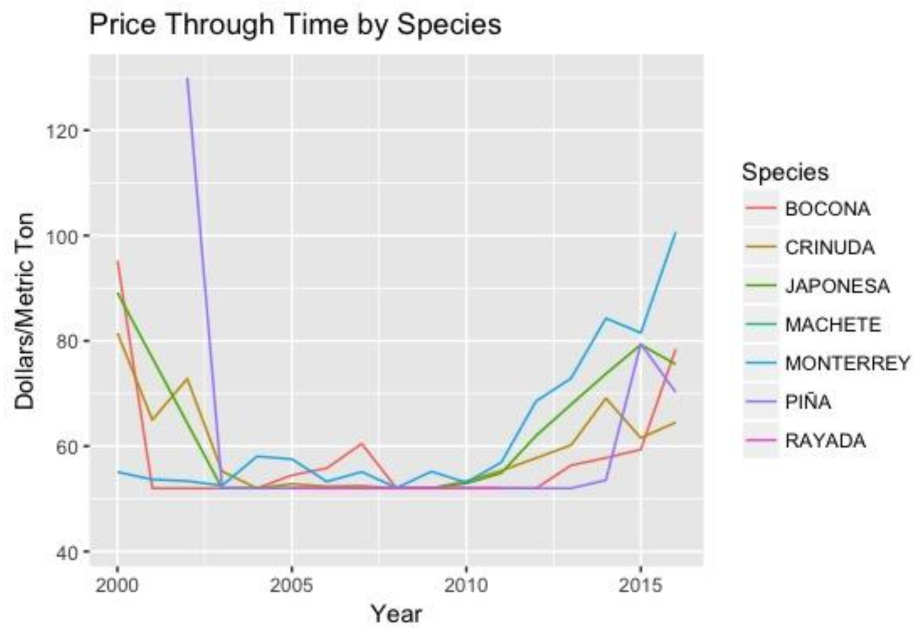


Figure 6 shows price through time again by quality. Again, notice that price doesn't really seem to differ much from the baseline of $52/MT until about 2010.

Figure 6. Price Through Time by Quality for all Sardines

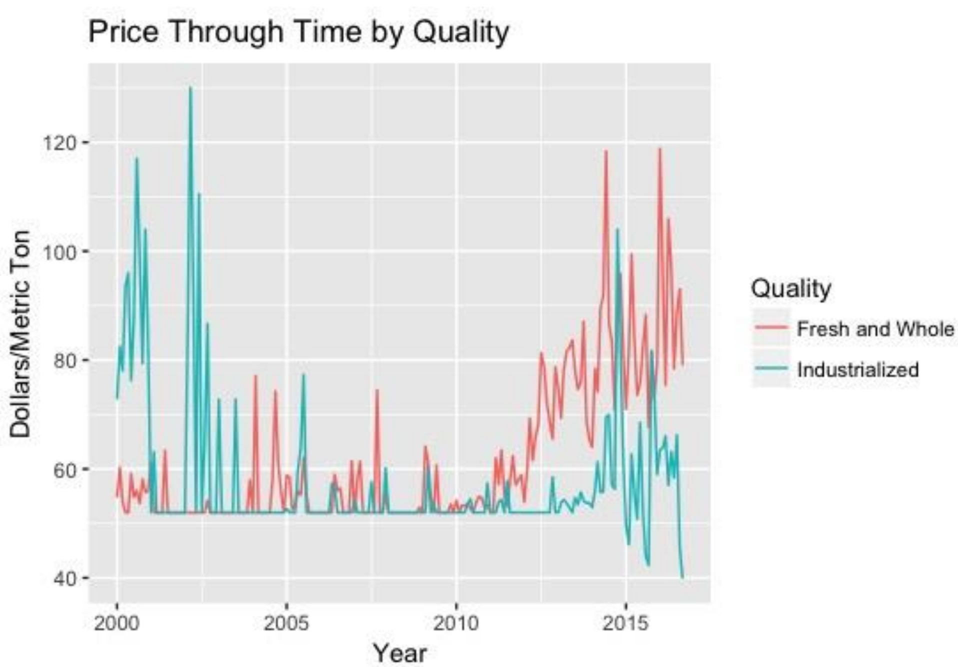
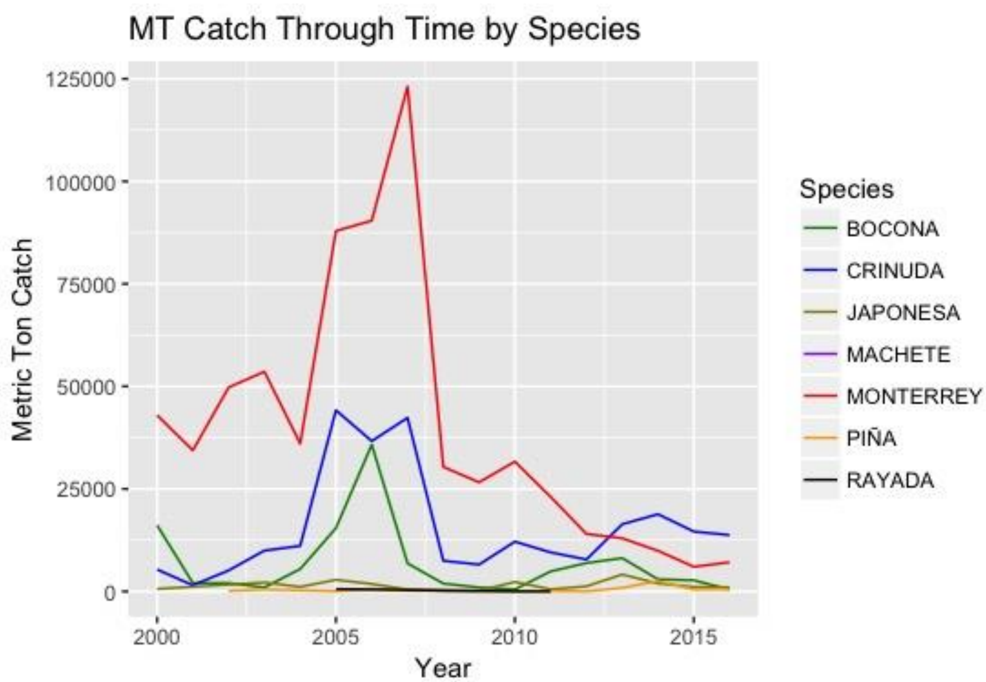


Figure 8 shows catch by weight (metric tons) for all sardines species. After filtering of the data, catch resembles what is known about the fishery through the literature. For all species, catch seems to be decreasing about 2008 onward.

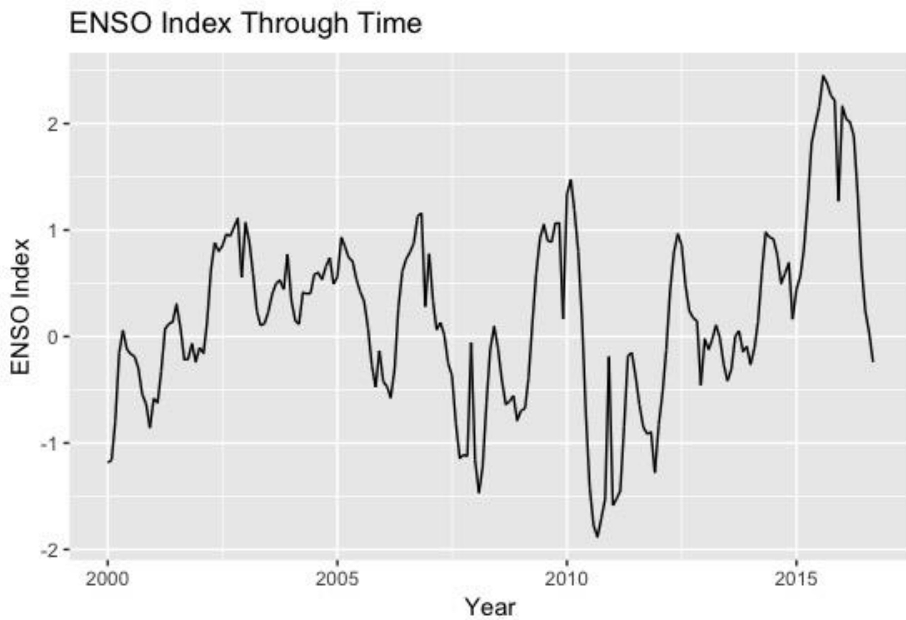
Figure 7. Catch Through Time by Species for all sardines in the Gulf of California



The Enso index is used as a control in our final regression results and shown in

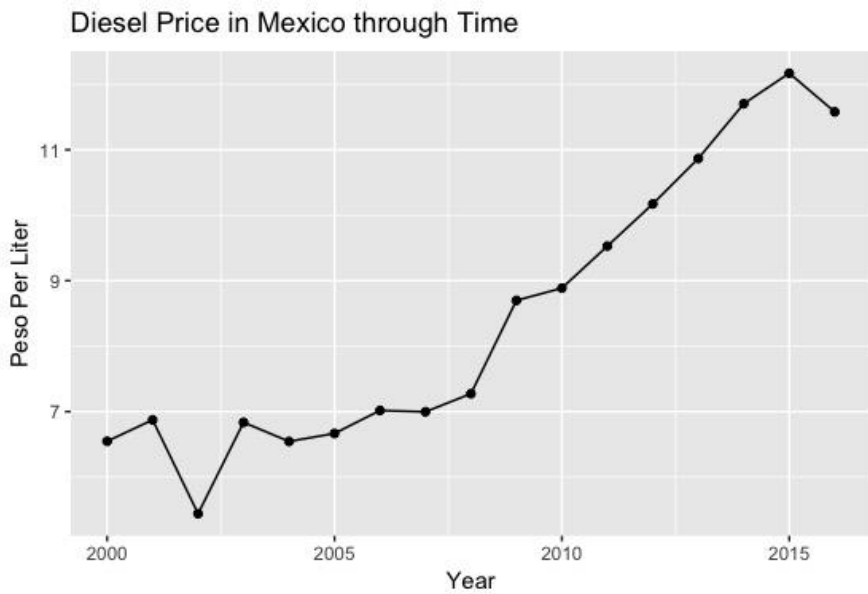
Figure 8. Enso values are monthly. Positive values mean abnormal warmer water and negative values mean abnormal negative water. More information on where the data came from and how it was cleaned can be found in the data sections of the methods.

Figure 8. Enso index from 2000 to 2016



Price of diesel in Mexico is an important variable used in the final regression, evaluating the effect that fuel costs have on catch. Diesel prices have been deflated

Figure 9. Diesel Prices in Mexico from 2000 to 2016



Difference in price and fresh ratio variables are shown below. These are two variables calculated for use in a regression of the effects of quality price on fresh ratio caught. More information on how these variables are calculated can be found in the "manipulating data for the final regression" section within the methods. **Figure *10*** shows the distribution of the fresh ratio variable, ratio of fresh quality catch per trip. The data for this seems evenly distributed. There are no 0 or 1 values, given that only vessels that had at least some catch of both qualities, are used in the analysis.

Figure 10. Ratio or Percent Catch of Fresh Quality Sardines per Trip

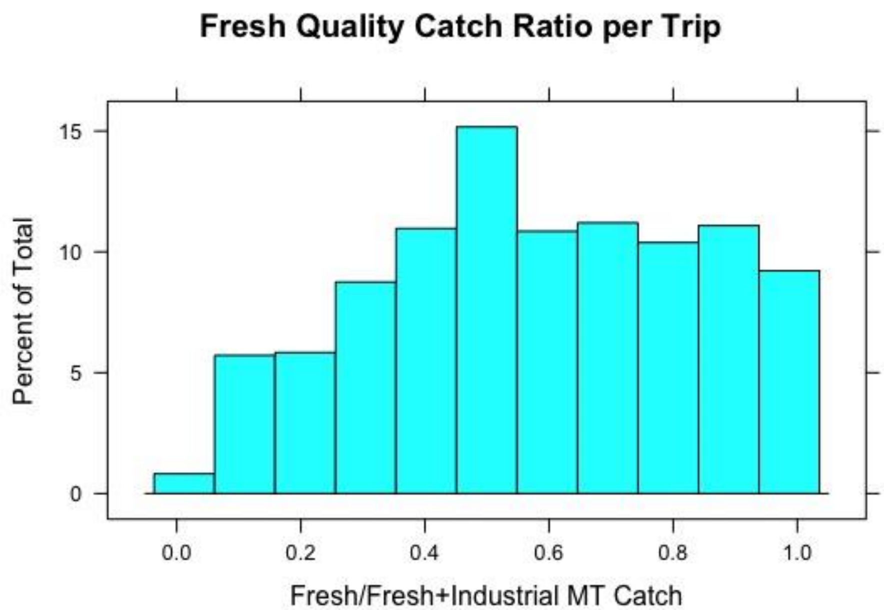
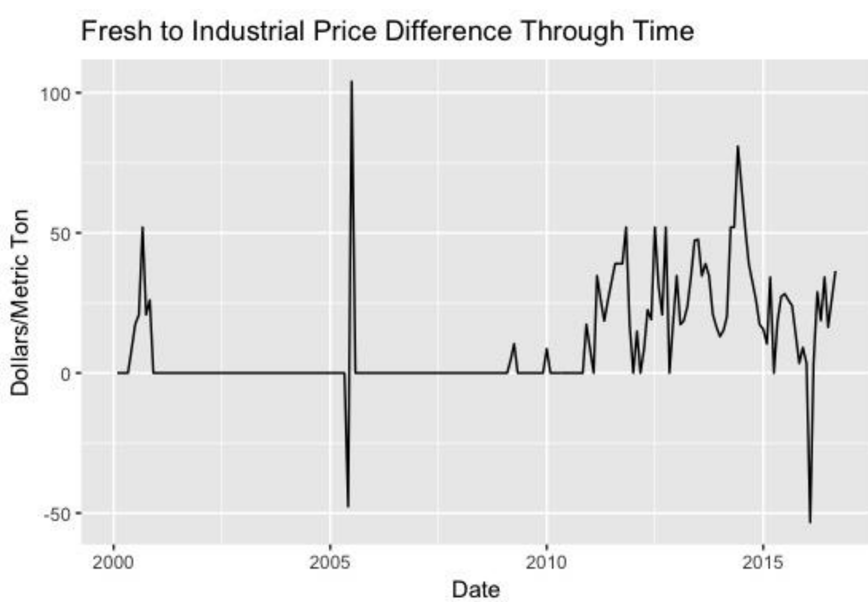


Figure 11 shows the difference in price variable. Notice that differences in price only become clear after approximately 2010. This has to do with prices all being recorded as extremely similar previous to 2010. The price variable is further discussed in summary statistics.

Figure 11. Difference in Price between Fresh and Industrial Quality Sardines



After calculating the difference in price and fresh ratio variables, enso and diesel prices are added to the data frame to then run a regression. Fixed effects are included for months and vessels. Results shown in **Table 5.** Regression Results and Summary Statistics for Effect of Sardine Quality Price on Fresh Sardine Ratio Landed

Table 5. Regression Results and Summary Statistics for Effect of Sardine Quality Price on Fresh Sardine Ratio Landed

Significance of Variables: Signif. codes: 0 (***), 0.001 (**), 0.01 (*). No stars means the p value is greater than .1 and not significant

	Difference in Price (Fresh/Fresh+Industrial)	Real Diesel Prices (Pesos Per Liter)	Enso (MEI Index)	Date
Coefficient	***0.001603	***0.05326	-0.01	*-0.00003944
Standard Error	0.00	0.01	0.01	0.00
t Value	4.05	3.94	-1.19	-2.43
P value	0.00	0.00	0.23	0.02
Residual SE	0.2133			
Multiple R^2	0.3573			
Adjusted R^2	0.2974			
F-statistic	5.963			
DF	783			
Equation	FreshRatio ~ VesselDummies+MonthDummies+Date+Enso+DieselPrice+DifferenceinPrice			
Min	-286	5.44	-1.882	Feb-00
1st Quarter	0	6.997	-0.3935	Feb-06
Median	0	8.698	0.054	Feb-10
Mean	12.36	8.914	0.1647	Aug-09
3rd Quarter	26	10.994	0.7695	Jul-13
Max	104	12.17	2.448	Sep-16
SD	24.92	2.07	0.823	-
N	857	857	857	857

Notice that the coefficients of both differences in price and diesel price are positive and significant. This means that as price difference between fresh and industrial grade sardines increases, we expect to see an increase in the percent of fresh sardines caught. Likewise, if we see an increase in fuel prices, we expect to see an increase in the percent of fresh sardines caught. This is discussed further in the “discussion of results from this study” section.

6. Discussion

Looking at the change of certain variables over time and evaluating the effect of quality price on catch, it becomes clear that fuel costs are an important factor influencing fisher men behavior. Fuel costs in this fishery seem to affect the quality of sardines that fishermen catch, therefore influencing their fishing behavior. Through subsidies the government could influence fuel costs and thus influence quality of sardines caught. Below is literature review on the effects of subsidies on fisheries management and how fuel costs influence fishing behavior. There is also theory discussed on why higher fuel prices might affect catch and finally a discussion of results from this study.

6.1 Literature

6.1.1 Effects of Fishing Subsidies

Academic literature on the effects of fisheries subsidies varies depending on the subsidy and the management of the fishery. There are multiple papers agreeing that subsidies increase profits in the short term, but might decrease profits in the long run or cause socially suboptimal outcomes (Duy and Flaaten, 2016). Furthermore, subsidies can be expected to have an effect on the management and sustainability of the fishery (Munro and Sumaila, 2002).

There have been findings suggesting that subsidies can actually have no effect on stocks with individual quota-based management (Sakai, 2017). However, if management is traditional input/output restrictions, subsidies can have varied effects on stocks. Input controls can be restrictions on the number and size of vessels, amount of time vessels are allowed to fish, gear, etc. Output controls are limits on catch or total landings, such as total tonnage or bycatch limits. In cases of traditional input/output management, subsidies that reduce costs of fishing directly for fishermen can be harmful for stocks while subsidies on general services can be beneficial for stocks (Sakai, 2017). General services are defined as transfers of money not directly received by the fishermen but that reduce costs for the sector as a whole. Examples of this can be expenditures on research, management, enforcement, and infrastructure.

Furthermore, the literature suggests that common pool management strategies correspond to negative stock effects from subsidies while quota based management strategies can be more effective in preventing negative stock effects from subsidies (Duy and Flaaten, 2015 ; Sakai, 2017). In a common pool system subsidies will increase profits in the short run, thus encouraging more vessels to join the fishery. More vessels in the fishery will ultimately cause overfishing, which means lower fish catch and lower profits for everyone (Duy and Flaaten, 2016). The idea is that quota based management will prevent subsidies from resulting in overfishing in the long run. However, studies have shown that under the right set of circumstances, subsidies can drive a fishery resource to extinction even under quota based management (Munro and Sumaila, 2002). It seems that several conditions are required for a quota based management to work effectively, thus suggesting that the existing of a quota based management alone is not sufficient in preventing negative stock effects from subsidies (Sakai, 2017).

Subsidy policies are also likely to be a social and geopolitical tool. Often governments use fishing subsidies to maintain employment, prevent collapse of communities, develop infant fishing industries, maintain cultural and heritage values, or maintaining fleets in internationally conflicting waters (Duy and Flaaten, 2016). In the South China Sea, for example, there is the possibility that counties are subsidizing their fleets, at the expense of an economically inefficient industry, for border security reasons and to maintain their fleets in the shared stock fishery (Duy and Flaaten, 2015).

In conclusion from the literature, quota based management systems appear to be more effective in preventing harmful stock effects from subsidies. However, under the right circumstances subsidies can cause negative stock effects even in quota based management. General service subsidies have been found to have beneficial stock effects in input/output managed fisheries. Cost reducing subsidies have been found to have negative stock effects in input/output managed fisheries. There are also many social and geopolitical considerations when subsidizing fisheries. Therefore, further empirical analysis and international cooperation is needed to determine which subsidies, if any, have beneficial effects for specific management systems.

6.1.2 Fishing Behavior in relation to Fuel Costs and Distance to Fishing Grounds

In terms of how fuel prices and distance to fishing grounds influence location choice and fishing intensity, academic literature does suggest revenues, vessel heterogeneity, distance from port, and market price all being influential variables (Haynie and Layton, 2010; Tsitsika and Maravelias, 2008).

Discrete choice models have been made capable of estimating fishing location choice and expected catch with price and catch data (Haynie and Layton, 2010). It's found that fishing vessel characteristics impact location and expected catch as well because there are different welfare impacts depending on the size of the vessel (Haynie and Layton, 2010). This model can also link catch to revenues and in turn location choices. Monetizing location choices for heterogeneous vessels is useful in predicting the effects that increased fuel prices might have on costs and effort distribution.

Another study found that distance from port and market prices have a significant effect on catch and location choice (Tsitsika and Maravelias, 2008). They find that fishermen in specific fishing grounds develop strategies that maximize their profits, with the best landings to price combinations (Tsitsika and Maravelias, 2008). Things indicates that profits, and therefore costs, are a significant determinant in location choice as well as species and total catch. Furthermore, fishermen seem risk averse given the payoff of increased landings (Tsitsika and Maravelias, 2008). If fuel prices increase, this might indicate that fishermen are more likely to target species and locations that will maximize their profits while minimizing risk.

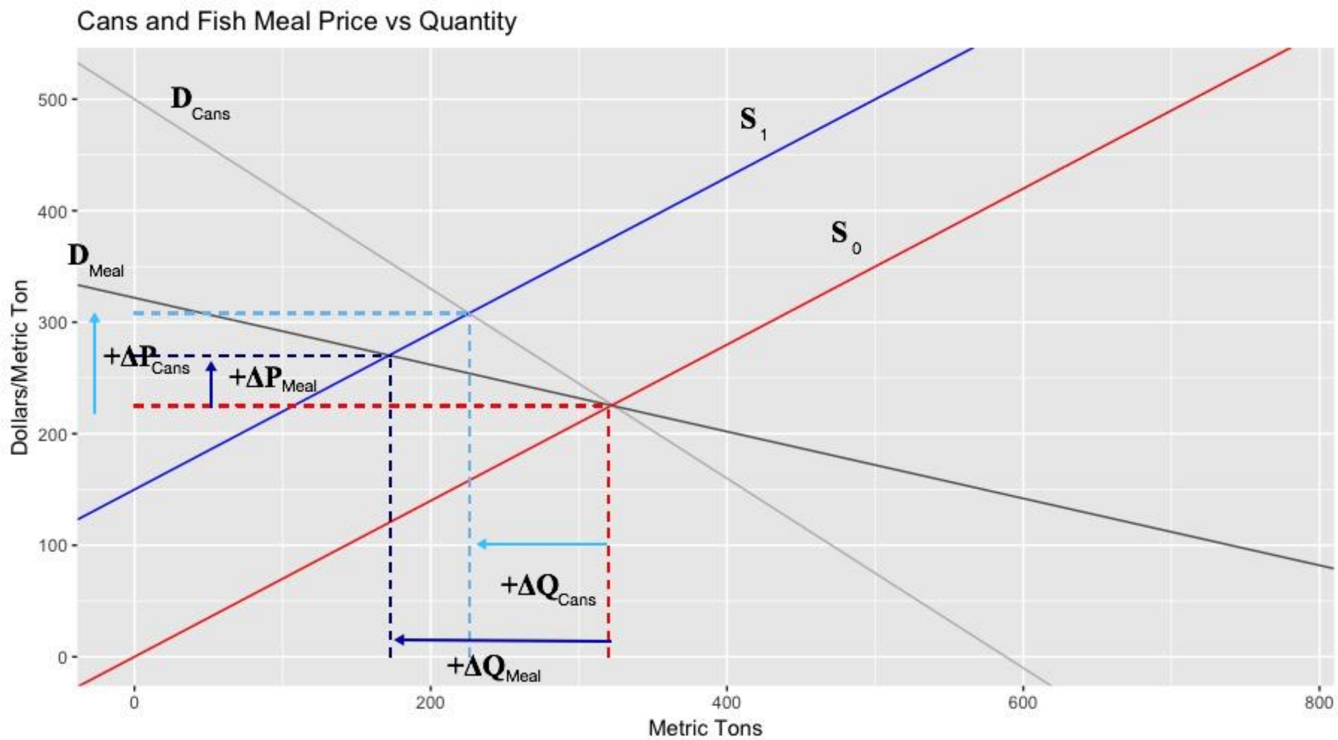
However, in cases where fishermen face a common property, it has been shown that proximity, costs, as well as habit play a strong role in predicting location and distribution of effort (Abbott and Wilen, 2011). The idea of "spatial inertia" is introduced, meaning that if some of the fishermen are having a good catch in a particular area, other fisherman will likely fish there as well regardless of their direct costs or known habitat for the species. Reducing the incentive for fishermen to escape congestion results in localized depletion of the fish resource (Abbott and Wilen, 2011). Habits seems to be strong in determining location and effort choice until catch decreases or alternate information is shared in small groups (Abbott and Wilen, 2011). "Spatial Inertia" could disrupt typical cost and distance incentives brought about by an increase in fuel prices. Likewise, substitute fisheries should be analyzed so that regulations in one fishery does not result in fishermen altering their target species and thus shifting the same problems to another fishery (Holland and Sutinen, 2000).

Finally, it's noted that even with a daily allocation policy management approach, there are exogenous global market and environmental factors that can affect the profitability of a fishery (Huang and Smith, 2014). The general idea of a daily allocation policy is that there are dispatchers which facilitate which vessels fish and which vessels stay in port each day. Daily allocation policy is suggested as a tool to solve the commons problem and manage fisheries in which timing of exploitation is an important source of inefficiency. However, even in efficiently managed fisheries, high global fuel costs, low global product prices, and low target species recruitment can affect the profitability of the industry (Huang and Smith, 2014). Therefore, exogenous variables are important to consider when evaluating whether influencing domestic fuel prices is an effective fisheries management strategy or not.

6.2 Theory

Refer to
Figure 12 as a visual for what this sections is explaining

Figure 12. Theoretical Effect that an Increase in fuel Prices could have on demand function for Fresh and Industrial Grade Sardine
To help visualize the impact, fresh sardines are assumed to be resource for the supply and demand of canned sardines, while industrial grade sardines are assumed to be the resource for the supply and demand of fish meal. Supply moves from S_0 to S_1.



From a microeconomics perspective, fuel subsidies can influence total catch and quality of the catch. Because the quality of catch determines the use of the catch, in theory subsidies can influence the use of catch. In the sardine industry, low quality product is ground up for fish meal, while high quality product is turned into cans for human consumption or kept fresh as feed for tuna mariculture farms. Therefore, fuel subsidies could have an effect on whether production shifts towards more fish meal or more cans/fresh sardines.

If the costs of resources used to produce a good increase, the supply curve for that good will shift to the left. A shift in supply will in turn increase the price of the good. Increased price then leads to a lower equilibrium quantity of sardines produced and consumed.

Assuming the supply curve is the same for both high and low quality sardines, we can analyze demand curve difference and thus different effects a change in price would have in the equilibrium quantity. The steeper the demand curve (bigger slope), a given increase in price will have a smaller decrease in quantity. If the demand curve is flatter (smaller slope), a given increase in price will have a larger decrease in quantity.

It's worth noting that a reduction of subsidies will increase the price for both low and high quality sardines. This will in turn reduce the quantity supplied of both high and low quality sardines. High quality sardines are typically processed into direct human consumption products such as sardine cans. Low quality sardines typically get processed into indirect human consumption products such as fish meal. Therefore, although quantity supplied of both products go down, the supply of fish meal is reduced more than the supply of canned sardines. This means that the percentage of sardine cans being produced from sardine catch, goes up. Assuming the government is willing to continue spending money on the fuel subsidy and can effectively control a sustainable quantity of sardines being fished, the government could instead redirect fuel subsidy funds to a direct high quality sardine subsidy. Going further, the government could subsidize sardine can production directly. If the desired outcome is more sardine can production, a sardine can subsidy might help offset some of the decline in quantity produced when the fuel subsidies go away. Furthermore, the more targeted the subsidy the less distortion and unanticipated consequences there will be in the market.

This leads to conclude that an increase in the price of diesel will shift the supply curve left, thus increasing prices for both high and low quality sardines. This increase in price will reduce in different amounts the equilibrium quantity consumed and produced of high and low quality sardines. Assuming high quality sardine quantity gets reduced less than low quality sardine quantity, the increase in fuel prices will be seen to shift a greater percentage of production towards high quality sardines. This means that a greater percentage production will now be cans and fresh sardines. Ultimately, an increase in fuel prices could be seen to increase the percentage of can and fresh sardines that get produced in Baja California, Mexico.

It's likewise worth keeping in mind that any subsidy will distort the sardine market. If the desired outcome is addressing income inequality and food security concerns, the least economic intrusive approach would be to redirect fuel subsidy funds towards a program designed to reduce income inequality and food security concerns in Mexico at large. Because this sweeping type of program might be very difficult to implement, incentivizing production of more canned sardines is suggested here as a second-best approach.

6.3 Discussion of Results from this Study

The question addressed with the regression in **Table *5*** is whether fuel costs and price change in different quality sardines, influences the percent of the catch that is of higher quality ("Fresh and Whole"). Having fixed effects for vessels, months, and controlling for Enso effects, we notice that both difference in price and diesel prices have a significant effect on the fresh quality ratio of the catch.

Both difference in price and diesel prices have a positive significant effect on the fresh quality ratio of the catch. If the difference between fresh and industrial quality sardines increases by $1/MT, we expect to see an increase of .16% in the percent of fresh quality sardines out of the total catch. If the price of diesel increases by 1 peso per liter, we expect to see an increase of 5.3% in the percent of fresh quality sardines out of the total catch. Therefore, as fuel costs increase, we can expect to see a greater percent of the total catch being higher quality ("Fresh and Whole") sardines. Likewise, as the difference between fresh (high quality) and industrial (low quality) sardines increases, we can expect to see a greater percent of the total catch being fresh (high quality) sardines.

These findings corroborate some of the academic literature on the significant effects of revenues and market prices on fishing behavior (Haynie and Layton, 2010; Tsitsika and Maravelias, 2008). Fishing behavior is seen to be influenced, for example, in fishing location choice (Tsitsika and Maravelias, 2008). Because findings from this report suggest that revenues and market prices influence the quality of catch, we can assume that the fishing location is also influenced by revenues and market prices. It can be assumed that fishermen are adjusting their fishing location in order to catch more of the high quality sardines. Either this, or they are taking better care when storing their catch to maintain it at a higher quality. Further studies would be needed to determine exactly how their behavior is being influenced by higher fuel and difference in prices. However, it's clear that their behavior is affected by more expensive fuel and differences in prices.

From a management perspective, this suggests that the Mexican government could influence fishermen behavior by increasing or decreasing price through fuel subsidies. Currently the sardine fishery is fuel subsidized at 2 pesos per liter. By changing the price of fuel, the government could cause a greater percent of catch to be of higher or lower quality sardines and thus directly influence their use. Regression results from this report suggest that a decrease in subsidies (and thus an increase in fuel prices) would lead to higher quality sardines being caught and thus more cans or fresh sardine products being produced. Proportionally, more cans and fresh sardines would be produced over fish meal.

The implication of higher percentages of sardine catch being used to produce cans or fresh sardines, is that there would theoretically be more sardines for direct human consumption. This ties into consideration of food security as a managing body. Sardine cans as a relatively cheap and storable source of protein, could enhance food security particularly for low income communities. There is literature written on the concern of using a significant amount of human consumption grade fish for non-direct human consumption (Cashion et al., 2017). This is primarily in the use of fish meal or fresh as feed in aquaculture or mariculture.

This study shows that market prices and fuel costs do influence sardine products generated. Therefore, from a social perspective, what is the best use of sardines and should the government use fuel subsidies to influence this? Are there social externalities not being considered by the market that, if internalized, could alter use of sardines toward direct human consumption? Are there externalities in using a direct human consumption grade product for non-direct human consumption? More studies need to be carried to determine if food security is appropriately being accounted for in the market.

Furthermore, even though one can expect higher quantities of fresh quality sardines with rising prices and fuel costs, it's not clear how much of these fresh quality sardines will be turned into caned products. Alternatively, they could be used as feed for blue fin tuna farms. Some processing plants are exploring new markets for direct human consumption of fresh sardines. However, this market is negligible at the moment. Given the historic rise in diesel prices seen in **Figure *9***, we can expect cost of fuel to continue rising and thus incentivizing a greater percentage of fresh quality catch. Therefore, a more throughout market study would be useful to determine what percentage of the increased fresh quality sardines, will be turned into canned products.

Finally, it might be the case that fuel subsidies are not the best course of governmental action if the intent is to promote more canned sardine. The sardine fishery in Mexico is an input/output managed fishery and some academic literature has found that direct cost reducing subsidies (such as fuel subsidies) can have a negative stock impact on input/output managed fisheries (Sakai, 2017). However, it's also pointed out that beneficial effects have been observed with general service (infrastructure, management, research, etc.) subsidies in input/output managed fisheries (Sakai, 2017). Therefore, if a subsidy is chosen to promote canned sardine production, care should be taken to determine which has the least detrimental impacts for the given management system. Alternatives to a fuel subsidy could be directly subsidizing canned plants or encouraging imports of can quality sardines. A study of the Brazilian sardine fishery suggests that importing sardines could have beneficial impacts to for the stock, consumers, and the processing plants (Pincinato and Asche, 2017). However, this is at the detriment of the local fishermen (Pincinato and Asche, 2017). Processors benefit by having a steady product supply that reduces their costs, consumers enjoy lower prices on the product, and the stock recovers because local fishermen get outcompeted by global prices. This could increase food security, but at the expense of local fishermen. Further studies should be done as well to determine what are actual food security concerns associated with diverting sardines to fish meal rather than human consumption.

Looking at

Figure 5, we notice that the data supports traditional knowledge that species differ in quality and therefore differ in price. In the beginning of the data set there seem to be anomalies, such as the extremely high price of sardine Piña. There are also the irregularities with the base price at $52/MT, thought to be due to internal transactions or lack of enforcement for reporting. This trend seems to break to diverse and higher prices after 2010. However, chronologically ahead of that we notice that species, overall, follow an order from lowest to highest price.

Sardine Monterrey is known to be of the highest quality and this data corroborates that because it consistently has the highest price per ton. Monterrey catch has been decreasing in current years, which might explain why prices follow a sharply increasing trend in recent years. Because it's of the highest quality, Monterrey is usually used to produce canned or fresh sardine, not fish meal.

Japonesa, and Piña are also of good quality, typically also used to produce cans or fresh. We can see that the data corroborates this as well. Both overall have higher prices than their counterparts, particularly in recent years. Piña is hard to predict because it makes up such a small percentage of the total catch for the fishery. Crinuda is of decent quality, capable of being used for either cans or fish meal and as such we notice a middle range price for it. Lastly, Bocona is only used for fish meal and it's interesting that its price has recently seen a steady increase. It seems to be rising with the price of Monterrey. Perhaps there is a relationship in those markets worth exploring further.

Figure *6* breaks down price through time by quality and we notice overall higher prices for "Fresh and Whole" (high quality) than "Industrialized" (low quality). However, this isn't consistent throughout the data. Particularly in the early 2000s we notice prices of industrial grade sardine to be much higher than fresh grade sardine. However, we are skeptical of price data prior to 2010. Potential internal transactions and misreporting seem to be prevalent prior to 2010, with large quantities of the data being the same price of $52/MT regardless of species or quality. Analyzing data post 2010, we notice that the expected relationship is clearer and consistent. Higher grade "Fresh" quality is usually of a higher price than "Industrial" grade lower quality.

Another potential explanation for why industrial prices are higher early in the data and then fresh prices become higher, is the introduction of blue fin tuna farms and thus the increase in demand for fresh sardine feed. Although tune farms in the northern part of Baja California were introduced in 2000, they might have become a significant part of the market around 2010, continuing to increase since then.

Figure *7* again supports previous studies of the fishery, indicating that Monterrey is not only the species of highest quality and price but also the most fished by weight in the fishery. Monterrey has consistently remained the most fished species until approximately 2013, at which time it dropped to second most fished by weight. Crinuda has consistently been the second most fished species and since approximately 2013, has surpassed Monterrey to be the number one most fished species. As can be seen, all other species make up very small amounts by weight of the total catch in the fishery.

The significant drop in Monterrey catch is something that is being evaluated and thought to be due to increasing Enso temperatures. Enso temperatures in

Figure 8 do show some of the highest temperatures in the past 16 years, happening in the last few years. Furthermore, since 2010 sea surface temperature has steadily been increasing, with the exception of 2016. Most literature on the effects of Enso events on forage species suggests that warmer sea surface temperatures (SST) prevent upwellings from happening (Bakun and Broad, 2003). Since upwellings provide the nutrients needed for phytoplankton to prosper, higher SST means less phytoplankton. Since phytoplankton is the main source of food for a lot of forage fish, higher SST would suggest less forage fish.

However, there is also literature saying that Enso affects different forage species differently (Lluch-Belds et al., 1991). For sardines specifically, literature suggests that Enso induced warmer SST causes them to increase in numbers (Jacobson and MacCall, 1995). The thought is that warmer temperature also creates an unfavorable environment for sardine predators, causing predators to drift further from the coast and into cooler waters. Sardines typically move toward deeper waters near the coast to escape the warmer temperatures. This separation from their predators gives sardines a reproductive advantage. Furthermore, sardines are thought to be one of the most enduring forage species (Bakun and Broad, 2003). They are capable of filtering smaller particles of food than other forage fish, migrate long distances in search of optimal food and breeding conditions, and can control when they lay their eggs (typically in spurts of 2-3 days) (Bakun and Broad, 2003). These adaptive qualities combined with the reduced number of predators, enable sardines to have abnormally successful breeding spurts which add up to an increase in the population over time. Enso induced warmer temperatures could therefore be thought to actually benefit sardine numbers.

Furthermore, in **Figure *7*** we don't see a decline in the catch of other sardine species, only Monterrey. In fact, catch of crinuda increases since 2010. Catch of all other species remains constant throughout the entire data set, 2000 to 2016. Therefore, analysis of the data used for this project leads to skepticism of Enso as an explanation for recent declines in catch of Monterrey. It's believed that overfishing of Monterrey sardine has led to its decline and that management and enforcement policies should be reevaluated.

7. Small Pelagics Fishery Rules and Regulations

7.1 Minimum Catch Size and Net Regulations

Based scientific research in the early 90's, it was determined that there was a small population of sardine and anchovy in a stage of expansion within the Gulf of California as well as the western side of the Baja California peninsula. In light of this, it became necessary to take administrative measurements to prevent focused capture of young groups of the existing populations. As a result, minimum catch sizes were established for three species, listed in Table 6 (CONAPESCA, 1993).

Table 6. Minimum capture size within federal jurisdiction waters of the Pacific Ocean, including the Gulf of California
(CONAPESCA, 1993)

Species	Minimum Capture Size
Monterrey Sardine	150 mm in length
Crinuda Sardine	160 mm in length
Anchovy	100 mm in length

It was also determined that some nets were being used that could capture greater quantities than what the boat could store, resulting in waste and mortality of captured species. Therefore, net size is regulated to an adequate size given the storage capacity of each boat, as shown in Table 7 (CONAPESCA, 1993).

Table 7. Maximum Allowable Net Size in Relation to Vessel Storage Capacity
(CONAPESCA, 1993)

Boat Capacity (Metric Tons)	Length of Net (meters)
80 or less	366
81-120	549
121-150	585
151-200	604
201 +	640

There appear to be two kinds of nets used in the small pelagics fishery, anchovy and sardine nets. Sardine nets are typically larger, having openings of 1 inch. While anchovy nets are smaller with openings of less than 1 inch. Typically, one net is loaded onto the boat at time, depending on whether sardines or anchovy are being targeted on the given day. Out of the ports listed in Table 2, only Mazatlan has no anchovy to fish commercially and thus only uses sardine nets (Coppel, 2017). All other ports have use for both nets and it becomes convenient to only use anchovy nets, regardless of what fish is being targeted. Because anchovy nets are smaller, this often results in juvenile sardines being caught (Coppel, 2017). Data from a 2006 report on small pelagics indicates that above 30% of landed Monterrey sardine is under the 150mm minimum capture size (Martinez-zavala et. al. 2006). This is quite common and the use of anchovy nets to fish sardine is quite accepted despite regulations and agreements regarding minimum size.

Sardine industry leaders involved in the fresh or canned production sector are particularly concerned about this misuse of nets and the consequent landings of below minimum size fish. This affects the sustainability of the fishery and affects can and fresh producers the most, given that they target a higher quality product that becomes less abundant and more competed for when there is overfishing (Coppel, 2017).

Based on biological stock monitoring research continually done by INAPESCA, INAPESCA can order temporary bans on sardine or anchovy fishing when it’s detected that most sampled individuals are in a spawning process (CONAPESCA, 1993).

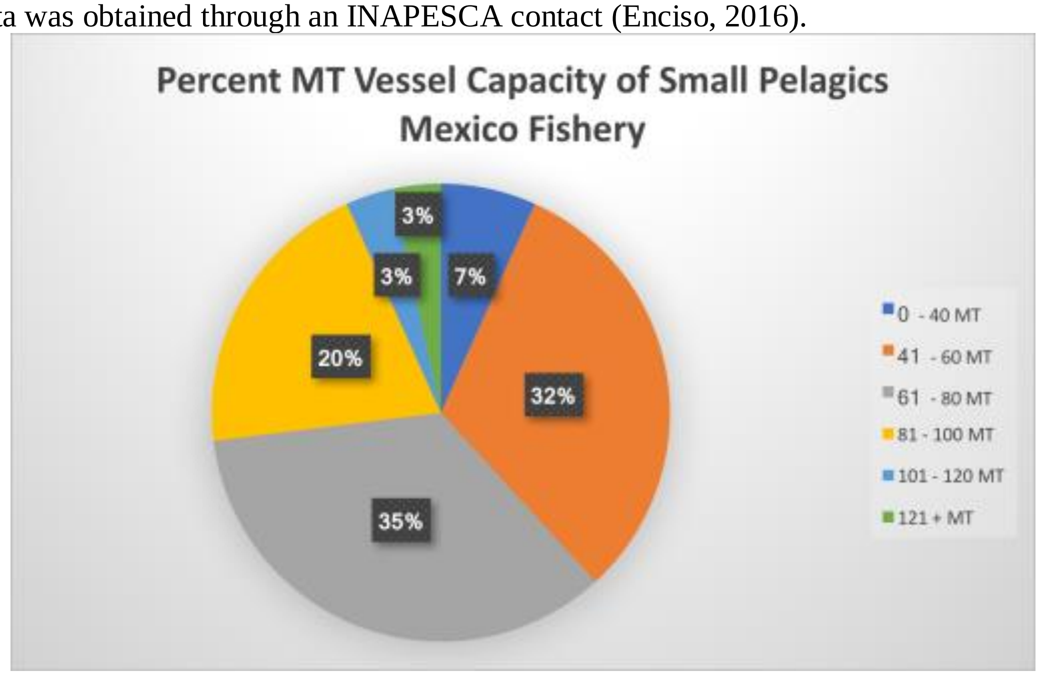
7.2 Restrictions in Effort and Vessels

Effort, in terms of the number of fishing vessels in the sardine, anchovy, and mackerel fishery, cannot be increased in waters of federal jurisdiction within the Pacific Ocean, north of the 20th parallel north (including the Gulf of California). New vessels will only be allowed to be incorporated into the sardine and anchovy fishery if these carry appropriate refrigeration units and they replace existing vessels. All fishing vessels that are equipped with refrigeration systems must maintain it in proper functioning conditions for the preservation of catch. Those vessels that are not equipped with a refrigeration system can only operate within a radius of 40 nautical miles from their port base of operations (CONAPESCA, 1993).

The FMP lists as of 2011 the fleet to be composed of 78 vessels. 21 are located in Baja California, 5 in Baja California Sur, 40 in Sonora, 12 in Sinaloa. However, it is not uncommon for vessels to be replaced or change names from year to year. A list of vessels provided by INAPESCA for this analysis, shows vessels changing over time and contains at any given year approximately 90 vessels. In some years there's recorded catch from over 100 vessels. This is assumed to be errors in the data given that no vessels outside of the registered 78 are allowed to fish, without any exceptions found. INAPESCA did not provide a logical explanation for this discrepancy. According to the FMP from 2011, the most common vessels range in length from 25-28 meters and 140–180 Metric Ton cargo capacity (SAGARPA 2012b).

Figure 13 provides percentages of current vessels and corresponding MT cargo capacities. Between 1990 and 1993 76% of the fleet was owned by the private sector, 15% by the public sector, and 9% by the social sector. Currently, 100% of the fleet is privately owned (SAGARPA, 2012b).

Figure 13. Percent MT vessel cargo capacities for the entire small pelagics fishery in Baja California, Mexico
This data was obtained through an INAPESCA contact (Enciso, 2016).



Furthermore, CNP limits effort in the number of trips as well. It states that effort should not be increased beyond the typical range of 4,000 to 6,000 trips. CNP also recommends not allowing vessels to move between fishing zones, particularly between the Gulf of California and the Pacific west side of Baja California.

Entities or individuals listed as permit or concession holders for the commercial fishing of sardine, mackerel, and anchovy must:

- Allow on board and support accredited personnel by competent authorities in research and inspection of their vessels and corresponding installations on land, to ensure compliance with regulations
- Present CONAPESCA an annual program of operation and production that must contain the number of trips that are planned to be made by month, fishing zone, prognostic of monthly landings and destination of production.
- Must provide support and collaboration in fisheries and technology research intended for conservation and better management of the resource
- Provide accredited personnel by competent authorities, when needed, organisms of target species and/or bycatch species. These are to be separated and conserved for analysis in whichever conditions he or she specifies
- Provide accredited personnel by competent authorities the same food, lodging, and facilities as that of the crew

7.3 Bycatch Regulation

Bycatch is mentioned briefly in the CNP, stating that bycatch cannot be more than 30% of individuals landed by season. Given that the small pelagic fishery is more appropriate to be measured in terms of weight than individuals because of its large volumes, it could be more appropriate to measure bycatch in terms of percent weight of total landings. This might also be due to lack of clarity or misinterpretation of regulation. However, data obtained from INAPESCA and displayed in the Fourth Annual Marine Stewardship Council (SCS, 2016) Surveillance Audit Report shows that going back to 2000 bycatch has never been more than 1% of total landings weight per year. Additional studies have been done on species guilds and individual species bycatch composition as well as workshops and new methods to reduce bycatch (SCS, 2016). Overall, bycatch with purse seine methods is low and not a concern in this fishery.

7.4 Subsidies

Major subsidy currently in place is for marine diesel fuel. CONAPESCA contributes 2 pesos per liter with varying limits of approximately 50 thousand liters per vessel per year (CONAPESCA, 2016). Beginning with the presidential administration of Enrique Peñanieto in December of 2012, SAGARPA contributed an additional 3 peso per marine diesel liter subsidy (Coppel, 2017). However, at the start of 2017 Mexico underwent the final stage of its energy reform which, among other actions, eliminated federal subsidies on fuel and opened the gasoline market to privatization and market prices. Thus, it's anticipated that this additional 3 peso per liter subsidy will be eliminated. CONAPESCA is currently evaluating whether or not and if so, by how much to increase its current 2 peso per liter subsidy (Coppel, 2017).

An additional subsidy aid that the government provides is for the maintenance and modernization of the fleet. The government gives up to 1 million pesos per vessel per year (Coppel, 2017). However, the subsidy is designed to match expenditures from the owner of the vessel. It's estimated that a vessel's lifespan is 25-30 years and each vessel costs approximately 3 million dollars (Coppel, 2017). Current conversion as of February 2017 is 20.65 Mexican pesos per USD (Department of the Treasury, 2017). Therefore, 1 to 2 million pesos is a relatively small aid. "It's not even enough for an engine", as was said by Armando Coppel (Coppel, 2017). Because of the high costs, it's common practice to heavily maintain a vessel and expand its lifespan as much as possible. Typically this is done in the off season, from July to October. This is when boats are taken out of commission and owners make use of the full 1 million peso subsidy for maintenance and/or modernization (Coppel, 2017).

7.5 Biologically Acceptable Catch (BAC) and Marginal Sustainable Yield (MSY)

A unique and significant contribution to management from the FMP is the description of a sustainable landings amount based on a calculated Biologically Acceptable Catch (BAC). BAC is computed as a fraction of the MSY. The rationale behind this comes from a simulation study finding that, for Monterrey sardine, a fishing mortality rate that is 90% of MSY "would not only produce higher economic returns and be safer biologically, but will reduce intrinsic population oscillations" (Nevares-Martinez et al. 1999). BAC is a "prudent level of catch" that can vary between 5 and 25% of the estimated biomass. The plan also states that overfishing "occurs when fishing takes place at a rate that is high enough to risk the stock's ability to continuously produce

MSY on the long term". In terms of BAC for the fishery of small pelagics, the plan states that "overfishing occurs if the catch exceeds the BAC". This is considered met if the predictive models indicate that the fishing mortality or the harvest rate will exceed the BAC over a period of two years (SAGARPA, 2012b).

If overfishing occurs, the Plan defines "emergent actions" that are implemented "if pertinent and possible". These actions include seasonal or temporal area closures for one or more species, change in the minimum capture size for one or more species in a single area or more, change of allowable catch, and change in restrictions to fishing effort (SAGARPA, 2012b). FMP also states that some species are to be actively managed while others passively managed. The intent of this categorical management is to use institutional resources as efficiently and effectively as possible while still meeting management goals. Passively managed defines the CBA for all stocks the same at 25% of the most recent biomass estimate of reproductive adults. Table 8 lists which species are managed actively and which are managed passively (SAGARPA, 2012b).

Table 8. Small Pelagic Species Fishery in the Gulf of California Mexico, categorized for the two main forms of management
(SAGARPA, 2012b)

Actively Managed	**Passively managed**
Sardina Monterrey (Pacific Sardine) *Sardinops sagax caerulea*	Sardina Japonesa (Red-eye round herring) *Etrumeus teres*
Crinuda Azul (Slender Thread Herring) *Opisthonema bulleri*	Sardina Bocona (Pacific Anchoveta) *Cetengraulis mysticetus*
Crinuda Machete (Middling Thread Herring) *Opisthonema medirastre*	Anchoveta (California Anchovy) *Engraulis mordax*
Macarela (Chub Mackerel) *Scomber japonicus*	Charrito (Pacific jack mackerel) *Trachurus symmetricus*
Sardina Crinuda (Pacific Thread Herring) *Opisthonema libertate*	Sardina Piña (Shortjaw Leatherjacket) *Oligoplites refulgens*

Those species that are actively managed make use of the BAC rule, forcing catch to be reduced if the biomass declines. If the biomass threshold is reached, the fishery stops operating. The formula used is the following:

BAC = (B-Bmin) * FRACTION

Bmin *= lowest level of estimated biomass at which harvest is allowed*

B *= Estimated biomass of fish age 1 and older*

FRACTION *= Proportion of biomass above Bmin that can be captured by the fishery.*

Bmin is the safeguard to the fishery to prevent fishing when the stock numbers are too low and fraction is to specify how much of an above Bmin stock is available to the fishery.

There is more information on the Gulf of California Sonora fishery because it’s currently Marine Stewardship Council (MSC) certified. In the Sonora fishery, the Monterrey sardine makes up the vast majority of landings with the exception of the last few years (Nevarez-Martinez et al, 2015). Thus, most BAC measurements are of the Monterrey sardine of the Sonora fishery. Landings since 1972, with the exception of the 2008-2009 season, have never exceeded BAC levels (Nevarez-Martinez et al, 2015). For MSC certification there is no obligation to score performance indicators for species that comprise <5% of the catch in the fishing season. However, particularly due to recent drops in the catch of Monterrey sardine, other species have begun to be assessed more in depth for BAC and Bmin levels. Species comprising >5% of the catch in the fishing season (2012/2013) were Sardine Bocona (Pacific Anchoveta) with 28%, Anchoveta (California Anchovy) with 26%, sardine crinuda (Pacific Thread Herring) with 22%, and Macarela (Chub Mackerel) with 4% (SCS, 2016). In the (2013/2014) season there were slight variations in the catch: Sardine Bocona (Pacific Anchoveta) with 22%, Anchoveta (California Anchovy) with 11.5%, sardine crinuda (Pacific Thread Herring) with 45%, and Macarela (Chub Mackerel) with 14% (SCS, 2016).

The Sonora sardine crinuda (thread herring) fishery, for example, entered into full MSC assessment in November of 2011. Catch landings for sardine crinuda, as can be seen in , indicate that it has generally been the second species most captured by volume since 1970. Using an ASAP model, FRACTION values were estimated for crinuda. These were found to be higher (.879) than the generic FRACTION reference point (.25) used in the management plan, which is based on assumptions of the Monterrey sardine (SCS, 2016). Actual fishing mortality for crinuda from the early 90s to 2012 was estimated to be between .05 and .25. Even though values are not available for bocona (Pacific Anchoveta), results of the ASAP model indicate that bocona and crinuda biomass is far above the level producing MSY and that fishing mortality rate (FRACTION) for both is far below the level producing MSY (SCS, 2016). Furthermore, Armando Coppel, general director of the sardine division of the Pinza group, responded to an interview saying that the limiting factor in landings is not governmental regulation. He said it's simply the availability of the fish, indicating that BAC and MSY levels are generally not reached (Coppel, 2017).

MSY and BAC values found for the Sinaloa and the Sonora small pelagics fishery are available in the appendix.

7.6 MSC Certification

The Marine Stewardship Council is an international non-profit organization established to safeguard seafood supplies for the future and address the problem of overfishing (MSC, 2017).

The MSC certification program is designed to recognize and reward sustainable fishing practices worldwide. For certification, a fishery employs and is evaluated by a MSC independent certification body against certain MSC performance indicators that relate to the three principle:

1.) Fish stocks and fish being caught are maintained at sustainable levels

2.) Fishery must minimize environmental impact and not jeopardize the supporting ecosystem

3.) Effective fishery management system in place

Out of the distinct fisheries shown in Table 2, Sonora and Sinaloa (situated in the Gulf of California zone) are Marine Stewardship Council (MSC) certified since July 21st, 2011 and October, 2016 respectively. Both fisheries are certified with the Monterrey sardine (Pacific Sardine) as the main fished species, with all others comprising less < 5% of catch. This composition of catch changed in recent years and as a result new stock and Biologically Acceptable Catch (BAC) assessments will be made. Because of this change in catch composition, the Crinuda sardine (thread herring) fishery entered into full MSC assessment in November of 2011. Mexican sardine fisheries have been certified by SCS Global Services, a trusted leader in third party environmental, sustainability, and food quality certification (MSC, 2017).

It should be noted that estimates of the B*min* were all computed with the objective of providing a minimum biomass to protect recruitment. However, for trophic low level species, MSC requires minimum biomass levels to be determined based on ecosystem needs. Therefore, this change in calculations is being processed by INAPESCA and will likely generate different BAC values.

Once the above three principles are considered satisfactorily met by the third-party certifier, it takes on average 18 months for the fishery to become certified. More information on the scoring and 31 performance indicators that make up the three core principles can be found on (MSC, 2015).

7.7 Summary

The small pelagic fishery in the Gulf of California, Mexico, is regulated by a minimum catch size, restrictions in the number of vessels, bycatch regulations, subsidies, biologically acceptable catch (BAC), and though a Marine Stewardship Council (MSC) sustainability certificate. There are three official documents regulating the fishery, La Carta Nacional Pesquera (CNP), NOM-0003-PESC-1993, and the Small pelagics Fisheries Management Plan (FMP).

Minimum catch is dependent on the species, typically larger for sardine species and smaller for anchovies. This is regulated through the size of openings in nets used. Vessels are required to use larger nets for sardines and smaller ones for anchovies. However, due to lack of enforcement, often times small nets get used for all catch. This results in below minimum size sardines caught. Refer to **Table *6*** for sizes by species

As of 2011, the FMP lists the fleet to be composed of 78 vessels, each located in different regions of the map shown in

Figure 1. This total number of vessels is capped and new vessels can only replace existing ones. All vessels equipped with refrigeration systems are required to maintain it in proper conditions and those without one are limited to operate within a 40 nautical miles radius from their port

base. All new vessels are required to have a refrigeration system. Vessels are of different sizes, shown in **Figure *13***.

Currently bycatch cannot be more than 30% of individuals landed by season. Surveillance audit reports by MSC, show that bycatch going back to 2000 has never been more than 1% of total landings weight per year. It's a targeted fishery with little known bycatch.

The government subsidies diesel at 2 pesos per liter with limits of approximately 50 thousand liters per vessel per year. A much smaller subsidy aid is for boat maintenance and repair. Up to 1 million pesos per vessel per year are matched to owner expenditures. This is just over $53,000 and vessel costs can be upwards of 3 million dollars.

The BAC is a measurement of total acceptable catch for the entire fishery combined. There are different BAC levels per species and for each of the regions in

Figure 1. This is approximately 90% of MSY. If the BAC is exceeded, the government reserves the right to implement seasonal or temporal closures as well as change in minimum size limits and/or further restrictions in fishing effort. Landings since 1972, with the exception of the 2008-2009 season, have never exceeded BAC levels (Nevarez-Martinez et al, 2015).

Out of the regional fisheries shown in **Table *2***, Sonora and Sinaloa are MSC certified since July 21st, 2011 and October, 2016 respectively. Certification means the fishery is sustainable, meeting three criteria: Fish stocks and fish being caught are maintained at sustainable levels, fishery must minimize environmental impact and not jeopardize the supporting ecosystem, and there is an effective fishery management system in place.

More information on the history of the Mexican small pelagic fishery, federal entities regulating fisheries in Mexico, and legislation regulating the Mexican small pelagic fishery are provided in the appendix.

8. Revisions to Management and Regulation Documentation

A new version of the NOM-0003-PESC-1993 has been, as of 2015, drafted. Revisions include a less stringent requirement of minimum catch size not exceeding 30% per fishing season. Minimum size will also be determined by zone and given time, instead of a static minimum size. No new vessels will be allowed into the fishery and existing ones cannot move between west of Baja California and the Gulf of California. Vessels also cannot increase their current carrying capacity. There will be a more stringent management of bycatch, requiring monthly reviews.

9. Conclusion/Recommendations

From analyzing the sardine fishery data in the Gulf of California, Mexico, we notice several inconsistencies, particularly prior to 2010. Recorded prices prior to 2010 seem very homogeneous at $52/MT, regardless of species or quality. It is recommended that this be paid closer attention to, and improve enforcement if necessary. Catch of the main sardine species in the fishery, Monterrey sardine, has been declining in recent years and is stipulated by Mexican agencies to be due to warming Enso induced SST. However, academic literature suggests that warmer temperatures increase sardine populations. In addition, catch for no species other than Monterrey is seen decreasing with increasing Enso SST. It is recommended that the cause for reduced Monterrey numbers be reevaluated and management adapt if overfishing is found to be occurring.

We find that fishermen behavior is responsive to quality associated price of sardines as well as to increasing diesel prices. As the difference in price between high quality and low quality sardines increases, we notice an increase in the percentage of high quality catch. Likewise, as the price of diesel increases we notice an increase in the percentage of high quality catch. High quality catch is used for canned or fresh sardines. Low quality sardines are used for fish meal. Therefore, increased high quality catch could mean a higher production of canned sardines and therefore a cheap and storable source of protein to increase food security for low income populations.

Further studies are recommended to determine if a decrease in fuel subsidies by the Mexican government will have predicted effect of significantly increasing sardine can production. Although we find that increased fuel prices increase high quality sardine catch, it is not clear how much of that additional high quality catch will be turned into a sardine canned product. High quality sardines are also processed as fresh sardines, often used as feed in blue fin tuna farms. Therefore, although percent canned production would increase, it’s unclear by how much that would be.

Furthermore, if food security is the objective, other alternatives should be explored to minimize unintended consequences for the fish stock or sardine market. Academic literature suggests, for example, that cost reducing subsidies for input/output managed fisheries can have negative effects on fish stocks (Sakai, 2017). Because the effect of subsidies on a fishery depend on the type of subsidy and management system for the fishery, benefits and costs of multiple options should be reviewed. More research should also be done to determine if there are real food security concerns associated with diverting sardines into fish meal rather human consumption.

This is the start of what could be a comprehensive benefit cost market analysis, resulting in sound guidance on optimal use of the sardine resource at a national scale. There are social, economic, ecological, geopolitical, and many other considerations when deciding how much of the resource should be allocated to produce fish meal, cans, or fresh sardines. Depending on how much weight is given to the different considerations, distributions will vary. Therefore, it would be very valuable to provide a range of possible variables to consider, quantify them, and then provide a guideline on different choice combinations and resulting impacts of sardine resource distribution.

10. Acknowledgements

I'd like to thank my advisor, Martin Smith. His insight throughout this project was extremely valuable, helping me notice trends in the data and address key factors to make my results more robust. I'd like to specially thank Justin Kirkpatrick, Environmental Economics PhD student at Duke. He was extremely helpful in donating much of his time to think through my data, test different hypothesis, and help me narrow down a research focus. Thank you to my contacts at INAPESCA, general director Pablo Arenas and Mazatlan branch manager Concepcion Enciso, for providing the data and addressing multiple follow up questions throughout the process. Thank you to the general director of Maz Industrial, S.A. de C.V, engineer Armando Coppel Azcona, for interviewing with me and providing valuable inside information.

11. References

Abbott, J.K. and Wilen, J.E. (2011). "Dissecting the tragedy: a spatial model of behavior in the commons". *Journal of Environmental Economics and Management, 62(3), pp.386-401*.

Alvarez-Trasviña E., J.P. Santos-Molina, J.G. Padilla-Serrato y C.I. Navarro-Bojorquez. (2015). "Resultados de cruceros de pesca exploratoria de pelágicos menores en el Golfo de California, primavera y verano del 2014". *Abstract. XIII Taller de Pelágicos Menores. La Paz, B.C.S. June 2015.*

AMEGAS (Asociacion Mexicana de Empresarios Gasolineros). (2017). "Precio del Diesel Historico*". El INPC. http://elinpc.com.mx/precio-diesel/*

Arenas, F.P., R.J. Hunter y L.D. Jacobson. (1996). "The 1994 México-U.S. spawning biomass survey for Pacific sardine (*Sardinops sagax*) and the 1995 CalCOFI Sardine Symposium". *California Cooperative Oceanic Fisheries Investigations Reports 37: 129-133*.

Bakun Andrew and Broad Kenneth. (2003). "Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on El Niño effects in the Pacific" *Fish Oceanography 12:4/5, 458-473*

Banco de Mexico. (2017). http://www.banxico.org.mx/portal-inflacion/inflation.html. Retrieved. "April 3, 2017".

Banco Mundial and Sociedad Alemana de Cooperacion Internacional (GIZ). (2016). "Precio del diesel para el usuario (US$ por litro)". *Banco Mundial.*

http://datos.bancomundial.org/indicador/EP.PMP.DESL.CD?locations=MX

Beveridge M. C. M, S. H. Thilsted, M. J. Phillips, M. Metian, M. Troell, and S. J. Hall. (2013). "Meeting the food and nutrition needs of the poor: the role of fish and the opportunities and challenges emerging from the rise of aquaculture". Journal of Fish Biology (2013) 83, 1067–1084.

Burkhard, B., de Groot, R., Costanza, R., Seppelt, R., Jørgensen, S. E., & Potschin, M. (2012). Solutions for sustaining natural capital and ecosystem services. Ecological Indicators, 21, 1–6

Cashion Tim, Le Manach Frédéric, Zeller Dirk, and Pauly Daniel. (2017). "Most fish destined for fishmeal production are food-grade fish". *Fish and Fisheries*

CONAPESCA (1993). "Norma Oficial mexicana 003-pesc-1993, para regular el aprovechamiento de las especies de sardina monterrey, piña, crinuda, bocona, japonesa y de las especies anchoveta y macarela, con embarcaciones de cerco, en aguas de jurisdiccion federal del oceano pacifico, incluyendo el golfo de California". *Diario Oficial de la Federacion*.

Coppel, Armando. Phone Interview. 14 February, 2017

Darling S. Emily. (2014). "Assessing the Effect of Marine Reserves on Household Food Security in Kenyan Coral Reef Fishing Communities". *PLOS ONE*

Department of the Treasury. Bureau of Fiscal Services. Funds Management Division. (2017). "Treasury Reporting Rates of Exchange. Treasury Reporting rates of Exchange as of December 31, 2016". https://www.fiscal.treasury.gov/fsreports/rpt/treasRptRateExch/currentRates.htm

Duy, N.N. and Flaaten, O. (2015). "Government support and profitability effects–Vietnamese offshore fisheries". *Marine Policy*, 61, pp.77-86.

Duy, N.N. and Flaaten, O. (2016). "Profitability Effects and Fishery Subsidies: Average Treatment Effects Based on Propensity Scores". *Marine Resource Economics*, 31(4), pp.373-402.

Enciso, Concho. Personal Communication. August 2016

Erisman Brad, Octavio Aburto-Oropeza, Charlotte Gonzalez-Abraham, Ismael Mascareñas-Osorio, Marcia Moreno-Báez & Philip A. Hastings. (2012). "Spatio-temporal dynamics of a fish spawning aggregation and its fishery in the Gulf of California". Scientific Reports 2: 284

Essingtona E. Timothy, Pamela E. Moriartya, Halley E. Froehlicha, Emma E. Hodgsona, Laura E. Koehna, Kiva L. Okenb, Margaret C. Siplea, and Christine C. Stawitz. (2015). "Fishing amplifies forage fish population collapses". *PNAS*

Fabinyi Michael, Wolfram H. Dressler, Michael D. Pido. (2016). "Fish, Trade and Food Security: Moving beyond 'Availability' Discourse in Marine Conservation ". *Hum Ecol (2017) 45:177–188*

FAO. (2017). "FAO Yearbook of Fishery and Aquaculture Statistics". *Fisheries and Aquaculture Department*

Golden D Christopher, Allison H Edward, William W. L. Cheung, Madan M. Dey, Benjamin S. Halpern...Samuel S. Myers. (2016). "Fall in fish catch threatens human health". *Nature, 534, 317-320.*

Hammann M.G., M.O. Nevarez-Martinez and Y. Green-Ruiz. (1998). "Spawning habitat of the Pacific sardine (Sardinops sagax) in the Gulf of California: egg and larval distribution

1956-1957 and 1971-1991". *CalCOFI Rep. 39:169-179*.

Haynie, A.C. and Layton, D.F. (2010). “An expected profit model for monetizing fishing location choices”. *Journal of Environmental Economics and Management, 59(2), pp.165-176.*

Holland, D.S. and Sutinen, J.G. (2000). "Location choice in New England trawl fisheries: old habits die hard". *Land Economics, pp.133-149*.

Huang, L. and Smith, M.D. (2014). "The dynamic efficiency costs of common-pool resource exploitation". *The American Economic Review, 104(12), pp.4071-4103*.

INAPESCA (2011). "Integracion y Asistencia para las Concertaciones de Politicas Publicas para la Pesqueria de Pelagicos Menores en el Noroeste de Mexico incluido el Golfo de California"

Jacobson D. Larry and MacCalI D. Aiec. (1995). "Stock-recruitment models for Pacific sardine (Sardinops sagax)". *Fisheries and Aquatics Science 52: 566-577*

Konstantinos, Ganias (Editor). "Biology and Ecology of Sardines and Anchovies". New York: *CRC PressTaylor & Francis Group*, 2014

Laws A. Edward (2000). "El Niño and the Peruvian Anchovy Fishery. Biological Effects". *University Coporation for Atmospheric Research*. *http://www.ucar.edu/communications/gcip/m12anchovy/m12html.html#3_1*

Lenfest Forage Fish Task Force (2012). "little fish BIG IMPACT". Lenfest Ocean Program & Institute for Ocean Conservation Science

Lizárraga Saucedo, Salvador (February 2017). "Aspectos Relevantes de la Pesqueria de los Pelagicos Menores". *INAPESCA*

Lluch-Belds Daniel, Lluch-Cota B. Daniel, Hernandez-Vazquez Sergio, Salinas-Zavala A. Cesar, Schwartzlose A. Richard. (1991). "Sardine and Anchovy Spawning as Related to Temperature and Upwelling in the California Current System". *CalCofi Rep., Vol. 32*

Martínez-Zavala, M.A., M.O. Nevárez-Martínez, M.L. Anguiano-Carrazco, J.P. Santos-Molina and A.R. Godínez-Cota. (2006). “Diagnosis de la pesquería de pelágicos menores en el golfo de California, temporada de pesca 1998/99 a 2002/2003”. *SAGARPA, Centro Regional de Investigación Pesquera (Guaymas, Sonora, México).*

MSC. Marine Stewardship Council. Certified Sustainable Seafood. (2015). "Get Certified! Your Guide to the MSC fishery assessment process"

MSC. Marine Stewardship Council. Certified Sustainable Seafood. (2017). "What is the MSC?". About Us. https://www.msc.org/about-us/what-is-the-msc

Munro, G. and Sumaila, U.R. (2002). "The impact of subsidies upon fisheries management and sustainability: the case of the North Atlantic". *Fish and fisheries*, 3(4), pp.233-250.

Murphy, G.I. (1966). “Population biology of the Pacific sardine (*Sardinops caerulea*)”. *Proceedings of the California Academy of Science Series 34: 1-84.*

Nevárez-Martínez, M.O., E.A. Chavez, M. A. Cisneros-Mata, and D. Lluch-Belda. (1999). "Modeling of the Pacific sardine Sardinops caeruleus fishery of the Gulf of California, Mexico”. *Fisheries Research*

Nevarez-Martinez M.O., M.A. Martinez-Zavala, J.P. Santos-Molina, M.E. Gonzalez-Corona and A.E. Lopez-Lagunas (2015). Evaluacion poblacional de la sardina Monterrey (*Sardinops* *sagax*) en el Golfo de California, Mexico, 1971/72-2013/2014. Informe Tecnico. *SAGARPA-INAPESCA/CRIP Guaymas*

Nevarez-Martinez M.O., M.A. Martinez-Zavala, J.P. Santos-Molina, C. Enciso-Enciso and M.E. Gonzalez- Corona. (2015b). "Evaluacion pesquera de sardina crinuda (Opistonema libertate) y de sardina bocona (Cetengraulis mysticetus) en el Golfo de California, Mexico". *Informe Tecnico. SAGARPA- INAPESCA/CRIP Guaymas. 11 pp.*

NOAA. (2017). "Multivariate ENSO index (MEI)". Earth System Research Laboratory. *Physical sciences Division*. https://www.esrl.noaa.gov/psd/enso/mei/. Retrieved. “April 3, 2017”

Parada Carolina , Yannicelli, Beatriz, Hormazábal Samuel, Vásquez Sebastián, Porobić Javier, Ernst Billy, Gatica Claudio, Arteaga Marcos, Montecinos Aldo, Núñez Sergio, & Gretchina Alexandre. (2013). "Variabilidad ambiental y recursos pesqueros en el Pacífico suroriental: estado de la investigación y desafíos para el manejo pesquero". *Latin American Journal of Aquatic Research, vol. 41, num. 1, pp. 1-28. Pontifica Universidad Católica Valparaíso, Chile*

Pauly, D., Belhabib, D., Blomeyer, R., Cheung, W. W., Cisneros-Montemayor, A. M., Copeland, D., ... Osterblom, H. (2014). “China’s distant- water fisheries in the 21st century”. *Fish and Fisheries, 15, 474–488.*

Pincinato Ruth Beatriz Mezzalira, Asche Frank. (2017). "Potential Effects of increasing Seafood imports Relative to Domestic Production in Emerging Countries: The Brazilian Sardines Market". *University of Stavanger and University of Florida*

Ramírez Leonardo. (2014). Análisis de los precios de los combustibles en México 2007-2013:

Del precio subsidiado al precio de mercado. *Universidad de Guanajuato División de Ciencias Económico – Administrativas*

SAGARPA (2012a). "Carta Nacional Pesquera". *Diario Oficial de la Federacion*.

SAGARPA (2012b). "Plan de Manejo Pesquero para la Pesqueria de Pelagicos Menores (sardinas, anchovetas, macarela y afines) del Noroeste de Mexico". *Diario Oficial de la Federacion*.

Sakai, Y. (2017). "Subsidies, Fisheries Management, and Stock Depletion". *Land Economics*, 93(1), pp.165-178.

SCS (2015). SC Full Assessment Public Certification Report. Southern Gulf of california Thread Herring Fishery, Sinaloa & Nayarit, Mexico". MSC Certification Requirements

SCS (2016). "Fourth Annual MSC Surveillance Audit Report. Gulf of California Mexican Sardine Fishery". *MSC Certification Requirements*

Taboada Ibarra Eunice Leticia, Osnaya García Silvia Guadalupe. (2009). "El diesel para autotransporte en México. Situacion actual y prospectiva". *El Cotidiano, núm. 157, septiembre-octubre, 2009, pp. 65-74 Universidad Autónoma Metropolitana Unidad Azcapotzalco*

Tsitsika V. Efthymia and Maravelias D Christos. (2008). "Fishing strategy choices of purse seines in the Mediterranean: implications for management". *Fisheries Science, 74: 19-27*

Zuñiga-Flores, M.S., C. Enciso-Enciso y D.I. Arizmendi-Rodriguez. (2015). "Variabilidad ambiental y su efecto en la abundancia de sardina capturada en Baja California". Abstract. XIII Taller de Pelágicos Menores. La Paz, B.C.S. June 2015

Appendix

Appendix A: Biologically Acceptable Catch (BAC) values for the Sonora and Sinaloa small pelagics fisheries (SCS, 2016 and SCS, 2015)

Sonora BAC Values	2007-2008	2012	2014	2015
Monterrey			130,000 to 140,625 MT	87,000 to 90,000 MT
Sinaloa BAC Values	2007-2008	2012	2014	2015
Crinuda	72,714 MT	81,814 to 114,077 MT		

Appendix B: Marginal Sustainable Yield (MSY) values for the Sonora and Sinaloa small pelagics fisheries (SCS, 2015 and INAPESCA, 2011)

Sonora MSY Values	1991-1993	1993-1996	1996-1997	1997-1998	1998-2000	2000-2003	2007-2008
Monterrey	7,600MT	168,100 MT	210,000 MT	60,000 MT	60,000 MT	210,000 MT	585,500 MT
Crinuda	54,000 MT	54,000 MT	41,200 MT	41,200 MT	50,500 MT	50,500 MT	50,500 MT
Anchoveta	10,682 MT	10,682 MT	2,570 MT	2,570 MT	2,570 MT	2,570 MT	
Macarela	11,240 MT	11,240 MT	2,494 MT	2,494 MT	43,400 MT	8,200 MT	
Japonesa	5,572 MT	5,572 MT	4,329 MT	4,329 MT	4,329 MT	4,329 MT	
Bocona			71,100 MT	71,100 MT	21,300 MT	84,550 MT	
Sinaloa MSY Values	2012						
Crinuda	137,500 MT						
Crinuda Machete	215,280 MT						

Crinuda Azul	144,907 MT						
Bocona	60,717 MT						

Appendix C: History of the Mexican Small Pelagic Fishery

In Mexico, the sardine fishery started in the port of Ensenada, Baja California in 1929 (SAGARPA, 2012b). There was a small demand for the product and consequently low levels of catch are recorded. First uses of sardine were canned and as fish meal and oil (Lizárraga, 2017). Some of the first companies for this in the port Ensenada, Mexico are "Pesquera del Pacifico" and "Pesquera Peninsular" (Lizárraga, 2017). Shortly thereafter "Pesquera Isla de Cedros" in the port Isla Cedros and "Productos Pesqueros de Mantacitas" in the port Adolofo Lopez Mateos became established. The ex- president at the time, Abelardo L. Rodriguez founded most of these companies (Lizárraga, 2017).

Mid 1940s the sardine fishery off the coast of California crashed (Murphy, 1966; Arenas *et al.*, 1996) because of overfishing and abrupt environmental changes. During the 60s this crash in the United States has repercussions in the Mexican coast, resulting in the virtual disappearance of the sardine fishery in Mexico as well (except for Isla Cedros and San Carlos Lopez Mateos). Isla Cedros and San Carlos Lopez Mateos are ports on the southern part of Baja California, as opposed to Ensenada which is in the north. Refer to

Figure *1* for a map. Due to the low reported catch in Ensenada and the discovering of other fish stocks, a small part of the fleet is deployed to the Gulf of California during the late 60s and early 70s (SAGARPA, 2012b). This set the precedent for the establishment of the sardine Mexican fishery in the Gulf of California, which has ports located in Guaymas and Yavaros, Sonora and Mazatlan, Sinaloa (SAGARPA, 2012b).

The Mexican Anchovy fishery started in the 60's, also in the port of Ensenada, Baja California. Catch in the 60's was very low and destined for human consumption, mainly as a canned product (SAGARPA, 2012b). With certain fluctuations, these catch levels were maintained until beginning of the 70's. However, with the reduced Peruvian anchovy stock that happened in the early 1970's due to overfishing and the 1972 El Niño event, new markets opened for the Mexican anchovy which consequently increased catch. An economic crisis from 1982-83 caused a decrease in catch. Finally, in 1989-90 there was a total substitution of the anchovy fishery in Ensenada for that of sardine and mackerel (SAGARPA, 2012b). Anchovy continued to be fished in ports further south, but very minimally in Ensenada.

Overall, five stages can be identified in the history of the Mexican small pelagics fishery. The first is exploration until 1975/76. This led to the development of major ports in different states for fishery. Ports and corresponding states are shown in

Figure *1*. Development follows up until 1981/1982. Markets continued to develop for different products in different locations and the fleet scaled accordingly. Stabilization occurred around 1988/89. Then there is a decrease in catch until 1992/93. This is due to a combination of ENSO events as well as overfishing. Finally, as a result of management legislation and sustainable practices the fishery has been recovering from 1993/94 to present time (SAGARPA, 2012b).

Appendix D: Federal Entities Regulating Fisheries in Mexico

The Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA), is a unit from the Federal Executive Branch of the Government of Mexico, which has among its objectives promoting the execution of policy. It aims to improve production practices, more efficient utilizing of resources, and making use of competitive advantages from the agricultural, livestock and fisheries sectors. SAGARPA also aims to integrate the economic activities from rural areas into larger productive chains (SAGARPA, 2015).

Within the fisheries sector of SAGARPA, CONAPESCA and INAPESCA focus on public policy and research respectively. CONAPESCA is a decentralized body of SAGARPA responsible for designing and conducting fisheries and aquaculture public policy. Its main objective is administration and promotion of fisheries and aquaculture, as well as ensure policy is followed and enforced (CONAPESCA, 2016).

INAPESCA is a decentralized public body sectored with SAGARPA. INAPESCA is the only Mexican public institution in charge of fisheries and aquaculture research with national coverage, permanently in contact with the fisheries and aquaculture sector and its development and administration problems (INAPESCA, 2016).

Appendix E: Small Pelagics Management and Regulation Legislation

On December 14th of 1993 CONAPESCA enacted NOM-0003-PESC-1993, the first and up to date most comprehensive policy for the management of the small pelagic fishery in Baja California Mexico. Target species for NOM-0003 are listed in

Table *1* (CONAPESCA, 1993).

The Carta Nacional Pesquera (CNP) is also a document regulating all fisheries and aquaculture ongoing in waters of federal jurisdiction within Mexico. It includes general information for the different sectors to aid in adoption and implementation of policy to regulate effort, concessions, and execution. It is binding, and could be considered a supplement to NOM-0003, containing less but some different information relating to small pelagics management (SAGARPA, 2012a).

The Small Pelagics Fisheries Management Plan (FMP) was published in July 2011 and the final version was passed into law in November 2012. The plan goes beyond regulation and gives information on the history and current status of the fishery, different uses of landings, and slight information on processing and the markets of each. A relevant addition by the Plan is the definition of limit reference points, maximum sustainable yield catch levels (SAGARPA, 2012b).

NOM-003, CNP, and FMP manage waters of federal jurisdiction within the Pacific Ocean, including the Gulf of California. NOM-003 states the intent of said norms to be conservation, and rational use of these resources. Policy is based on research carried out by INAPESCA as well as other national and international institutions of scientific research.

Appendix F: Permission from Engineer Armando Coppel for using material from our interview in this report

Maz Industrial, S.A. DE C.V.

April 04, 2017

To Whom It May Concern:

As general director of Maz Industrial, S.A. de C.V, I engineer Armando Coppel Azcona grant Esteban Arenas permission to use information from our interview on February 14, 2017 in his masters project for Duke Nicholas School of the Environment.

In case of questions my contact information is listed below:

acoppel@mazindustrial.com
669 9849 199 EXT 118

Best Regards,

Armando Coppel Azcona