Should Sculpin from the Bering Sea and Gulf of Alaska Be Added to the North Pacific Food System?

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ABSTRACT

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With the world's population increasing rapidly and expected to reach 8 billion by 2024, food sources are quickly becoming over-utilized. Fish and seafood are a popular source of nutrition for many cultures; however, policy and history have lead United States fisheries in the Bering Sea, Alaska, to throw away many fishes (bycatch) that could possibly be used for human consumption. One example of bycatch from the Bering Sea that has potential for human consumption is sculpin, a diverse group of fishes that exist in all oceans, except the Indian Ocean and is currently not targeted. By changing U.S. policy to mandate all bycatch in Bering Sea and Gulf of Alaska fisheries be kept and marketed, impacts on the ecosystem could be lessened and more fish foods could enter the American and world diets.

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Chapter I: Introduction

As human populations have increased worldwide and continue to grow exponentially, fish sources are decreasing at a steady rate. Many of the fishes being caught do not have an existing market in North America, and are, therefore, thrown overboard without reaching shore. These undesired fishes are called bycatch. The rising need for a source of protein to feed many developing countries, means new food sources should be explored. One such food source is fisheries bycatch currently wasted as a food source by throwing it overboard, causing shifts in ecosystems and often leading to declines in multiple fish populations. Bycatch causes many problems in an already fragile ecosystem due to its removal, sometimes resulting in the depletion of populations, and the reintroduction of dead fish material into the food web.

Adding bycatch species to the North Pacific food system, North American diets, and world market could increase exports from Alaska and the United States of fish proteins and food sources helping to alleviate many hunger issues around the world while also decreasing the amount of fish waste removed, killed, and returned to an ecosystem already endangered by many anthropogenic stressors. Therefore, should sculpin from the Bering Sea and Gulf of Alaska be added to the North Pacific food system?

Historically, humans have targeted species that are easy to catch, then began targeting a different species when overfishing caused the original species to become more difficult to catch in large amounts. The resulting management attempts have caused policies mandating certain vessel can only target specific species during designated seasons, giving us the term “bycatch.” This has resulted in an increase in bycatch species and a decrease in marketability and/or desire to market non-target species, as single-fish fisheries have emerged in the Bering Sea and Gulf of Alaska.

As an observer aboard commercial fishing vessels in the Bering Sea and Gulf of Alaska, I personally witnessed many species of bycatch wasted as the dead fishes were thrown overboard. Many of these species would produce a fillet of meat as large as or larger than the targeted species and have the same white meat preferred by the North American market.

One example of an underutilized bycatch species is the sculpin. Found in the North Pacific, sculpin have potential of expanding North America's fish supplies due to abundance in the Bering Sea, fillet size, meat flavor, and meat texture. However, due to policies and ease of catch followed by generations and generations of fishing, North American fishers target fishes that can be caught in abundance with greater ease, were easier to process historically, and had a less menacing look than sculpin.

Traditionally, the recommendation for problems concerning overfishing and bycatch is to stop what is causing the problem: stop targeting certain fish that coexist with undesired species, stop fishing in particular areas to help increase populations or avoid non-target species, or, even, to stop fishing completely. However, by developing bycatch policies, similar to those found in other parts of the world, mandating all bycatch be kept in Bering Sea and Gulf of Alaska fisheries, a market would develop for all species and sculpin could be used for human consumption allowing less waste of fish protein from the Bering Sea. These more inclusive bycatch policies allowing fishing operations to continue as they are currently, but with all fish kept and marketed creating a multi-fish fishery, would also alleviate many problems associate with what we currently term bycatch and overfishing.

While creating a market for all fish could potentially create a larger problem with overfishing, mandating all fish be kept and placing taxes on fish the stakeholders wish fishers to avoid would ensure fishers continue to use avoidance measures to prevent the capture of fishes they do not have a quota for. By creating a tax high enough to discourage continued catch but low enough to prevent incentive to misrepresent numbers, fishers would be encouraged to bring all fish species caught to market and some profit could be made by the fishers and fishing companies even if the vessel does not own a quota.

To help create a market for fishes caught and kept, non-profit organizations could use social marketing, the use of marketing to help solve a social issue or issues, to encourage the consumption of fishes unfamiliar to the North American consumer. In recent history, non-profit organizations have used a wide variety of methods to inform the public on overfishing, bycatch, and sustainability issues. An extension of programs already in place could include listing sustainably caught “bycatch” as a potential choice in the American and Canadian diets or creating media, such as cookbooks, to encourage the consumption of “bycatch” species that are unfamiliar.

Many fish species are often mislabeled in our currently food system, such as Patagonian toothfish and Chilean seabass, as a result of market preferences, policy, and overfishing or bycatch problems. As a result of this mislabeling, misnaming, and/or renaming or mixing of fishes sent to market, often consumers purchasing sea food from their local market do not know what they are eating.

Potentially, this not knowing could be used to the advantage of fishers attempting to market new fishes. However, it does encourage questions about what North America and the world are actually eating.

Chapter II: A Short Review of Food and Fish Literature and Research Methods

With the world's population reaching 7 billion in 2011, and estimated to reach 8 billion by 2024, food and nutrition have becoming increasingly important topics. Malnutrition, especially in less developed countries, is a widespread issue. Despite a recognition of food scarcity, fisheries policies and commercial fishing histories, have created a social issue preventing some fishes that are caught from entering the market. Therefore, potential fish proteins are thrown away due to a lack of market, leading to unwanted bycatch and a loss of possible food sources. This often also means that fishes entering the market are priced too high for people who need fish proteins the most to afford. Frequently, the very people who catch many fish species cannot even afford them.

Fish is a known source of low-fat protein, vitamins and some necessary trace minerals. Research demonstrates omega-3 fatty acids aid in optimal brain function, reduce danger of heart attack and strokes, and possibly delay onset of arthritis and osteoporosis (Clover, 2008). There are also reports that a diet full of fish can help with weight loss by switching off human hunger hormones (Clover, 2008; International Seafood Byproduct Conference & Bechtel, 2003).

The health benefits of seafoods come from long chained omega-3 polyunsaturated fatty acids (PUFA), found exclusively in marine organisms, including fishes, algae, and marine mammals. Popular fish oils on the market contain mainly triacylglycerols and fish liver oils, a source for vitamin A that helps human health by lowering the level of serum triacylglycerols; cholesterol; and, sometimes, blood pressure (International Seafood Byproduct Conference & Bechtel, 2003). They can also relieve arthritic swelling and pain, type II diabetes, and increase the body's immune system.

Fish oils may increase fluidity of blood, and have also been shown to dominate the fatty acid spectrum of the brain and retina lipids and play an essential role in development of fetus and infant brains. Fish oils, especially, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), may also be helpful in decreasing cancer, metabolic syndrome, depression, bipolar disorder, and angry and hostile behavior. Some naturopaths even suggest fish oil supplements for Attention Deficit Disorder (ADD) and Attention Deficit Hyperactivity Disorder (ADHD). In most of these disorders, EPA and DHA insufficiency displaces the metabolic homeostasis of a healthy state.

Some examples of the role of fish in the human diet are walleye pollock and Pacific salmon. Pollock has about .5 g of EPA and DHA per 100 g of fish. Pacific salmon has about 1-1.4 g of EPA and DHA per 100 g of fish. Pacific salmon is considered to have the highest amounts of EPA and DHA. Recommended daily intake of EPA and DHA is between 160 – 850 mg a day depending on what organization produced the numbers (International Seafood Byproduct Conference & Bechtel, 2003). The lingcod is comparable to a sculpin based on life history and evolutionary traits. It is found only in west coast waters of the United States, and is a member of the greenling family (*Hexagrammidae*). Ling cod is considered by many to be 'one of the least attractive but best tasting fish in Pacific waters' (Green, 2007). Nutritionally, ling cod is made up of 89% protein and 11% fat and has an amino acid score of 148 indicating a high quality protein (anything above 100 is considered to be a high quality protein) (Conde Nast, 2011). It is a good source of niacin, B6, potassium, B12, selenium, and phosphorus (Conde Nast, 2011). Ling cod, as with most white fish, is considered to have mildly anti-inflammatory properties due to the omega-3 fatty acids (Conde Nast, 2011). One drawback to eating ling cod, however, is that it is high in cholesterol (Conde Nast, 2011). Due to similarities, it can be estimated that sculpin meat would produce similar nutrition for humans as the ling cod.

In addition to social concerns related to overpopulation and decreasing food sources, the discard of unwanted fishes causes changes in ecosystems. Often fish that do not have a market are less regulated and can easily become overfished (Larson, House, & Terry, 1998). Decreases in some species of fish coupled with the addition of discarded fish waste often leads to decreases in biodiversity in commercially fished areas.

Due to the overexploited status of most fisheries in the world and the diverse populations of all fishes, identification of species or populations that are vulnerable to extinction is much needed with a hope of implementing regulation and/or measures to counter damage caused (Cheung, Pitcher, & Pauly, 2005). There is some debate of assessment of extinction vulnerabilities, particularly with the issue of what defines a 'large fish;' and much more research is needed, not only for sculpins specifically, but for fishes and fish vulnerabilities and the impacts of the fishing industry on the ecosystems as a whole (Cheung et al., 2005).

Research methods for this investigation include an archival literature review including secondary resources and studies over the history of commercial fishing, fishing as a cultural issue, and a review of cook books for fish cooking methodology and as a historical reference for consumption of fish (Barka, 2008). Primary literature review includes fish as a social science, the history of fish consumption and commercial fishing, fisheries ecology, Bering Sea ecology, and anthropological studies discussing food sources throughout the world.

In addition, to archival research, personal experience as a National Marine Fisheries Service North Pacific Groundfish Observer (NMFS-NPGOP) from June 2005 through July 2007 in the Bering Sea, Gulf of Alaska, and off the United States North Pacific coasts of Washington and Oregon are included. As an observer, I collected data on specific species, weight, and numbers of all fishes brought aboard commercial fishing vessels targeting pollock, Pacific cod, rockfishes, flatfishes, and hake as part of the NMFS Bering Sea and Gulf of Alaska management programs. As part of this program, I potentially collected the data used in many of the archival records used in this investigation.

Methodology for taste-testing was performed using a Preference Taste Test (Succop, 1998). Taste tests have been used by consumer marketers and behavioral researchers for a long time. Taste tests have been shown to have validity when addressing food and human consumption (Borderias, Lamua, & Tejada, 1983; Gruber & Lindberg, 1966). Following the taste test, panel members were presented with frozen whole fishes similar to ones that would be found at a grocery for visual assessment.

Bycatch is a major international ecological, social, and economic issue. Because of its impact, many organizations throughout the world recognize the importance of understanding the issue. Bycatch harms ecosystems and the economic integrity of the commercial fishing industry, often meaning unsustainable amounts of fish are removed from the ecosystem, greatly affecting biodiversity of the area. Return of the bycatch to the system can also change foraging patterns of scavengers and opportunistic feeders that learn to utilize discarded bycatch.

In addition bycatch that is thrown overboard is lost as potential food for a growing world population indicating a growing social issue. For these reasons assessing whether sculpin should be added to the North Pacific food system is an interdisciplinary issue that should be addressed from many angles.

Historical Fishing. As has been previously discussed by many authors including Mark Kurlansky (Kurlansky, 1998), Taras Grescoe (Grescoe, 2009), and Charles Clover (Clover, 2008), the history of commercial fishing is a complicated one filled with economic, technological, biological, and social issues. It seems commercial fishing has always been about what resource is convenient. For example, salmon became popular commercially because they were easy to catch as they headed up rivers to spawn. The ease that they were caught and the predictability of salmon runs were probably why natives and early settlers caught them originally.

As fishing technology has increased, the ability to catch schooling fishes in the North Pacific has also increased, causing fishers to target Pacific Ocean perch, flatfishes and other easy to catch fishes. Often the ease of catch has led to issues of overfishing. History, however, shows that humans have overfished populations time and again. The walleye pollock (*Theragra chalcogramma*), listed as a baitfish into the late 19th century, began being fished commercially in the 1930s (Aydin & Mueter, 2007). Then, as stocks of yellowfin declined due to overfishing by Japanese and Soviet Union vessels, pollock became the primary target species (Barns, Loefflad, & Karp, 2005). Pollock and Pacific cod became a main target species as the abundance of Pacific Ocean perch decreased after the mid-1960s, suspected to be caused by overfishing. By the mid-1970s, pollock had become the biggest single species fishery in the world because pollock is well suited to trawl fishing: it schools in masses and prefers shallow water (Browning & Cole, 1980). As a result, the pollock fishery too has shown signs of over exploitation. Generally, as one species begins to show signs of depletion, commercial fishing for another species picks up. As one fish becomes overfished, we just supplement it with another fish. The change in public taste is often a reflection of the changes in marine ecosystems (Jacquet & Pauly, 2007).

Overfishing. Overfishing refers to a situation where the fishing industry removes more fish than can be replaced by reproduction of fish left in the ecosystem. Due to improvements in fishing technology, fishing yields have grown dramatically in the last fifty years (Lerner & Lerner, 2009). There are several examples of fisheries that have been destroyed by overfishing, such as, the Atlantic cod fishery in North America or the orange roughy fishery in New Zealand (Lerner & Lerner, 2009).

In 1992, one of the worst examples of overfishing occurred in Newfoundland, Canada where overfishing and poor management caused the collapse of the entire fishery in one year leading to the loss of 35,000 jobs when Atlantic cod did not return at the beginning of the next fishing season (Lerner & Lerner, 2009). The story prompted news coverage and a book, entitled Cod (Kurlansky, 1998). Pacific cod (*Gadus macrocephalus*) began being fished heavily as a hopeful replacement for Atlantic cod after collapse of the fishery (Browning & Cole, 1980).

In 2006, the FAO reported that 80 percent of the world's fisheries were threatened by overfishing. More than 25% of the world's fish stocks were overexploited or depleted, and more than half of the total fish stocks were exploited. The same report estimates that at least 90% of the world's largest predatory fishes, such as the oldest tuna and swordfishes, are no longer in existence (Kourous, 2006; Lerner & Lerner, 2009). Industrialized fisheries have been shown to reduce community biomass by 80% within 15 years of exploitation. Myers and Worm estimate large predatory fish biomass today to be about 10% of pre-industrial levels (Myers & Worm, 2003).

Despite the abundance of fish and species found in the North Pacific, there are only a few of commercial importance to United States fishermen. Americans eat little seafood compared to the rest of the world at 17 pounds per head compared to Britain at 44; Canada, 52; Spain, 97; and Japan, 128 (Clover, 2008). The 20 or so fishes taken from the 100 or so trawlable fishes is all the market traditionally keeps for human consumption or industrial uses in American and Canadian markets. The 'Americanization' of the Bering Sea and North Pacific lead to a change in fisheries from single species to multi-species, also leading to increased discards in the American fisheries in those areas (Larson et al., 1998).

For example, American caught hake has no appeal to consumers in the United States; but they will buy the same fish imported under the name 'whiting.' However, other countries in the world regard hake highly as food (Browning & Cole, 1980). While "whiting" is a name carelessly given to several fish species on the market, sometimes even pollock, the name actually belongs to a croaker of the genus *Menticirrhus* found in the Atlantic (Browning & Cole, 1980).

Another example or creative fish labeling is a fish commonly used historically. During World War II, when meat and meat products were hard to come by, Americans consumed millions of pounds of shark, sold to them under a variety of names including: swordfish, sea bass, grayfish, fillet of sole, cod, and halibut. The fillets and steaks were solid, flaky, and could be baked, broiled, or fried. Shark was good food for Americans then, and still is; however, today, the average American and Canadian will not eat shark. Only gourmet foodies and a few ethnic groups dine on shark species (Browning & Cole, 1980).

This ease of catch followed by consumer demand for several generations created by availability of fish resources has led to many unwanted fishes without a market to be thrown away. When a fisher brings fish aboard, there are two kinds of fish in the net: ones with an existing market and buyer or bycatch of no value to the fishers or the market. For fishers to be encouraged to utilize bycatch a market must be created for those species considered bycatch, and fishers must have access to buyers who want that species. 'Some fish taken incidentally as bycatch are not profitable to retain – simply put, no one wants to buy small flatfish, sculpins, or some other fish – so they are discarded back to sea' (Benton, 2002). The market also ensures that it is in the fisher's best interest to maximize the value of fishes being kept in their hold due to limited space, often leading to high-grading, even within target species. Therefore, to make fishers keep sculpins, the market value of sculpins would have to be as high as or higher than the target species.

Bycatch. In 1996, Congress amended the Magnuson Fishery Conservation and Management Act (MSFCMA) to define the term 'bycatch.' Bycatch is defined by the MSFCMA as 'fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. The term does not include fish released alive under a recreational catch and release fishery management program' (Larson et al., 1998) 'Economic discards' is also defined in the MSFCMA as 'fish which are the target of a fishery but which are not retained because of an undesirable size, sex, or quality, or other economic reason;' (Larson et al., 1998) and 'regulatory discards' is defined as 'fish harvested in a fishery which fishermen are required by regulation to discard whenever caught, or are required by regulation to retain but not sell' (Larson et al., 1998).

Approximately twenty million tons of fish food are lost to bycatch every year (Cooper, 2006; Lerner & Lerner, 2009). The FAO estimates bycatch of fish alone, not including marine mammals; birds or turtles, to total 20 million tons, about a quarter of the annual marine catch; and the total of discards and unintentionally caught species totaled about 28 million tons in 1994 (McGinn, 1998). While a great deal of success has been made in the avoidance of bycatch of turtles, mammals, birds and prohibited species; very little has been done with regard to fish no one cares about due to a lack of market.

Aboard factory commercial fishing vessels in Alaskan waters, fish are dumped from a codend, or net, into tanks, called 'live tanks,' where they are allowed to age for between 2 and 8 hour with 6 hours being the average. Different aged pollock meat is used to make variable products. While some sculpin have been shown to live outside of water for up to 2 hours, the damage and trauma received from being in a tank for that length of time means most, if not all, sculpin are dead by the time they reach the sorting belt. Other less hardy fishes do not tend to fair as well as sculpin species (Vandever, 2005). When aged fishes enter the sorting belt, a human processor sorts the fishes to make assorted products. The processor also removes any fish that is not marketable (bycatch) and either throws it on chute directly overboard or puts it on a second conveyer belt leading overboard (Vandever, 2005).

Alternatively, if more caught fish were consumed by humans perhaps less of any one fish would have to be caught. By fishing for other fishes, pressure could be taken off of overfished populations, possibly allowing them to recover. Because fishing stocks are dynamic, adding another fishery could decrease pressure to help alleviate the problem of fishing down the food chain. Because the fishing industry is market driven, some non-profit organizations have started publishing guides to urge consumers to make smart decisions before purchasing fishes. Hopefully, by discouraging consumption of fishes caught with significant bycatch or in poorly managed fisheries, these organizations can influence the industry and its managers to make better decisions about sustaining fisheries (Lerner & Lerner, 2009). These same organizations could be the leaders to turn bycatch into catch. Instead of throwing back sculpins, they could lead a drive to keep them and market them.

When there is little information on bycatch of no economic value mortality is often justified because it contributes to the overall benefit received by efficiently harvesting desired species, such as pollock or Pacific cod. Public perception and the market has resulted in bycatch being treated as though it is biologically different from targeted species despite scientists and ecologists teaching that all species, whether targeted or bycatch, should be treated equally (Rawson, 1997). There is a great deal of evidence showing that fishing down the food chain causes many impacts in the oceans as a whole. However, because the public cannot see the bottom of oceans and ecosystems, no one knows what exactly we are doing to ecosystems; therefore, we need to take into account not just what we are doing to the catch and bycatch, but what we are doing to the ecosystem as a whole (Rawson, 1997).

A potential solution to the issue of bycatch is to create a market for usable fishes. Instead of throwing bycatch away as waste, fishes could be sent to market to help alleviate some of the demand for fish protein. Because of the heterogeneity of fish as a product within the market, there is a great deal of room for fishes that may not have been marketed previously. Many merchants choose fresh fish themselves to pick quality and variety best serving their purposes (Graddy, 2006). “The buyers [at Fulton Fish Market in Manhattan, New York] would take a sample, look at the color, rub the sample between their fingers to determine oiliness and taste it.” Buyers are interested in different varieties of high-quality fish for a restaurant or retail shop (Graddy, 2006).

Fish are a differentiated product. At fish markets, within each variety of fish, it is separated into large fish, small fish, fresh fish, and older fish. Some of the fish has even been at market for longer than it should (Graddy, 2006). This heterogeneity of fish explains why fish markets continue to survive, while other methods of supplying goods have become decentralized (Graddy, 2006). Fish are more perishable, supply is unpredictable, and individual fish are more differentiated within themselves than most other agricultural products (Graddy, 2006). Each purchaser of fish looks for something specific to their need.

<u>Diversity in the Human Fish Supply.</u> North Americans are selective about fishes they buy and eat; therefore, marketing in Eastern cultures first could create an export market. With nearly half of all fish caught today traded internationally, distant markets and foreign economies play a large role in the depletion of world fisheries. Due to overfishing in Northern, temperate waters, many previously self-sustainable countries, including the United States, now must turn to developing countries where nearly 85% of internationally traded fish products originate (McGinn, 1998). This also means that foreign markets are probably the better place to attempt to market bycatch, such as sculpin. Asian cultures buy fish often rejected by Western cultures. Therefore, many Asian cultures would be more likely to buy sculpin if put on the

market; and with globalization, North America and Europe would potentially catch on to the trend of sculpin for dinner.

Currently, most of Alaska's fishers, are concerned less by fish species desired in Seattle and the rest of North American than those species desired by Asia. For decades, Japan was the world's largest and most demanding market for many kinds of seafood. Japanese companies have led the way in developing technologies for shipping seafood around the globe. In 1970s, they began shipping Canadian Bluefin tuna; and developed 'superfreezing' with turns a half ton tuna into sashimi with a shelf life of 2 years (Freidberg, 2009).

Japanese markets have recently begun to be overshadowed by developing markets in China as younger generations develop a taste for varieties of fish traditionally scorned in their country because of tough, oily flesh. "They don't know what the taste is, but if it says in the magazines that it is expensive, that it's good stuff – they will go for it. They can pay for it" (Freidberg, pp. 16 2009). Traditionally, uncooked fish was considered unwholesome and inappropriate for social occasions in China. Those beliefs have changed drastically with globalization (Freidberg, 2009).

Wild-caught fish costs more in China and Japan because it is considered cleaner, more natural, and stronger (Freidberg, 2009). However, Japanese culture and Chinese culture look for very different things when purchasing fish. Japanese sushi bars assess quality of the meat in pieces: looking especially at color, texture, and cut of pieces, but Chinese buyers and consumers want fish whole and, usually, swimming. Chinese diners like the head and tail, not only because they believe it tastes good; but because in their culture it symbolizes completeness of the meal. They often like to observe the fish swimming because it shows the fish as full of vitality (Chi).

Ability to have fresh (live) fish in China symbolizes wealth and well-being. In the United States, larger markets for live sea food are found alongside large Chinese populations (Freidberg, 2009). It is also relatively easy to sell fish byproducts to Asia (International Seafood Byproduct Conference & Bechtel, 2003). In Asia, due to high bycatch/multispecies fisheries many fish products have been developed to utilize as much as possible: dry/salted fish, fish jelly, fermented products, fish crackers, and fish meal.

Sculpin as a Possible Human Fish Supply. An example of one such fish resource that is currently not being used and that could easily have a market developed for it is sculpin caught in the Bering Sea, Alaska. Sculpin is listed as 'other groundfish,' and is usually not targeted. Because most sculpin species originate in the Pacific Ocean and occupy the Bering Sea and Gulf of Alaska, a commercial fishery developed for sculpin would have to be done by U.S. or Polish fishers in the Bering Sea Aleutian Island (BSAI) or Gulf of Alaska (GOA) area; and because most vessels in the BSAI fish more than one species, adding another species to process would not be overly difficult. Sculpins are currently only taken as bycatch in the Gulf of Alaska and Bering Sea, and the NMFS predicts future catch of sculpins will remain dependent on distribution of targeted species, rather than be targeted itself (Cheung et al., 2005).

Because the historical 'ease of catch' is not there, recreational sculpin fishermen often complain about difficulty in finding and catching sculpin. Possibly, that is why they have not developed as a common diet historically. Availability followed by generation after generation of fishers has led to the market that we know now. Had sculpin not spent most of its life in areas that were once difficult for fishers to utilize, we would see sculpin on our dinner tables instead of pollock. Often many fishes get caught, but have little value to trawl fishermen. For example, sturgeon (usually the Green sturgeon) brings a good price but is caught rarely and not in abundance when caught making it not worthwhile economically to target (Browning & Cole, 1980).

The North Pacific Ocean and Bering Sea are the most productive fishery regions in the world, and the “Americanization” of the area has led to dramatic shifts in the composition of American fishing fleets and species it targets: changing from traditional single species fisheries to multiple species groundfish fisheries. This frequently occurs because many ground fishes exist in the same areas, feed on the same prey and provide food to the same predators and fishing gear is not selective. Many fishes are thrown away because technical and market conditions dictate that only certain sized fish and species of fish can be kept and processed (Larson, House, & Terry, 1998).

Chapter III: Fisheries Bycatch as a Potential Food Source

The act of commercial fishing and the use of fishes in human diets has been a social issue for many generations in North America and the world. As the demand for fish on the dinner table increases, the strain is felt in many of the world's fisheries. This impact is made more dramatic by policies allowing and, in many cases, mandating the waste of unwanted and unmarketable fishes. However, within many of those 'unwanted' fishes there is potential for a future food supply. The use of waste fish could help alleviate social issues from lack of protein sources and environmental issues from biodiversity decreases.

Fish has been eaten by many cultures throughout history. For example, Pacific salmon have been an important food source throughout the Bering Sea and became a large commercial fishery in the early 1900s (Aydin & Mueter, 2007). In fact, for many years, the most important product from the Pacific Northwest fisheries was salmon. However, competition and unsound practices, such as stringing traps and nets across river mouths characterized the Pacific Northwest commercial fishery from the beginning quickly leading to overfishing (Schwantes, 1996).

The Spanish also found North Pacific fishes to suit their tastes. Hake has always been a mainstay of traditional Spanish cooking (Clover, 2008). However, the big increase in the development of a fishery for Pacific hake occurred when Soviet fishermen began to concentrate on species, other than pollock, with little visual appeal that could be taken in great quantities off of the Washington coast and south of the Columbia River in the United States. Despite the use of many types of fishes from the North Pacific Ocean, historically forage fishes are generally not targeted by commercial fisheries. A few smaller fishes have been targeted, but fisheries have not developed (Reuter et al., 2010).

The evidence of fish in human diets is thought to extend back to some of the first coastal civilizations, many of which developed tools, such as spears and traps to aid in capture. As civilization and technology advanced, human ability to capture larger amounts of fishes has grown exponentially. As a result, evidences of eating different types of fish and creativity in use of fish proteins and marketing have also grown quickly.

Modern societies continue to search for fish proteins, as demonstrated by the fairly recent surge of interest in tilapia. In 20 years, tilapia production has tripled from 2 billion to 6 billion pounds annually (Greenberg, 2010). It was expected to grow another 10% by the end of 2010 and continue growing, with HQ Sustainable Maritime Industries, a tilapia grower with major production in China, concluding successful negotiations with a major fast food chain to use tilapia on its sandwiches (Greenberg, 2010). The increased consumption of tilapia has been in part due to seafood awareness campaigns and health and safety organizations stressing the benefits of tilapia because it is a vegetarian farm-raised freshwater fish. It has also been a large result of tilapia's mild flavor.

Cod originally made up fish fillets and fish sticks. However, after being nearly depleted, they have been replaced by haddock, then redfish, and, now, Pacific walleye pollock (Barns et al., 2005). Most of Gorton's fish products, including fillets and sticks, are minced pollock, unless specified on the package. Gorton's publishes all ingredients online along with their personal mission statement about sustainability and 'going green' at www.gortons.com. McDonald's fish filets are made up of Alaska walleye pollock or hoki from New Zealand: pollock is used 90% in each of the 275 million fish sandwiches McDonald’s sells each year (Clover, 2008). It is filleted, not the minced fish that lower grade processed white fish in fish sticks and breaded shaped fish are made up of. Minced fish, like Gorton’s sometimes has a superior taste due to the higher fat content.

Americans prefer fish to not be too fishy tasting, while Europeans prefer a fishier tasting fillet. Therefore, fish in the American market has ‘fat lines’ (the lateral lines of darker-colored meat), taken out, also improving freezer life because fat lines can go rancid even when frozen. Fish fillets, such as the Filet-O-Fish from McDonald’s, for the American market are instead ‘deep-skin fillets’ because they are skinned to leave just the white flesh, (Clover, 2008; International Seafood Byproduct Conference & Bechtel, 2003); however, consumer studies show children prefer fish sticks made from mince rather than whole fish fillets (International Seafood Byproduct Conference & Bechtel, 2003).

Many diverse products can be and are prepared from mince, including: fish chips, frankfurters, fish balls with sesame, noodles with 20% fish filling, and ravioli filling. Mince can be prepared with many different species of fish and the majority of consumers are unable to detect a difference. Hydrogen peroxide can also be used to whiten fish mince with coloring deemed unappealing to consumers. The hydrogen peroxide leaves little or no residue and is considered perfectly safe to consume (International Seafood Byproduct Conference & Bechtel, 2003).

With population increasing rapidly demand on food sources is a much discussed topic. If a market for bycatch could not be created in North America or Asia, it could have a future in developing countries because other countries are hungrier and less picky (Browning & Cole, 1980). Lower quality preserved fish could be the key to food scarcity in many developing countries, such as Senegal, where 8.8 million people rely on fish for about 75% of their diet (McGinn, 1998). Similarly, low-quality fish remains the staple low cost food source in many developing countries, such as Bangladesh, where 50% of their diet comes from small (less than 25 centimeters) fishes caught in flood plains and inland waters and eaten whole giving 90% of needed vitamin E and 15 – 30% calcium and iron needed daily (McGinn, 1998).

Fish represent about sixteen percent of protein in the human diet (Lerner & Lerner, 2009), and this percentage is higher in underdeveloped countries. According to the United Nation's Food and Agricultural Organization (FAO), in Asia, about thirty percent of animal protein consumed comes from fishes; in Africa, about twenty percent; and in Latin America, about eight percent (Lerner & Lerner, 2009).

Eating fish has always been and continues to be very fashionable. Even many vegetarians add fish to their diet to gain needed protein (Clover, 2008). Globally, consumer demand for fish continues to climb annually. Developed countries imported 33 million tons of fish worth $61 billion U.S. in 2004 (Kourous, 2006). Seafoods have traditionally been used because they contain a variety of textures, flavors, and colors.

<u>Present and Future Fish Supplies in North America.</u> The Bering Sea consists of a deep

central basin surrounded by continental shelves along the coasts of Alaska, United States, and Kamchatka, Russia. The 2 shelf ecosystems, created by the climate and geographical characteristics of the area, within this region have been defined as large marine ecosystems: the eastern Bering Sea (EBS) and western Bering Sea (WBS) (Aydin & Mueter, 2007). The Bering Sea straddles a major Arctic/sub-Arctic atmosphere front and is, therefore, influenced by both Arctic and sub-Arctic weather patterns (Aydin & Mueter, 2007). The Bering Sea shelves have some of the highest concentrations of nitrate, phosphate, and silicate in the world (Aydin & Mueter, 2007) due to what has been called the global ocean 'conveyor belt' (Aydin & Mueter, 2007).

The seasonal advance and retreat of ice and resulting temperatures strongly influence the trophic ecology of the Bering Sea and Gulf of Alaska by influencing primary production that is believed to concentrate along the shelf where concentrations of nutrients can be found (Aydin & Mueter, 2007). Total phytoplankton production as a result of nutrient rich waters are thought to extend past 175 to 275 g C m^{-2} yr^{-1} and are a mix of large diatoms and microplankton (Aydin & Mueter, 2007). Krill (Euphausiids) are a major prey for many upper trophic level species in the Bering Sea, including sculpin; juvenile and adult pollock; other forage and predatory fishes; and birds because krill tends to be less variable than copepods and provide a more sustained food source throughout the summer, fall and winter. The abundance of primary producers and primary consumers has provided an opportunity for the evolution of many different fish species as well, allowing for perhaps the most complex food systems of any ocean.

Production in the Bering Sea is greatly dependent upon timing of the ice retreat from shelf areas every year (Aydin & Mueter, 2007). Melting ice stratifies the water column forming a shallow layer of low salinity water on top. The ice melt must occur at a perfect time when sufficient sunlight is available to primary producers and storms have subsided for the season to ensure maximum productivity, making the Bering Sea ecosystem fairly fragile (Aydin & Mueter, 2007). It also means that the climate plays an important role in the overall health of the Bering Sea ecosystem, and global climate change may cause drastic impacts on the overall productivity of the Bering Sea.

In addition to climatic effects, due to an early discovery of the productivity in the Bering Sea, the area has received documented anthropogenic pressure for at least 200 years (Aydin & Mueter, 2007). Consequently, historically, the marine fishes, seabirds, and marine mammals have all shown changes in habitat patterns and predator-prey interactions. As fishing pressure has increased, sizes and numbers of targeted fish have often decreased while bycatch has increased.

Fishing in the Bering Sea. In general, the eastern Bering Sea has been dominated by walleye pollock since the early 1980s and the western Bering Sea has been dominated by cephalopods and small forage fishes. The walleye pollock is an important mid-level predator and prey to numerous predators, including humans. Like many fishes, they are also cannibalistic. The eastern Bering Sea has a much higher production of small flatfish and commercial crabs than the western part (Aydin & Mueter, 2007).

There are about 20 families of fin fishes in the North Pacific, including 50 species of fish found between the surface and mid-water and 55 species of rockfish, 20 species of flatfish (flounders and sole), and many other bottom dwellers inhabiting the area lower than mid-water. These include the members of the classification of sculpin (Browning & Cole, 1980). The predator population in the eastern section of the Bering Sea is made up of large flatfish and other species existing above the bottom but lower than the middle of the water column, including sculpins, rockfish (*Sebastidae*), and sablefish (*Anoplopoma fimbria*) (Aydin & Mueter, 2007).

The rapid growth of the Bering Sea fishing industry over a relatively short period was greatly influenced by the Fishery Conservation and Management Act (FCMA) of 1976 when the U.S. extended political jurisdiction over oceans to 200 nautical miles, the Exclusive Economic Zone (EEZ), and began developing a domestic fishery focusing on this 200 nautical mile area (Mansfield, 2004). Until then, the pollock fishery was dominated by Japanese fishers, who initiated it in the 1960s, using their new technology of factory trawlers (International Seafood Byproduct Conference & Bechtel, 2003; Mansfield, 2004). Once the U.S. extended jurisdiction over Bering Sea waters, 'Americanization' of the fishery began to phase out Japanese fishing vessels and developed a U.S. industry to replace it (Mansfield, 2004). Unlike Japan, who lost free access to the world's oceans, the creation of the EEZ gave the United States exclusive access to one of the world's largest fisheries (Ludicello, Weber, & Wieland, 1999).

The enactment of the EEZ and FCMA cut catches of dominant species of groundfish by Eastern Asians and gave the American fishing fleet incentives to seek fish that, until then, had been fished mostly by the Soviet Union, Japan, and South Korea. The U.S. and Russia quickly made pollock a target fish in the Bering Sea and Gulf of Alaska.

Commercial fishing is and has been a significant economic activity in the United States Pacific Northwest historically. The annual income for marine sources in the Pacific Northwest region regularly exceeds 300 million dollars, and it is a large employer both directly and indirectly (Lambert, 1998). Alaskan fisheries are also an important source of food for much of the United States and world: about half of the total U.S. fish catch each year comes from Alaska. In 2001, fish catch off of Alaska was over 1,834,000 metric tons for groundfish, and 93% of that was processed causing the fishery to be valued at over $1 billion per year (Benton, 2002). Today, many coastal communities are supported by commercial fisheries, and they are the largest private employer in Alaska (Fishing Industry (Commercial), 1999).

The commercial fishery for groundfish in Alaska is reported to have begun in 1864 when the fishing vessel, *Alert*, sailed from San Francisco to Alaska and harvested 9 tons of Pacific cod in Bristol Bay. A large commercial sailing fleet continued to target cod for decades as the fishery for sablefish and Pacific halibut developed in the early 1900s (Barns et al., 2005). In the 1930s, Japanese fishing fleets began exploiting pollock and flatfish, stopping during World War II and picking back up in the mid-1950s, targeting yellowfin sole. Through the 1960s, Japan and the U.S.S.R. fished with little competition (Barns et al., 2005).

In the Pacific Ocean, large commercial fisheries for yellowfin sole (*Limanda aspera*) and other flatfishes on the shelf, as well as, the Pacific ocean perch (*Sebastes alutus*) and other rockfishes did not begin until the late 1950s with a peak in the mid-1960s. However, zooarchaeological records suggest that rockfishes have been opportunistically fished in the Puget Sound region of the United States for over 1500 years (Williams, Levin, & Palsson, 2010). Rockfishes of various species have been marketed as red snapper for many decades. Despite the United States Food and Drug Administration (USFDA) tightening regulations governing nomenclature of marketed fishes, misnomers still happen regularly (Browning & Cole, 1980), whether purposeful deception or accidental mislabeling.

Scandinavian countries have harvested Atlantic cod (*Gadus morhua)* for centuries, taking advantage of 'unlimited' quantities available close to shores. Fishers in these countries had good boats and skill, but lacked ways to preserve fish: Salting and drying were the only methods available for longer storage. The first recorded United States west coast fishery producing salt cod was developed in San Francisco Bay area (Shields, 2001). Salted cod was served with boiled potatoes and cream sauce, and the immigrants in San Francisco, largely Spanish or Italian, were schooled in the preparation from an early age as it had been a cultural favorite for generations (Shields, 2001).

Many flatfishes, most frequently called flounders or sole in the market, from the Bering Sea remain underutilized because Pacific halibut bycatch quotas are a limiting factor; therefore, they also represent an untapped resource and could potentially be used as a commercial fishery (International Seafood Byproduct Conference & Bechtel, 2003). This could alleviate some loss due to pollock abundance decreases that have been occurring since 1989, due to low recruitment causing it to be considered fully utilized (International Seafood Byproduct Conference & Bechtel, 2003). Due to overfishing and bycatch issues, in addition to many other reasons, the list of Pacific fishes favored by Americans and Canadians should be lengthened to take in more species living in the Pacific Rim. Currently, these fishes are termed bycatch and treated as waste. However, with a market these species, including members of the sculpin group, would become another option of fish to order at a restaurant, supermarket, or local fish market.

Sculpin in the North Pacific. Sculpin are a group of fishes belonging to order Scorpaeniformes, suborder Cottoidei and superfamily Cottoidea that contains 11 families, 149 genera, and 756 species. These are numbers expected to change as more genetic work is performed (“What is a Sculpin?,” n.d.). Representatives of sculpins exist in all of the world’s oceans, except the Indian Ocean. However, the North Pacific Ocean has been identified as the center of origin and diversity.

Sculpins vary in color from brick red, green, brown, or yellow and are usually striped or mottled. Their coloring is largely due to variations in habitat and offers the ability to blend in with surroundings to hunt prey. They live on mud, sand, or pebbles. Their bodies are compressed and frequently covered with bumps. They also possess an array of spines on the head and dorsal fins. Many sculpins carry toxins in their spines that can cause skin irritation, sweating, nausea, or dizziness similar to that of many catfish species. They are a group of relatively small, benthic-dwelling, highly predatory teleost (bony fishes) containing many species. Sculpins are almost always cold-water fish, preferring water with temperatures lower than 55 - 60° Fahrenheit, but can survive temperatures close to freezing due to an antifreeze chemical found in their blood (Patel & Graether, 2010). They usually swim slowly with an undulating motion, and use very ornate pectoral fins comparable to a bat’s wing. Sculpins are highly predatory eating almost anything that will fit in its mouth; therefore, recreational fishers have found sculpins are easily caught off of piers and along rocky shores because they will bite on almost any bait and are often caught more than once.

In the Bering Sea/ Aleutian Islands (BSAI), as well as the Gulf of Alaska (GOA), Sculpins belong to Families Cottidae, Hemitripteridae, Psychrolutidae, and Rhamphocottidae, including about 46 species (Ormseth & TenBrink, 2010a, 2010b). In U.S.-Japanese trawl surveys 41 species of sculpin were identified in the Eastern Bering Sea (EBS) and 22 species were identified in the Aleutian Island (AI) region (Ormseth & TenBrink, 2010a) making them one of the most abundant groupings in the North Pacific Ocean.

Depth range and distribution has been recorded for some sculpin species since 1982, especially by Russian scientists; and length frequency information has been collected since 2000 for larger sculpin species (Reuter et al., 2010). However, recent data collected by U.S. National Marine Fisheries Services – North Pacific Groundfish (NMFS – NPGOP) observers and other studies have provided some much needed life history data on sculpins. This has occurred in part because the Alaska Fisheries Science Center (AFSC) initiated a species identification project due to a need for population data for non-commercial species, including sculpin, in 2002 (Reuter et al., 2010).

Most, possibly all, sculpins lay adhesive eggs in nests and show some parental care for the eggs (Ormseth & TenBrink, 2010a). The sea raven (*Hemitripterus villosis*), closely related to yellow Irish lord, was observed releasing eggs into crevices of rocky bottomed shallow waters in Peter the Great Bay, Sea of Japan (Ormseth & TenBrink, 2010a). This type of reproduction may make sculpins more susceptible to natural or anthropogenic environmental changes due to their dependence on a very specific environment (Cheung et al., 2005; Ormseth & TenBrink, 2010a).

Because sculpin are not generally eaten by humans due to their toxic spines; appearance; and boniness, they are not usually considered a species at risk ("What is a Sculpin?," n.d.). However, by using the scheme adopted by the American Fisheries Society (AFS) for productivity as an inverse, estimations of vulnerability can be assessed for fishes (Cheung et al., 2005). The scheme incorporates life history characteristics such as intrinsic rate of population increase, longevity, age at first maturity, fecundity, and the von Bertalianffy growth parameter (K), which can be used to determine vulnerability to extinction (Cheung et al., 2005). Generally, species with larger body size, longer longevity, higher age at maturity, and lower growth rate suggest higher vulnerability to extinction (Cheung et al., 2005). Many of the larger sculpin species exhibit these characteristics, showing a potential of having high vulnerability to extinction and making them poor candidates for a targeted fishery.

In addition, sculpin are at risk to environmental degradation because sculpin species prefer specific environments which vary by species ("What is a Sculpin?," n.d.). It should also be noted that while it has been suggested that high fecundity would imply high productivity and, thus, low extinction vulnerability, data does not support this relationship (Cheung et al., 2005). Therefore, fecundity is not considered a good indicator. As far as sculpin research used in this analysis, the fecundity for each species examined extends from very low to relatively high depending on the area making an analysis based on fecundity difficult.

Figure 2: Codend (net) filled with about 120 mt of pollock and bycatch species (sculpin).

Despite having no directed fishery, sculpin are caught in a wide variety of fisheries: trawl fisheries for yellowfin sole, Pacific cod, walleye pollock, Atka mackerel, and flathead sole. The Pacific cod hook-and-line fishery and hook-and-line Halibut fishery catch the most sculpin. Observers indicate retention rate of sculpin bycatch increased to 13% from the BSAI fishery and 18% in the GOA fishery in 2009 (Ormseth & TenBrink, 2010a, 2010b), most likely due to fish meal increases. Fish meal is a product made by grinding whole fishes and fish parts to a thick slurry then drying it. It is most often used for fertilizers and pet foods.

Policy. Today, Hong Kong merchants must import fishes from all across the South Pacific, Anchorage, Johannesburg, and Boston because industrialization of Hong Kong has greatly decreased natural populations of fish and polluted water ways making farming difficult. Lamma Island in the village of Sai Kung offers up to 25 different kinds of live seafood, most of which is foreign. Due to poor conditions, including chemicals like Malachite Green, farmed fish in Hong Kong is deemed no good (Freidberg, 2009).

Some fisheries retain incidental catch as secondary catch. For example, in the Hawaii longline fishery, vessels target swordfish or tuna, but also plan on catching other marketable pelagic species (Benaka & Dobrzynski, 2004; Rawson, 1997). To benefit and address issues, the NMFS's position remains that requiring retention of all species caught will not eliminate problems associated with bycatch in the BSAI fisheries. They state it is critical to account for all catch: target catch, bycatch, and retained incidental catch, and provide restraints to solve problems of excessive catch (Benaka & Dobrzynski, 2004; Burns & Kerr, 2008).

Due to management difficulties, New Zealand has a very ambitious regulatory program for its fisheries, called the Quota Management System (QMS), which aids in bycatch enforcement that is difficult to regulate because trawlers often catch 5 to 10 species at one time, making a difficult quota range to predict. To address the issue, a tax is assessed on all fish that fishers do not have a quota share for. The tax is set at a level to eliminate any incentive (from the market) for fishers to catch non-target fish (Ludicello et al., 1999).

Fisheries in the Mediterranean are predominately 'Artisanal fisheries,' small capital exploitations where fishers use their own property rather than big fishing companies controlling most of the fishing. This usually means there are no long periods at sea, unlike the Bering Sea fisheries where fishers can go several weeks without seeing land (Farrugio, Oliver, & Biagi, 1993). Because Mediterranean fisheries catches are made up of a large number of species, there are many complications in management of the fishery (Stergiou, Machias, Somarakis, & Kapantagakis, 2003). Complications are increased by the fact that fishes are diverse and research is lacking in many of the systems (Caddy, 1993).

Most enforcement exists in the form of gear regulations causing a typical multi-species multi-gear fishery to use more than 50 types of gear to catch 150 species of fish of commercial interest (MatiAe-Skoko et al., 2011). Despite the use of multiple gear types, larger adult fishes, including *Scorpaenidae*, run a high risk of being caught unless mesh sizes of nets are 80-100 mm, making the nets ineffective for smaller fishes that make up a large portion of the fishery. Therefore, the 'ideal' mesh size is 40 mm with larger species caught as incidental bycatch and making mesh size limits alone an ineffective management practice (Morales-Nin, 1993). Due to the difficulty defining target species in the Mediterranean trawl fishery, management practices heavily emphasize gear limitations. For example, the European Union (EU) enforces a minimum stretched mesh size of 44 millimeters (MatiAe-Skoko et al., 2011; Stergiou et al., 2003).

The line between target species and incidentally caught species in tropical and Mediterranean trawl fisheries is often much less clear than fisheries found in the North Sea, Barents Sea, and Bering Sea because tropical and Mediterranean fisheries are characterized by high species diversity in one location and many small species, whereas high-latitude trawl fisheries, such as the Bering Sea pollock fishery, only a few species make up the major part of landings (Stergiou et al., 2003).

In Nigeria, The Sea Fisheries (Fishing) Regulation of 1992, mandated 75% of landings found in fisheries must be kept to account for the estimated 1.53 million tons of fish demand found in Nigeria (Akande, 1998). The same policy prohibits dumping of anything at sea that is edible or could be a marketable product. Because fishers are accustomed to the policy they have created a method for sorting fish at sea by species, then size, making the job seamless, and the resulting market has also allowed for many different products to be created (Akande, 1998).

The South China Sea has had similar policies because they are also considered a multispecies fishery. Because 60 – 70% of species caught have a low market value or are juveniles, a market was created for bycatch (lin, 1998). While much of this is used for aquaculture and other animal feeds (fish meal products), many bycatch products are used for direct human consumption or fish products, such as fish cakes, fish balls, or surimi products (lin, 1998)

Bycatch is predominately monitored in the Bering Sea because catch and discard of a species in one fishery imposes an opportunity cost on other vessels in the industry that would otherwise catch and market them. The Magnuson Stevens Fishery Conservation Act developed the need to manage non-target species in the North Pacific. It requires annual catch limits to be set for all species within a fishery (target and non-target species) in order to maintain healthy stocks of both non-target and target species, as well as allowing for development of new fisheries (Reuter et al. 2010).

In BSAI fisheries, there are five species referred to as ‘prohibited species’ within the industry: herring, halibut, tanner crabs, king crabs, and salmon. These species are prohibited to be caught by a pollock vessel or a Pacific cod vessel because they are commercially fished and regulated by other groups (Rawson, 1997; T. Smith, 1996). Even though mortality rates for discards of these fishes (and crabs) can be very high, their high value in other fisheries causes retention to be prohibited due to policies in place to discourage targeting by groundfish fleets. These species are often greatly avoided by fishers in the BSAI fisheries. However, there are numerous other fishes not prohibited because they do not currently have a fishery and are, therefore, often discounted.

In late 1996, the North Pacific Fishery Management Council passed an increased retention and utilization requirement prohibiting discards of pollock and Pacific cod based on size and mandated minimum ratios of product weight to catch weight of those species (Barrett, 1999; Larson et al., 1998). According to the NMFS, commercial fishers must minimize waste by ‘avoiding species they do not want or need, minimizing the number of unwanted species they catch and keep, and fully utilizing everything they bring ashore’ (Barrett, 1999). However, in trawling industries, bycatch cannot be completely avoided, and this mandate also did not specifically address the issue of many kinds of bycatch, such as sculpin.

All ‘harvested’ species have been closely monitored since the loss of Pacific Ocean perch populations, including cod, flatfishes, rockfishes, crabs, salmon, and Pacific herring (*Clupea pallasii*) (Aydin & Mueter, 2007). One of big issues with bycatch management is allocation. Sometimes the goal of bycatch reduction is to make sure one boat does not kill a fish so another boat can (Rawson, 1997). In Alaska, there is no gear type that is excluded from bycatch regulations: all bycatch is counted against a total quota and individual species quotas. Therefore, fisheries can be closed down because of targeted fish or bycatch. Either way, the boats have to stop fishing, making this an effective management practice and a well-managed fishery (Rawson, 1997). For example, rockfishes in the Gulf of Alaska are divided into 4 assemblages for management purposes. Rockfishes are conservatively managed due to long life spans and sensitivity to overexploitation.

Fisheries Management. Due to the frequency that sculpin catches occur, in 2010, the North Pacific Fishery Management Council passed amendment 87 to the Magnuson-Stevenson Act Gulf of Alaska Fishery Management Plan and Bering Sea/Aleutian Island Fishery Management Plan separating the ‘other species’ complex into its make up species, and making BSAI sculpins and GOA sculpins their own grouping with their own harvest specifications in each zone.

Historically, sculpins have been managed as part of the BSAI or GOA ‘other species’ along with skates, sharks, and octopus (Ormseth & TenBrink, 2010a). Because sculpins are extremely diverse, many scientists have suggested further separating ‘sculpin complex’ into even smaller components because sculpin populations may react differently to natural and anthropogenic stressors (Ormseth & TenBrink, 2010a, 2010b; Samuel Rauch III, 2011). The total allowable catch (TAC) for sculpins in 2011 and 2012 is 5,200 metric tons, lower than in previous years because they have been deemed easily avoidable. The ABC was determined to be 43,700 metric tons for both years (Samuel Rauch III, 2011).

The sculpin complex biomass is healthy with a current estimate of 208,181 metric tons for the Bering Sea and 7,328 metric tons for the Gulf of Alaska, though the number changes as real time survey data becomes available. The biomass is based on the 6 most abundant sculpins in the GOA and BSAI: bigmouth, great, plain, threaded, warty, and yellow Irish lord (Ormseth & TenBrink, 2010a, 2010b). Total sculpin biomass in the BSAI for 2010 was estimated at 207,658 metric tons, down from 239,174 metric tons in 2004 (Ormseth & TenBrink, 2010a). Despite a dominance on the continental shelf by these 6 species, there are also many smaller species frequently caught; and the continental slope is dominated by smaller sculpin species, such as the darkfin sculpin (*Malacocottus* zonurus), though it does not make up a significant portion of the biomass estimate (Reuter et al., 2010). The United States National Marine Fisheries Services (NMFS) has determined neither the GOA nor BSAI populations of sculpin to be in danger of being overfished, and sculpin diversity remains high in all areas of the GOA, Eastern Bering Sea, and Aleutian Islands.

Observers from the BSAI North Pacific Groundfish Observer Program (NPGOP) began identifying sculpins to genus level in commercial catches starting about 2007, and the NMFS has started focusing on species from the genera *Myoxocephalus*, *Hemitripterus*, and *Hemilepidotus,* the largest sculpin genera in the Bering Sea and representing 90% of all sculpin catch according to observers (Ormseth & TenBrink, 2010a).

Some small sculpin species, such as the threaded sculpin, occur in great abundance and are relatively short lived; therefore, they may make up and important part of the biomass resource in its ecosystem due to its abundance and role as both prey and competitive predator (Hoff, 2000). The ecological importance of many such sculpin species is not understood (Hoff, 2000). Therefore, some species of sculpin would be better to target as a fishery, such as yellow Irish lord.

Ecology of Sculpin. Sculpin have been researched by Russian scientist since the 1960s, however, much of what is known about the life histories of sculpin has been discovered relatively recently as a result of information collected by the NMFS North Pacific Groundfish Observer program and several Japanese-American survey cruises. With the implementation of a more ecosystem based management program in the Bering Sea and Gulf of Alaska, scientists have recognized the need to understand more about the species previously thought of as waste. However, there remain many holes in the understanding of several sculpin species and their life histories and ecology.

Musick et al. suggests species with specialized habitat requirements, such as those breeding in rocky crevices, including sculpin, or those breeding in eel grass beds should be considered threatened due to degradation and destruction of their habitats (Musick, 1999; Musick et al., 2001). They also suggest that habitats of these species be closely monitored. Because fish show a correlation between age/size and fecundity, research suggests using fecundity at first maturation (Musick, 1999; Musick et al., 2001). According to Musick, despite the fact that large species generally show more resilience to fishing due to higher fecundity, a fish with high fecundity ($\geq 10^4$), but late maturation (5-10 years) and a long lifespan (≥30 years) is considered in the ‘very low productivity’ category (Musick, 1999; Musick et al., 2001). He also found that colder water resulted in slower growth, later maturity, and lower rates of population increase even if comparing different populations of the same species; and he found species with erratic and infrequent recruitment tended to have longer life spans (Musick, 1999). These factors, common to sculpin species, result in lower resilience to mortality outside of natural mortality. In addition, fishing has been shown to affect slow growing, late maturing species with sporadic recruitment disproportionately (Williams et al., 2010), such as rockfish and, potentially, sculpin.

There is little known about feeding habits of sculpin in the BSAI or GOA, especially in fall and winter months (Ormseth & TenBrink, 2010b). However, limited dietary analysis indicates larger sculpin members of the Eastern Bering Sea and Gulf of Alaska prey on similar things: shrimp, benthic invertebrates, and juvenile pollock (Hoff, 2000; Ormseth & TenBrink, 2010a). Large sculpins found in the Aleutian Islands prey on crabs, Atka mackerel, and other small to mid-sized shallow water fish: they have also been seen with full sized pollock partially digested and/or regurgitated upon capture (Vandever, 2005). Smaller sculpin species feed predominately on shrimp and benthic amphipods. In the Aleutian Islands, they also eat infauna, consisting of polychaetes and benthic crustaceans. (Ormseth & TenBrink, 2010a)

The threaded sculpin (*Gymnocanthus pistilliger*), along with many other sculpin species, have a diet that shifts from smaller invertebrates, to larger invertebrates, then to fishes as their body size increases showing an ability to capture and digest larger prey (Hoff, 2000). This ability prevents intraspecific competition and increases feeding efficiency (Hoff, 2000). It also means sculpin are important as a mid-level predator by not only controlling populations through predation in many trophic levels, but providing food in many different tropic levels.

Smaller sculpin species in the Gulf of Alaska provide important resources to larger predators (Hoff, 2000). The yellow Irish lord has been shown to feed on different decapods off of Kodiak Island, along the east coast of the Kamchatka (Tokranov, 1985). The main prey for yellow Irish lords are snow crab (*Chionoecetes opilio*), hermit crab (*Pagurus pubescens*), and fish eggs, mainly of other sculpin (Tokranov, 1985). However, like larger sculpin, they also have and extremely diverse diet, including more than 120 members of different taxonomic groups (Tokranov, 1985). Many small sculpins are fed upon by pinnipeds, Pacific cod, and small to mid-sized demersal fishes. The main source of mortality for smaller sculpins is from consumption by eelpouts, wintering seals, and Alaska skate (Ormseth & TenBrink, 2010a). However, Pacific cod and walleye pollock are also main predators of small sculpins (Hoff, 2000).

Sculpins share their ecosystem with many commercially important flatfish that use shallow waters throughout the Gulf of Alaska and Bering Sea shelf for spawning and nursery grounds causing sculpin diets to overlap diets of many flatfish species consisting of amphipods, polychaetes, and Echrurus (Hoff, 2000). Because both flatfishes and sculpin show diverse dietary patterns based on substrates, interspecies competition is frequently lessened despite competition between species (Hoff, 2000).

Large sculpins are preyed on by Pacific halibut; however, the main predators of large sculpins are Pacific cod. The main source of natural mortality for large sculpins remains unknown, but most

Figure 3: Image of a Great Sculpin (Myoxocephalus polyacanthocephalus) ("Great sculpin," n.d.)

total mortality is from fishing vessels (Panchenko, 2002). The proportion of sculpin over 20 cm long has been shown to decrease in stomach surveys of top sculpin predators due to increases in spines and armor around that size (Panchenko, 2002). However, as sculpins become larger, spine length decreases in relation to body size, causing their spines to be less daunting to predators.

Representatives of the Most Abundant Sculpin Caught in the Bering Sea and Gulf of Alaska.

Great Sculpin. Great sculpins (*Myoxocephalus polyacanthocephalus*) reach sexual maturity between 5 and 8 years of age and have a life span of between 13 and 15 years of age, a short period of sexual maturity compared to other groundfish (Ormseth & TenBrink, 2010a, 2010b; Tokranov, 1984, 1987a). In the Aleutian Islands they reach a maximum length of 76 cm, 82 cm in the Eastern Bering Sea, and 72 cm in the Gulf of Alaska (Ormseth & TenBrink, 2010a, 2010b), and they can weigh up to 8 kg (Tokranov, 1984). The maximum known age is 17 in the BSAI (Ormseth & TenBrink, 2010a). The great sculpin has a fecundity of 48,000 to 415,000 eggs in eastern Kamchatka waters (Ormseth & TenBrink, 2010a, 2010b; Tokranov, 1984, 1987b). Tokranov (1984) found that fecundity in great sculpin species depends on weight, followed by length, then age. The estimated biomass for 2010 of great sculpin in the BSAI is 50,820 metric tons (Ormseth & TenBrink, 2010a); and the great sculpin, along with warty sculpin, are the most abundant species found in the Eastern Bering Sea. Because the great sculpin is the most common species of Family *Cottidae* in Kamchatka waters, it has been studied more than any other species of sculpin.

Due to a large body size, longer life, and an older age at maturity the great sculpin would be considered vulnerable to extinction and would not be a good target for a commercial fishery. However, it could be a candidate for use when caught as bycatch due to its size.

Warty Sculpin. The warty sculpin (*M. verrucosus*) has a maximum length of 78 cm in the Eastern Bering Sea, but the maximum length is unknown for the Aleutian Islands area. It has a maximum age estimated at 18 years; but it is unknown at what age the warty sculpin reaches sexual maturity (Ormseth & TenBrink, 2010a). The fecundity of this species is estimated to be about 2700 eggs; and in 2010 it had an estimated biomass in the BSAI of 6,998 metric tons (Ormseth & TenBrink, 2010a).

Figure 4: Image of a Warty Sculpin (M. verrucosus). ("Quarterly research reports for Resource Ecology & Fisheries Management Division, Apr-June 2009 - page 2," n.d.)

From the known information, the warty sculpin would also not make a good target for a commercial fishery. It could potentially be used when caught as bycatch. However, due to the extreme lack of data on the warty sculpin, much more research should be conducted before a conclusion can be made.

Plain Sculpin. The plain sculpin (*M. joak*) can live up to 16 years and reaches sexual maturity at 5-8 years (Ormseth & TenBrink, 2010a; Panchenko, 2001, 2002; Tokranov, 1987a, 1988, 1995). They have an estimated fecundity of 25,400 and 147,000 eggs (Panchenko, 2001; Tokranov, 1987b). In the Eastern Bering Sea, the maximum length is 63 cm, and in the Gulf of

Figure 5: Image of a Plain Sculpin (M. joak) ("Quarterly research reports for Resource Ecology & Fisheries Management Division, Apr-June 2009 - page 2," n.d.)

Alaska it has a maximum length of 59 cm (Ormseth & TenBrink, 2010a, 2010b). It has an estimated biomass in the BSAI of 55,135 metric tons for 2010 (Ormseth & TenBrink, 2010a).

Due to size, longevity, and age of maturity, the plain sculpin would also be considered to have a higher vulnerability to extinction and should not be targeted for a commercial fishery. It is also extremely vulnerable due to its habitat preference. Panchenko (2001) discovered clutches were often deposited on mussels (*Mytilus trossulus*) covered in brown alga (*Dichloria viridis*), and were often guarded by a male of the species. The plain sculpin is one of the few sculpin that have been observed exhibiting guarding behaviors.

Bigmouth Sculpin. The bigmouth sculpin (*Hemitripterus bolini*) reaches a length of 83 cm in the Aleutian Islands, a length of 86 cm in the Gulf of Alaska, and a length of 78 cm in the Eastern Bering Sea (Ormseth & TenBrink, 2010a, 2010b). It has a maximum known age of 20 years, but there is little or no data on fecundity and age of maturity from the BSAI or GOA. However, the preliminary fecundity data from the Gulf of Alaska averages 2283 eggs per female (Ormseth & TenBrink, 2010b). The bigmouth sculpin had an estimated biomass of 36,461 metric tons for 2010 (Ormseth & TenBrink, 2010a, 2010b).

Figure 6: Image of a Bigmouth Sculpin (Hemitripterus bolini) caught on a pollock commercial fishing vessel

The bigmouth sculpin is one of the largest sculpin species. It also lives longer than many other species. Because of this and the lack of fecundity and age of maturity data, it has the potential to also be very vulnerable to extinction and should not be targeted as a commercial fishery. However, like all of the other vulnerable species discussed, the bigmouth sculpin could be a great candidate for marketing bycatch because of the large number caught and the size of fish caught.

Yellow Irish Lord. The yellow Irish lord (*Hemilepidontus jordani*) accounts for the highest proportion of sculpin biomass in the Aleutian Islands and Gulf of Alaska. It has a maximum length of 65 cm in the Aleutian Islands and 50 cm in the GOA. In the Eastern Bering Sea its maximum length is also about 50 cm (Ormseth & TenBrink, 2010a, 2010b). Its estimated total biomass in the BSAI is 36,785 metric tons (Ormseth & TenBrink, 2010a). The yellow Irish lord has an estimated maximum age of 28 years and reaches sexual maturity at about 3-5 years (Ormseth & TenBrink, 2010a, 2010b; Tokranov, 1985). The fecundity is estimated between 52,000 and 389,000 eggs in the Bering Sea/Aleutian Islands and between 25,000 and 241, 000 in the Gulf of Alaska (Ormseth & TenBrink, 2010a, 2010b). However, there is very little data on the age and growth maturity of GOA specific sculpin species; therefore, all fecundity and maturity data used by the NMFS for Gulf of Alaska management is taken from outside the GOA region (Hoff, 2000; Ormseth & TenBrink, 2010b).

Figure 7: Image of yellow Irish lord (Hemilepidontus jordani)

The yellow Irish lord could be targeted for a commercial fishery in the Aleutian Islands and Gulf of Alaska, in addition to many parts of the Bering Sea, because of its relatively low age of sexual maturity, small size, and relatively high fecundity. Its high biomass also indicates that populations are healthy, and they have a low vulnerability to extinction. In addition, Tokranov (1985) found that in winter months in Kamchatka, yellow Irish lords form dense groups making them easier to target for a trawl fishery.

Effects of Bycatch in the Fishing System. The North Pacific Ocean and Bering Sea are the most productive fishery regions in the world, and the "Americanization" of the area has led to dramatic shifts in the composition of American fishing fleets and species it targets: changing from traditional single species fisheries to multiple species groundfish fisheries. This frequently occurs because many ground fishes exist in the same areas, feed on the same prey and provide food to the same predators and fishing gear is not selective. Many fishes are thrown away because technical and market conditions dictate that only certain sized fish and species of fish can be kept and processed (Larson, House, & Terry, 1998).

Defining what fishes are targeted, are considered to be incidentally caught bycatch, and are discarded for trawl fisheries is important for fisheries management, especially with the modern trend to focus on management practices using an ecosystem based approach rather than single-species approaches common historically (Stergiou et al., 2003). The FAO estimates 25-30 million tons of fish are being discarded or wasted. This leads to a great deal of controversy because many feel this fish should be used for fish meals and fish oils while others believe we should actually process more of it for human consumption (International Seafood Byproduct Conference & Bechtel, 2003). Minimizing bycatch has become an increasingly important priority for the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) over the past several years. In 2003, the NMFS even launched its National Bycatch Strategy (NBS) (Benaka & Dobrzynski, 2004).

Most often bycatch is removed from the catch and returned to the ocean. Many fishes do not survive being caught, sorted, emptied onto the deck, or pumped out of a seine (Barrett, 1999; Hill & Wassenberg, 1990; Jacquet & Pauly, 2007; McGinn, 1998). Hill and Wassenberg

(1990) estimated nearly 90 percent of animals died within 12 hours of being trawled. Often their outer mucus coating or swim bladder is also damaged in the process (Barrett, 1999; Jacquet & Pauly, 2007; McGinn, 1998). These fishes can become sick and die upon being returned even if handled extremely gently. Bycatch are thrown back because they are the wrong size, sex, or species or because trip limits or quotas have been met. The estimate of landed catch often underestimates what is caught and the total amount of fishing related mortality.

To obtain better data, many fisheries have been forced to carry onboard observers trained to sample catch for size and age and to estimate bycatch and discards. By using length-age tables, scientists can also estimate the number of discards in each age class (Cooper, 2006; Rawson, 1997). To make estimates of discards throughout fleets, scientists assume unobserved vessels and observed vessels behave similarly. Fishers, however, do not always report accurate data as has been shown with the over reporting by China and other research projects. Therefore, we do not know how much fish is being killed while at sea without the knowledge of regulation makers. While the BSAI and GOA fisheries are heavily regulated; observed; and enforced, observers are not always present and there is little concern on the part of fishers; processors; and, even, observers and policy makers for many types of bycatch, including sculpin.

In addition to the loss of fishes to bycatch, the fate of bycatch returned to the ecosystem is cause for concern. When discarded, part of the waste sinks and part of it floats for a while before beginning to sink (Hill & Wassenberg, 1990). Sinking discarded material spends varying time in the water column.

Few studies have been done on the sinking/floating characteristics of fishery discards, though there are observations and some anecdotal information stating most discarded waste sinks. I, however, found in the Bering Sea and Gulf of Alaska a great deal of the discharge floats causing a trail leading out behind the vessel (Vandever, 2005), and Hill and Wassenberg (1987, 1990) found that nearly all discards in the prawn fishery in Moreton Bay, Australia, were eaten by birds and dolphins on the surface and crabs and fish on the bottom. Floating waste is generally made up of muscle, fat, and other tissue. Floating seafood processing discharge is first available for surface scavengers, such as savaging sea birds, often seen following processors.

The portion of birds in the Bering Sea feeding on discarded waste has not been estimated. Utilization of discharge by marine mammals is also poorly researched. Despite the lack of data on scavenging throughout the oceans, scavengers have been shown to use discarded fishes and invertebrates as some part of their diet. Some scavengers may use fishery discards as an exclusive food source. Increases in scavenging sea birds and other known scavengers have been shown in many heavily fished areas. For example, one gull species in the Mediterranean (*Larus audouinii*), has established colonies entirely dependent on fishery discards (International Seafood Byproduct Conference & Bechtel, 2003), and many fishers have stories of whales and dolphins that follow their vessels waiting for discharge and depredating from fishing catch. In the Bering Sea there is anecdotal evidence of Orcas following trawlers and research studies addressing Orca and sperm whales depredation (taking of catch) from longline gear and eating discards from longline vessels.

The size of dumped material determines what scavengers use it (Hill & Wassenberg, 1990). The United States Environmental Protection Agency (USEPA) regulations in Alaska mandate discharge to be ground to .5 inch, making it unsuitable for larger scavengers. It has been agreed that the dumping of large amounts of discarded bycatch has great ecological impact (Hill & Wassenberg, 1990). This fate of dumped seafood waste and discards is often determined by individual vessel practices, waste characteristics, environmental characteristics, and biological characteristics at the dumping site and/or fishing grounds. Oceanographic features, such as temperature and currents, have a huge impact on how fast waste products, including bycatch, are dispersed and degraded (International Seafood Byproduct Conference & Bechtel, 2003); and faunal composition in the area where fishing waste is dumped greatly determines who feeds on the waste, as does the time of day when discards are dumped (Hill & Wassenberg, 1990).

The waste not eaten in the upper levels of the water column ends up on the bottom for benthic scavengers, including some flatfishes and many sculpin species; however, the quantity is difficult to determine. Studies in both the North Sea and Australia show about 50% of discharged fishery waste sinks to the bottom and similar numbers are thought to exist throughout most of the world's oceans including the GOA and BSAI. (Bluhm & Bechtel, 2003) Evidence has shown fishery discards allow populations to become larger than they would otherwise (Link & Almeida, 2002). Benthic ecologists working in the Bering Sea list crabs, shrimps, amphipods, sea stars, flatfish, gadoids (cod), and sculpin as the leading scavengers benefiting from fishery waste, and while sampling, Link and Almeida (2002) observed scallop viscera (noncalcareous remains from shucked scallops) in stomachs of fish species in heavily fished areas, including the longhorn sculpin (*Myoxocephalus octodecemspinosus*) in Massachusetts (United States). By examining stomachs of longhorn sculpins, they evaluated the extent fishery discards provide food to fish populations. They found that while rock crabs (both *Cancer irroratus* and *C. borealis*) and small crustaceans make up a large part of sculpin diets at dredged stations of scallop fishing activity, the diet of longhorn sculpin was made up predominately of scallop viscera. They also found when scallop remains were present; sculpins consumed more food suggesting sculpins continue to feed on crabs and small crustaceans, while opportunistically gorging on remains of scallops. (Link & Almeida, 2002)

Actually, little is known about scavenging taking place in the middle of the water column because it is difficult to observe and quantify. However, it is thought to consist mainly of sharks. In the Gulf of Alaska, fishery waste was found to contribute 12% of total shark stomach contents, and Bering Sea discharge is thought to have a similar fate (International Seafood Byproduct Conference & Bechtel, 2003). Many have also cited evidence of increase in shark abundance in Alaskan waters since the 1990s as evidence of shark scavenging (International Seafood Byproduct Conference & Bechtel, 2003).

Chapter IV: Analysis of Findings

Primary and secondary literature sources discussing history of commercial fishing, issues with overfishing, and the need to use more of the food sources available and primary literature analyzing ecological, biological, and anthropological issues surrounding commercial fishing in the Bering Sea and policies throughout the world indicate that there are many problems with the policies used to regulate bycatch in the Bering Sea and Gulf of Alaska. Personal experience aboard commercial fishing vessels in the Bering Sea and Gulf of Alaska demonstrate a wasting of bycatch species, including sculpin that could be, and possibly are, used for human consumption. Further taste research over commonly caught sculpin species also indicates taste preference is not a driving factor for the market not utilizing bycatch species.

Numerous indications of overfishing in all of the world's oceans exist at a time when allocation of many resources has caused a great deal of starvation in the many countries. Difficulties feeding the world population will only increase as developing counties go through population transitions leading to increased growth in many of the poorest countries. A ready source of protein throughout the world is through fish and other seafoods. While many fish resources are currently used, and over-utilized in many cases, many species are thrown away as bycatch. Much of this bycatch has the potential to be used for human consumption. Sculpin, despite having a look that is intimidating to American consumers, produces a white, flaky fillet, comparable to rockfish, that is pleasing to residents of Washington State from different cultural backgrounds.

The largest issue with bycatch is the complexity of the issue. Many groups consider the discard of bycatch to be wasteful, but efforts to find productive uses for all bycatch have proven to be unsuccessful (Rawson, 1997). Bycatch caught by a vessel is no longer available in the ecosystem to be eaten by other predators or to eat other prey. However, many arguments have been made, usually by fishers and stakeholders, that if all of a certain species was mandated to be returned, it would still have a large impact on the environment and ecosystem because more of that species would be around to eat or be eaten by other members of the ecosystem. If a certain fish was required to always be returned even if dead, the carcass would provide more food for scavengers and also change the ecosystem. This is especially a problem with mid-trophic level eaters because their prey differs depending on age and size. For example, if the bycatch species returned is a major sculpin predator of small sculpins or juveniles, it could cause a decline in sculpin of one size and/or age; and once that sculpin population declined, the predator could die out due to starvation (Barrett, 1999).

Despite the acknowledged issues with bycatch, the BSAI mid-water pollock fishery is considered to be 'clean' compared to other groundfish fisheries because it has one of the lowest bycatch rates in the region. However, discard rates in the Bering Sea pollock fishery in recent years have been up to 50%, and overall discard rate was approximately 14% in 1995. (Larson et al., 1998) Though discard rate is not high, total discards are high due to the amount of fish caught in this fishery (Larson et al., 1998) causing the trawl fishery of the North Pacific to produce more bycatch than any other fishery in the world. In 1995, 9 million tons of the 27 million tons caught were discarded. Discards of crabs and their prey accounted for a loss of $50 million dollars in the crab fishery, and combined losses in the Bering Sea and Gulf of Alaska are estimated at $250 million annually (McGinn, 1998). Trawl vessels often fish with a net (codend) that can hold 120 metric tons of fish. If 1% of the fish in that codend is bycatch, then the vessel caught about 1.2 metric tons of bycatch. Generally, in 24 hours 4 to 8 full codends are brought aboard, giving between about 4.8 and 9.6 metric tons of bycatch a day for 1 vessel (Vandever, 2005). Often the net has much more bycatch than 1% and there are many vessels fishing similarly greatly increasing the amount of bycatch obtained in the pollock fishing industry.

While many species of bycatch are caught, sculpin represent a large amount of that bycatch. In 1992, total bycatch numbers for the BSAI was 585,152 metric tons, 1,227 of which was listed as "other fish," including sculpin (Larson et al., 1998). Sculpin has been estimated to be about 30% of that, or about 368.1 metric tons (Larson et al., 1998). In 2007, the estimate was also about 30%; however, it totaled 6500 metric tons by that time (Reuter et al., 2010).

Participant Observation. North Pacific Groundfish Observers frequently discuss bycatch in the field, and a common species discussed are sculpin. Sculpin caught are generally large and heavier than many other fishes caught, including targeted pollock (Vandever, 2005). Sculpin are 'ugly' and covered in bumps and spines (Vandever, 2005). If they are not dead, they bite and make grunting noises; and sculpin have teeth on the roof of their mouth and bottom lip that are small, but sharp, and will rip through the industry standard rubber fishing gloves quickly making them thought of as a nuisance by all involved (Vandever, 2005).

Generally, sculpin are not liked by observers or fishers. However, observers also discuss the large amount of fish waste that occurs when these species are thrown overboard (Vandever, 2005). Frequently, the most discussed waste of fish is because 'prohibited species' such as salmon and halibut are thrown back dead; but many feel that something should be done to minimize the amount of bycatch caught or at least use those fishes that are caught by marketing them (Vandever, 2005).

Bycatch as a new food supply. Historically, fishes that were originally thought of as bycatch have found their way to the dinner table as the market progressed. The Atlantic halibut (Hippoglossus hippoglossus) has been a marketed and prized fish of the North Atlantic since the middle ages. However, it was considered unpalatable in the early 1800s for many western countries, including the United States, which have a considerably different palate than the rest of the world (Jacquet & Pauly, 2007).

By the 1830s, tastes changed and a market for the Atlantic halibut developed, leading to a large commercial fishery, especially in New England and Nova Scotia. Western Atlantic halibut populations collapsed in less than 20 years and still have not recovered (Jacquet & Pauly, 2007). Despite the success of the Atlantic halibut, the Pacific halibut (*Hippoglossus stenolepis)* did not become popular until improved technology allowed it to be shipped from Seattle, Washington, to the East coast of the United States (Browning & Cole, 1980). The fishery started in 1888 in the Puget Sound around Port Townsend, Washington, near the mouth of the Strait of Juan de Fuca. As stocks were depleted, boats sailed further and further looking for the fish. By the turn of the century, about 20 years later, fishermen were forced to go to Alaska for halibut (Chasan, 1981). Most halibut was used as baitfish for cod in the 1920s (Shields, 2001).

Many fishes without markets have found small ones after bycatch was sold. The sablefish (*Anoplopoma fimbria*) found a market after being incidentally caught on long line gear and in pots. It is sometimes found in fresh markets and is mostly used by those of Scandinavian origin. It has oil rich flesh that does not become firm when fried, steamed, poached, or boiled causing it to usually be brined and dried then smoked and sold as ‘black cod’ or ‘finnan haddie,’ despite being neither. Sable fish is not a true cod (*Gadidae*) and a true ‘finnan haddie’ comes from haddock found in the North Atlantic (Browning & Cole, 1980).

The Pacific hake (*Merluccius productus*) was chosen because it belongs to a genus with species scattered throughout the world. Its close relative, the silver hake (*Merluccius bilinearis*), found in New England and Eastern Canada, had been marketed in the United States as whiting for many decades. In the late 1960s, Pacific hake was taken by Polish vessels, processed aboard and sold in Mexico, also marketed as whiting. Part of the appeal was the fact that it is unattractive, but could be caught in abundance and produce white fillets. The ling cod (*Ophiodon elongates*) is also marketed after being incidentally caught. It brings a high price because it is rated as one of the most palatable marine fishes, in addition to being very easy to cook. Neither of these fish are usually commercially fished due to the difficulty catching it with a trawler because they prefer intertidal zones among reefs, kelp beds, jetties, breakwaters, and rock patches (Browning & Cole, 1980).

The use of more fish food supplies in North America has been discussed by many authors throughout recent history. Clover (2008) suggests using Blue whiting. Despite its potential to be a popular commercial fish, most people have never heard of it. However, it is being marketed somewhere or something is eating it because there have been declines in the last decade. It is rumored to be sold in Russia and Baltic states (Clover, 2008). Charles Clover (2008) asks a critical question, ‘So what is stopping us from eating blue whiting, horse mackerel, sand eels, or even the Peruvian anchoveta?’ and poses his answer, ‘Nothing, except that the market is not yet used to providing them. So instead of asking for farmed salmon the next time you’re at the fish counter, try asking for blue whiting or horse mackerel and see what happens. You might just start something’ (Clover, 2008).

Building a market for human consumption of fishes can often mean it is fished more slowly than current rates in which it is being turned into fish meal, sometimes preventing the collapse of the fishery (Clover, 2008). However, encouraging consumption of ‘sustainably caught’ fish puts excessive pressure on presently healthy stocks of fish (Jacquet & Pauly, 2007).

To aid in bycatch becoming a food source, financial incentives can cause undesirable species to be renamed with more appealing titles. The Rock crab, once discarded as bycatch is now marketed as ‘peekytoe crab,’ the Patagonian toothfish (an endangered species) is often marketed as Chilean sea bass, and Slimeheads were renamed to orange roughy when the market developed. Imitation crab or ‘krab’ is generally made of low quality white fish, including pollock that has been aged too long, is too small, or was too damaged in the codend to make high quality fillets. Duel names and name changes are used to confuse consumers and complicate education efforts by seafood advocacy groups (Jacquet & Pauly, 2007).

France has used these tactics many times. Blue ling was popular in 1970, followed by orange roughy in 1991, and, now, a range of deep water fishes as these fishes became overfished. Unattractiveness of deep-sea fish has been overcome by filleting the fish causing them to look like any other white fillet. French marketing experts worked on the unfamiliar names to further help the market. They abandoned scientific names and instead used military sounding names to appeal to patriots: Black scabbard fish became ‘*sabre’*, orange roughy became’ *empreur’* (closely resembling the name for swordfish in Spanish, ‘*emperador’*), and the round-nosed grenadier was simply called *grenadier* (Clover, 2008).

Other suggested possibilities for human consumption include the pomfret (*Brama japonica*), which the NMFS in Seattle, Washington, researched as a food source and discovered that it is as tasty as the African pompano and could be quickly accepted as a food source, or the Pacific saury (*Cololabis saira*), highly favored throughout the world, but considered strange to Americans (Browning & Cole, 1980).

In some countries strong bycatch policies requiring vessels to keep all bycatch have caused a market. In many cases, this means the fishers and fishing companies use many methods to market their fish, including the traditional smoked, fried, or dried, but also including putting it in stews or in condiments like veggie soups (Akande, 1998). Many tropical fisheries, have also found crackers, spreads, cakes, and other 'snack foods' can be enriched with fish proteins to add protein and use difficult to market fishes. In some instances, such as in Nigeria, vessels have begun mixing fish with onions, spices, melon, salt, and vegetable oil on board during mincing processes to simplify the marketing process (Akande, 1998). This also allows for mixing of many fish species that do not bring a high market price (Akande, 1998).

In addition to marketing, non-profit organizations are often used to sway public perception. Many Nongovernment Organizations (NGOs) and aquariums have also launched campaigns to influence consumer behavior with wallet cards, cookbooks, and rulers to assure customers are not purchasing juvenile fishes (Jacquet & Pauly, 2007). While Eco-labeling is not effective in many Asian countries or developing countries (especially Latin America), an effective campaign could be used in the United States and Canada to encourage eating bycatch, such as sculpins. Many Americans would change behaviors when made aware of the need to use all fishes caught in commercial fisheries (Jacquet & Pauly, 2007).

Sculpin could be in the group with sablefish and ling cod because it is evolutionarily similar to these fishes. They are not caught in massive numbers at a time like pollock; but they could be caught occasionally and rather than throwing them out, they could bring in a good profit when caught. The same mild flavor that is appreciated in many popular white fishes is found in sculpin showing sculpin have the potential to be marketed in United States and Canadian markets.

A near shore live fishery for Cabezon (*Scorpaenichthys marmoratus*), among other species, including several species of rockfish (*Sebastes*) exists in California, where the demand for specialty foods in Asian restaurants and markets and consumers willing to pay higher prices for live fish over dead, created the need. A fishery first described as a niche soon became a multimillion dollar industry. Cabezon, the third ranked live fish fishery in California, accounted for $0.34 million; and as fishing for cabezon has increased, so has market price per pound (Heine, 2007). Because they are slow-growing and long-lived, they are protected in California's Nearshore Fishery Management Plan as a vulnerable species. The tighter regulations have resulted in commercial catches of Cabezon to level off in recent years (Heine, 2007). However, this small, but valuable commercial fishery for a species of sculpin indicates that larger sculpin fisheries may be on the horizon. There is also some indication that the great sculpin, found in the Bering Sea and throughout the United State Pacific coast may also be sold under the name scorpina (Green, 2007). However, although it is an edible fish and usually thought to be comparable to other white fish in flavor and texture, it is suggested that appearance and habits will prevent it from entering markets as long as other fish are plentiful. Historically, a market existed for the shorthorn sculpin but only because it was thought to be the best bait for lobster pots ("Shorthorn sculpin," n.d.).

Sculpin fished in California has mild-flavored, firm flesh and pairs well with almond, butter, fennel, garlic, lemon, olive oil, onion, orange, oregano, per nod, saffron, shallot, thyme, tomato, and white wine. The meat is off white and may be deemed too tough to eat by some (Green, 2007). Sculpin would probably be a good candidate to be cooked in a traditional 'Hong Kong Style' because it pairs well with strong flavors.

After World War II, a growing economy increased demand for fresh fish in Hong Kong, where they even developed a unique style of eating fish: having fish 'Hong Kong Style' means having it steamed with ginger and green onion (Freidberg, 2009).

> A modern version of 'Hong Kong Style' fish is found in The New Good Housekeeping Cookbook, called steamed seabass with ginger and green onions.
>
> '1 whole seabass (2 pounds)
> 1 tablespoon dry sherry
> ½ teaspoon salt
> ½ teaspoon ground black pepper
> 2 tablespoons soy sauce
> 1 tablespoon vegetable oil
> 1 teaspoon Asian sesame oil
> 1 teaspoon cornstarch
> 1 teaspoon sugar
> 3 green onions, cut into pieces
> 1 piece peeled fresh ginger, about 1 inch long and ½ inch in diameter, cut into slivers'
> (Good Housekeeping Magazine, 1999)

In addition, Jeff Smith, known as the 'frugal gourmet' has a recipe for Matalote from <u>The Virginia Housewife</u>, a Kenyan recipe for Baked Curried Fish, a steamed lingcod in black beans recipe, a French Bouillabaisse recipe, and a Plaki – Baked Fish recipe that would all work well with sculpin because they call for 'whitefish' (J. Smith & Jacobsen, 1999). Traditionally, the French fisherman's stew, *Bouillabaisse*, used whatever fish fishermen brought home from his days catch. The women at home already had a base of oil, garlic, tomatoes, and spices already prepared, allowing them to just add whole fish to the mixture.

Taste Test. On June 22, 2011, a panel made up of 7 members sampled yellow Irish lord (*Hemilepidontus jordani*), "rockfish", Pacific walleye pollock (*Theragra chalcogramma*), and darkfin sculpin (*Malacocottus zonurus*). The yellow Irish lord and darkfin sculpin were caught by a commercial fishing vessel trawling for pollock and flatfish in the BSAI, frozen, and shipped from Dutch Harbor, Alaska. They arrived in Tacoma, Washington, still frozen and were stored in a freezer until being removed to the refrigerator 24 hours before testing.

The pollock was purchased as frozen fillets from a popular grocery store, and the "rockfish" was purchased fresh from the same grocery store and immediately frozen after purchase to decrease differences between fishes tested. After thawing the sculpin representatives, I personally filleted them. This was done for personal commentary on boniness and difficulty filleting. The sculpins were weighed whole and fillets were weighed to represent a percent yield.

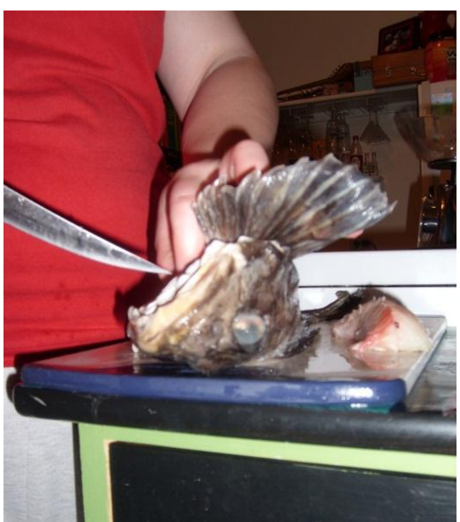


Figure 8: Image of yellow Irish lord being filleted for taste test.

The 2 darkfin sculpin were used to provide enough meat for the testing. Darkfin 1 weighed 200g whole and yielded a 10 g fillet and an 8 g fillet. Darkfin 2 weighed 225 g whole and yielded a 20 g fillet and a 10 g fillet. The darkfin was no more difficult to fillet and did not possess any more bones than I have discovered while filleting channel catfish (*Ictalurus punctatus*) or crappie (family *Centrarchidae*).

One yellow Irish lord was used to provide enough meat for the testing. The yellow Irish lord weighed 740 g whole and yielded an 80 g fillet and a 75 g fillet. The yellow Irish lord contained more bones than the darkfin sculpin, but it also was not difficult to fillet. If the sculpins are headed and gutted rather than filleted, as occurs on many vessels in the Bering Sea, called 'Head and Gut' or 'H&G' boats, they yield much more meat because both sculpin species used in this test had a piece of meat located behind the head before the dorsal fin and another piece of meat located at the pectoral girdle. All fishes were put in similar pans for cooking; seasoned with ¼ teaspoon of salt, pepper, and garlic powder; and baked at 350°F for 20 minutes simultaneously.

Methodology for taste-testing was performed using a Preference Taste Test. (Succop, 1998) One ounce pieces of each filleted fish were placed on white serving papers (cupcake cups) labeled with a random three digit number chosen by rolling a die three times consecutively and labeled by a colleague without my knowledge to avoid bias possibly introduced by my knowledge of fishes being tested. Small pieces of filleted fish were used because Western consumers often find the texture of fish paste offensive, possibly introducing bias due to a dislike of the unfamiliar texture and, possibly, also introducing a different result than found in filleted fish. It was also determined that samples tested should be presented in the same form encountered in markets, which for American consumers is usually a fillet. The cups were brought to the panel on a tray.

Evaluations were based on the odor, textures, and/or taste of the samples. A panel of testers made up of peers (academic, professional, and social) was chosen based on familiarity with consumption of fishes of different species. A ranking test is an effective method of screening for inferior samples in product development and was chosen to determine if sculpin meat is indeed an inferior product. It was also used to determine if a difference exists between sculpin meat, pollock meat, and “rockfish” meat. Seven panel members were given 4 samples and asked to rank odor, texture, and taste of each sample on a scale of one to five. (One being very pleasing and five being not pleasing at all). Following each ranking the panel was given opportunity to explain their ranking and describe odors, textures, and tastes. The panel was also asked which fish was the most appealing; whether the fishes were interchangeable with each other; and/or if the fishes were interchangeable with fishes they usually buy in order to determine a comparison level. (Succop, 1998)

Following the taste test, panel members were presented with frozen whole fishes similar to ones that would be found at a grocery for visual assessment. The panel was asked if they generally purchase fishes whole, which fish they would be more likely to choose in a whole fish market, and generalized opinions of the fishes based on visualizations. This was to determine if sculpin are not chosen for consumption because of their physical appearance.

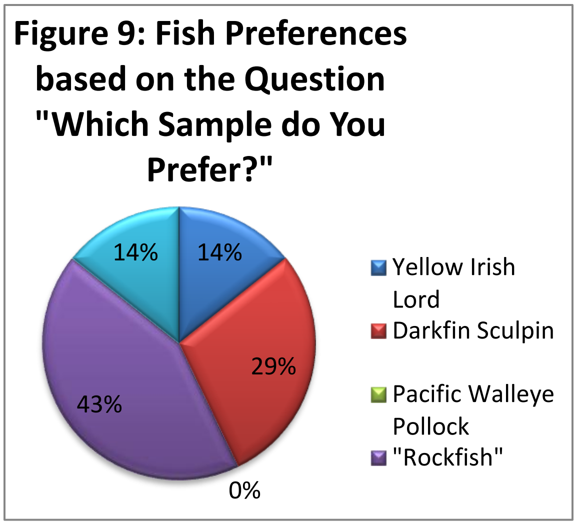
Pacific walleye pollock ranked lowest in odor with two samplers giving it a ‘3’ and only one tester giving it the highest ranking, and the yellow Irish lord ranked highest with three giving it the highest ranking. None of the fishes tested were given a ‘4’ or ‘5,’ being the lowest two rankings.

Pacific walleye pollock also ranked lowest in texture with two ‘4’ rankings and two ‘3’ ranking. It also had one ranking each or ‘1’ and ‘2.’ One tester said the poor texture of the pollock overpowered the taste, possibly biasing their ranking for taste (he/she gave the pollock a ‘4’ in both texture and taste)’ while another tester said it was the ‘wettest’ or ‘moistest’ of the four samples. “Rockfish” ranked highest in texture with 5 of the 6 testers giving it a ranking of ‘1’: the highest ranking. None of the fishes tested were given the lowest ranking of a ‘5.’ The two sculpin (yellow Irish lord and darkfin sculpin) ranked similarly in textures with the darkfin receiving one more ‘1’ vote than yellow Irish lord.

Pacific walleye pollock ranked lowest in taste as well with two votes each in the ‘2,’ ‘3,’ and ‘4’ categories. The yellow Irish lord ranked highest in taste testing with three votes each in the ‘1’ and ‘2’ categories. In the taste testing, again, the “rockfish” and darkfin sculpin ranked very close with the “rockfish” receiving one more ‘2’ vote than the darkfin sculpin. Many of the tasters commented that none of the fishes sampled were overly fishy, a trait that many American consumers look for in their fishes.

When asked ‘Which sample do you prefer?’ three votes were cast for “rockfish,” two for the darkfin sculpin, and one for the yellow Irish lord. One tester did not rank one fish over any other with an answer of ‘They were all about the same.’ That same tester stated that he/she would substitute any of tested fish, including the 2 sculpin species, for white fish usually bought and frequently described the two sculpin species as being like any other white fish. There was one more tester who answered this question than the other questions because a 10-year-old son of one of the testers tasted all of the fish but only wanted to tell his favorite: the “rockfish.” However, he liked all but the pollock; and is, generally, considered to be a very picky eater.

When presented a whole sculpin (darkfin and longfin, a species not taste tested due to quantity) and asked if they would buy the fish in front of them, most responded no. However, most testers said they would not/do not buy whole fish generally. One tester stated ‘[the sculpins] looked gross. Tadpole like;' and another called the sculpin 'creepy' and suggested if the head were removed he/she would buy it.



Testers generally agreed yellow Irish lord and darkfin sculpin were very similar and that they were comparable to 'rockfish' and could be substituted for each other. One taster suggested that if they were breaded they could easily be substituted, but if they were steamed or sautéed the different textures would be a noticeable difference. Most agreed that pollock was inferior to the other three fishes tested, probably predominately due to the texture. Tasters suggested the fishes sampled were similar enough to or better than pollock, cod, or sole.

Chapter V: Conclusion

According to the data presented in this research, fishers should not target sculpin species because so little is known about their life histories, and they could be overfished before all life histories were understood. However, keeping more fish by creating a market for bycatch would lessen the impact made to the environment through return of bycatch and catch of fish that serve as both predator and prey in the ecosystem. Through this assessment, it was found that North America could, in fact, use some sculpin from the Bering Sea and/or Gulf of Alaska as a food source for humans based on their life histories, taste, numbers, and historical information.

In the process of this research project, the extant of overfishing in the world's oceans became very clear. Most research shows similar conclusions. All commercially fished species are on the decline, and I fear that if sculpin were marketed to humans and a fishery developed, this species soon would be overfished as well. By eliminating single-fish fisheries in the Bering Sea and Gulf of Alaska, and creating all multi-fish fisheries, similar to those found in the Mediterranean, fisheries would be more productive from an anthropogenic view. All fish would be kept and a market would exist for all fish caught.

Taxing fishes in the North Pacific, as is the case in many other countries, would be an effective way of forcing fishers in the Bering Sea to keep bycatch. Generally, there is a willingness to pay for all species caught in the pollock fishery, because they are necessary to the production of pollock, with or without a market (Larson et al., 1998). However, if a market existed managers and fishers could assess the value of trade-offs when setting quotas on non-target fishes (Larson et al., 1998).

To address the issue of needing more fish diversity in the American diet, many agencies, especially non-profit organizations have launched campaigns and marketing schemes to increase the potential of using unknown species. Along with the generalized marketing of seafood, the phenomenon of social marketing bears some mention because is it a frequently used system, especially in the United States. Social marketing is defined as the application of marketing to the resolution of social problems, such as overfishing and bycatch..

In Florida, Key Largo-based Reef Environmental Education Foundation (REEF) has come up with the plan of eating the red lion fish, a non-native fish in Florida, to counter its invasion. Lad Atkins, the director of REEF, has done so by authoring a cook book with a professional chef, Tricia Ferguson. In addition, REEF has sponsored fishing derbies on the red lionfish, making humans the only predator due to venomous spines. Adkins says he hopes that creating a cookbook will help create a commercial fishery for the lion fish ("Eat'em stratagem for lionfish invasion in Florida | Reuters," 2010). With the right marketing, such as a cookbook, the public may also be swayed to consume fishes they would not otherwise think to purchase or ask their local fish merchant to purchase.

Fish, such as cod; pollock, and hake are fished because they are easy to catch in large numbers with a trawl or longline. The U.S. fisheries in Alaskan waters have further created the market North Americans know now by instituting policies prohibiting the catch of some bycatch leading to fishers not catching and/or marketing almost all bycatch.

If a market and fishery were created for bycatch the demand could cause more catch of the bycatch and potentially cause these fishes to be overfished as well. However, if U.S. policy were implemented to insure fishers keep the bycatch they would normally throw away to market, fishers would be forced to keep the fishes causing a small market to soon develop.

American policy is in place to prevent the fishing of certain fishes, termed in the business as ‘prohibs’ because these species are regulated by another organization or they are profitable to those who have a quota for these fishes. This policy prevents the use of prohibited species from being kept and utilized by fishers without a quota for the species. As a result, many other species have been deemed bycatch as well. Bycatch species, for various reasons do not have a market, and are thus thrown away rather than being taken to market as fisher try to use the limited space aboard the vessel for only the fishes they have a quota for and can get a good price for from the market.

Perhaps a bigger issue found in the system worldwide is a question of what we are eating. Sharks, are considered undesirable in Ecuadorian city markets; and are instead filleted and labeled as weakfishes or tuna. Some estimate that ¾ of fish sold as ‘Red snapper’ in the U.S. belong to species other than *Lutjanus campechanus* (the actual red snapper in the United States). The National Environmental Trust also published a report revealing that a substantial amount of illegal Patagonian toothfish enters the U.S. market mixed with other seafood or as ‘frozen fish fillets’ (Jacquet & Pauly, 2007) The fish labeled ‘rockfish’ in the taste test in this research could have been any member of the rockfish family, or a fish that looks similar to a rockfish. It could even be sculpin. Many fish are mislabeled or just labeled ‘whitefish’ so most North American fish consumers have no idea what fish they are actually eating. In an effort to market bycatch, this could play in favor of creating policies and markets toward keeping all bycatch for human consumption. However, as a consumer, we should be asking ourselves if the fish we are purchasing is actually what the package says and if that fish has been caught from healthy stocks in a way that will ensure sustainable fishing.

While creating a market and fishery for all fishes could potentially lead to widespread overfishing in a larger capacity than we currently see, creating a smaller niche market for bycatch could help eliminate waste and add extra fish protein to a growing population and demand. By changing American policies to force fishers to keep bycatch and instead pay a tax on those that they do not have quotas for, the fishers would continue to avoid 'prohibited species' with valuable markets being fished by other vessels; but the market would allow for fishers to bring all catch in and make a profit from everything caught.

To ensure bycatch does not become the targeted fish leading current targeted species to become bycatch and creating an identical problem for a different fish, policy could mandate all fishes be caught and a tax could be enforced on fishes that the fisher does not have a quota for. This is a common method in many multifish fisheries throughout the world, such as Nigeria, the South China Sea, and the Mediterranean. This tax needs to be high enough that it would not be negligible to the fishers and fishing companies, causing them to potentially target the 'bycatch' they do not have a quota for despite being taxed. It also needs to be low enough to ensure that fishers are not financially harmed by the tax if they do accidentally catch 'too much' of the 'bycatch.' The tax also needs to be low enough to not inspire a greater increase in illegal discharge of 'bycatch' species despite the mandate to keep all fishes.

By keeping all fishes caught, there will be more sources of fish protein from the Bering Sea, Alaska, meaning greater exports from the U.S.; potentially, more food sources; and less fish waste being removed from then returned to the ecosystem.

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