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EVALUATING MANAGEMENT SCENARIOS TO REVITALIZE THE CALIFORNIA COMMERCIAL SWORDFISH FISHERY

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by

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

ADVISOR

DATE

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ABSTRACT

Fisheries management is often complicated by the challenge of providing a sufficient supply of seafood while simultaneously protecting sensitive species that may be caught as bycatch. In the California commercial swordfish fishery, participation has declined in recent decades, resulting in decreased domestic swordfish catch and an increased reliance on imported swordfish from countries with relatively higher bycatch rates. Increasing imports is expected to result in a transfer of effort to these countries, thereby causing higher bycatch on a global scale. To simulate an increase in domestic swordfish catch while limiting bycatch, we created a model to analyze a range of management scenarios composed of drift gillnet, longline, and harpoon based on their associated catch, profit, and bycatch interactions. We conducted tradeoff analyses of catch and profit versus bycatch to evaluate viable management scenarios to revitalize the fishery. Our analysis revealed that utilizing a gear portfolio of the three gear types could increase catch and profit compared to the status quo without exceeding proposed bycatch constraints. Fisheries managers can use this model as a decision-making tool to consider management options to enhance productivity and conservation in the fishery and decrease reliance on imports with the goal of protecting sensitive species globally.

EXECUTIVE SUMMARY

Fisheries are critical to the development of coastal communities and are the sole source of income for many people around the world that rely on fishing for their livelihood. As a result, one of the most important aspects of fisheries is the renewable characteristic of the resources, allowing future generations to be supported by seafood as a source of income and protein as long as fisheries are managed effectively (FAO 2003). Fishing also results in considerable ecological impacts, including the incidental catch of non-target species known as bycatch[1]. Sensitive species, those threatened or endangered with extinction, are sometimes caught incidentally as bycatch. When bycatch is regulated under law, as in U.S. fisheries, fisheries managers are either required to restrict fishing to reduce bycatch, or must in some other way evaluate tradeoffs between profit and environmental impacts or externalities.

Our project used the California swordfish fishery as a case study to investigate the tradeoffs associated with restricting bycatch of sensitive species and enhancing fishing effort and profit. Recent assessments indicate that the swordfish stock along the U.S. West Coast is healthy and the annual catch rates of 10,000 metric tons in 2011-2012 of the Western and Central North Pacific stock are well below the estimated exploitable biomass of ~70,000 metric tons (Hinton and Maunder 2011; ISC 2014). High demand for swordfish has historically required the U.S. to import swordfish, however the percentage of imported swordfish compared to all swordfish consumed has been steadily increasing since 1996 (NOAA 2014b). Rising imports in the U.S. are partially the result of declining domestic swordfish supply (PFMC 2011b) and may have unintended consequences for marine ecosystems through the bycatch of sensitive species by foreign fleets (Bartram et al. 2010; Rausser et al. 2009). Many countries from which the United States imports swordfish have less stringent marine conservation regulations than U.S. fisheries, resulting in relatively high bycatch rates. The U.S. West Coast has an underexploited domestic swordfish stock, yet stringent regulations under the Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA) act to minimize bycatch of sensitive species, especially sea turtles, whales, and other marine mammals. The Pacific Fisheries Management Council (PFMC) and National Marine Fisheries Service (NMFS) are thus faced with a challenge of managing for a more productive and profitable domestic swordfish fishery while limiting bycatch, as required under law.

The goal of our project was to evaluate different management scenarios for increasing swordfish production while considering current and proposed marine conservation regulations in the California commercial swordfish fishery. The management scenarios explored different combinations of three gear types – drift gillnet, harpoon, and longline – at various fishing effort allocations, and in two areas – inside and outside the Exclusive Economic Zone (EEZ) off of California. Because longline was banned in California in 2004 due to concerns over sea turtle bycatch, the longline data used in this analysis are from the Hawaii longline fleet for swordfish landed specifically to California ports. The PFMC has proposed the implementation of bycatch hard caps for loggerhead and

[1] The Magnuson-Stevens Fishery Conservation and Management Act defines bycatch 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." In our analysis, "bycatch" refers to fishing gear's incidental interactions with non-market species, specifically loggerhead sea turtle, leatherback sea turtle, humpback whale and sperm whale.

leatherback sea turtles, and humpback and sperm whales. Therefore, our project constrained the management scenarios by using different hard cap levels to evaluate how fleetwide profit and swordfish catch varied with different bycatch restrictions. The results of our model allowed us to analyze the most effective management scenarios that would increase fleetwide profit and domestic swordfish production in California. Our project assumed the potential for a market transfer effect wherein an increase in local swordfish supply may lead to a resultant decline in the reliance on imported swordfish to meet consumer demand.

To determine how different combinations of effort and gear types increase swordfish catch and profit, we explored the following research questions:

1. *Is there intra-annual variation in swordfish catch and/or bycatch interactions among gear types?*

Result: The highest drift gillnet swordfish catch occurred during the months of September to January; the highest harpoon swordfish catch occurred during the summer months of July, August, and September; and the highest longline swordfish catch occurred over a longer monthly range compared to the other two gear types during the months of October through March. The temporal differences in catch means the utilization of different gear types in the fishery could provide a more consistent supply of swordfish year-round.

Observed bycatch interactions in the drift gillnet fishery varied intra-annually only minimally from August through December during the time period from 2001 to 2013. Bycatch interactions for longline varied significantly from October through April, during the time period from 2006 to 2013. Harpoon was assumed to have no bycatch interactions.

2. *Does profit vary temporally and spatially by gear type?*

Result: As catch varied among gear types, so did profit. Generally, the most profitable fishing months corresponded to the months with the highest swordfish catch because profit was a function of total catch. Differences in profit were due to the difference in price per pound for each gear type, swordfish catch efficiency by gear type, and revenue from other market fish species caught by each gear type.

Differences in profit due to spatial heterogeneity of catch from drift gillnet and harpoon were not evaluated because the fisheries operated only within the EEZ. However, profit varied spatially for longline because the longline fishery inside of the EEZ had a higher profit than the longline fishery outside of the EEZ. This difference in profit was attributed to longline inside of the EEZ having lower fuel costs compared to longline fishing outside of the EEZ.

3. *How do different bycatch hard caps impact swordfish catch and fleetwide profit?*

Result: The occurrence of bycatch interactions is a rare event within the California fishery (Stohs 2014). However, among the bycatch interactions[2] with drift gillnet and longline gear types, leatherback sea turtles have a relatively higher bycatch rate than loggerhead sea turtles and sperm and humpback whales. As a result of the relatively higher bycatch rate of the leatherback sea turtle in our model scenarios compared to the other bycatch species included in the analysis, the PFMC preferred proposed leatherback sea turtle hard cap of 3 individuals was reached before any of the other species' preferred proposed bycatch hard caps; thus, the number of leatherback sea turtle interactions determined when the fishery shut down and consequently when the maximum fleetwide profit was attained. In our model, the main driver of the bycatch problem within a fishery consisting of drift gillnet, longline, and harpoon was sea turtle interactions, rather than whale interactions. The analysis evaluated how fleetwide profit and swordfish catch changed by increasing and decreasing the leatherback hard cap by one individual.

By increasing the leatherback turtle bycatch constraint from 2 to 3 individuals, the swordfish catch increased by 64 metric tons; and by increasing the constraint from 3 to 4 individuals, the swordfish catch increased by 35 metric tons. The fleetwide profit increased by $260,000 and $190,000 when increasing the leatherback bycatch constraint from 2 to 3 and then from 3 to 4, respectively.

4. *Which management scenarios increase total swordfish catch and fleetwide profit under a bycatch hard cap?*

Result: We compared five of the most interesting management scenarios generated from our model with the status quo scenario, under the Council-preferred proposed bycatch hard cap levels. The five management scenarios were: A) maximum fleetwide profit and swordfish catch, B) reincorporation of shallow-set longline with constant status quo harpoon and drift gillnet effort, C) harpoon effort increased to meet historical harpoon catch levels and fill a niche-market, and D) removal of drift gillnet permits with longline reincorporated and harpoon effort constant, and E) drift gillnet latent, or inactive, permits filled. The following are results from our model:

A) Compared with the status quo, the management scenario with the highest profit and swordfish catch under the bycatch hard caps included both the reincorporation of longline through the addition of 3 longline vessels, and an increase in the drift gillnet fleet by 41 vessels. This high profit and swordfish catch scenario increased the profit by $1.16 million and the catch by 281 metric tons.
B) Under the bycatch hard caps, reincorporating longline as an allowable gear type with constant drift gillnet and harpoon effort increased the fleetwide profit by $740,000 and the swordfish catch by 188 metric tons.
C) To saturate the harpoon-caught swordfish niche market, based on the historical maximum catch since 1981 of 204 mt, an additional 71 harpoon vessels were added to the fleet. This increased the profit by $950,000, yet decreased the

[2] Due to data limitations, bycatch interactions are not based on mortality or serious injury within our analysis.

swordfish catch by 18 metric tons compared to the status quo. However, our model scenario is unrealistic because current harpoon effort, which is constrained by weather conditions and swordfish behavior, not regulation, represents revealed preferences; therefore, expansion of the harpoon fishery is unlikely.

D) Because the PFMC requested NMFS and CDFW to evaluate methods for reducing drift gillnet capacity, we included a management scenario that modeled the transfer of effort from the active drift gillnet permits to the longline gear type. Compared to the status quo, the number of longline vessels increased by 7, the fleetwide profit increased by $20,000, and the swordfish catch increased by 22 metric tons.

E) The filling of drift gillnet latent permits increased profit by $850,000 and increased the swordfish catch by 203 metric tons under the bycatch hard caps.

The results of our model indicated that there were various management options for a California commercial swordfish fishery composed of drift gillnet, longline, and harpoon that would increase both swordfish catch and fleetwide profit without exceeding the Council-preferred proposed bycatch hard caps for sensitive species. Based on our results, we suggest the PFMC and NMFS consider the following recommendations:

- Implement a gear portfolio composed of a mixed-gear fleet of drift gillnet, longline, and harpoon as this results in the highest profit and catch outcomes and will provide a steady supply of domestically-caught, California swordfish throughout most of the year. Furthermore, consider that harpoon is not a viable gear type to increase catch on a commercial scale.
- Approve EFPs for longline as a first step to assessing viability and bycatch performance of this gear off the West Coast.
- Use our model as a decision-making tool that may be adapted for other gear types – such as deep-set buoy gear and deep-set longline – and different effort levels while considering bycatch interactions.
- Transition the fishery to 100% observer coverage through a combination of observers and electronic monitoring based on capacity of vessels and given innovations that allow electronic monitoring to be feasible on vessels.
- If bycatch hard caps are implemented, the PFMC should implement bycatch hard caps that are based on scientific justification as proposed by NMFS.
- Consider a certain level of uncertainty in management decisions regarding proposed bycatch hard caps in order to adjust the level of effort for all gear types in the fleet to provide a buffer for uncertainty and reduce the risk of reaching an undesirable number of bycatch interactions.
- Attention should be paid to fishery participation and domestic swordfish catch when considering the implementation of bycatch hard caps as an additional regulation.
- Place special emphasis on creating opportunities for local success in order to decrease reliance on imports. Through our analysis, we conducted a thought experiment that illustrated that if all imported swordfish were replaced with domestic, California swordfish, there is the potential to reduce global sea turtle interactions by about 9,000 individuals.

Additionally, we explored other management and policy options that may be feasible for increasing swordfish catch and fleetwide profit without surpassing the bycatch hard cap thresholds. Future management options that we explored include: incorporating buoy gear and deep-set longline targeting swordfish, using electronic monitoring to increase observer coverage within the swordfish fishery, implementing bycatch individual transferrable quotas, and opening the Pacific Leatherback Conservation Area earlier in the fishing season. A future policy option that NMFS may consider implementing is the banning of swordfish imports from countries that do not mandate the same bycatch mitigation regulation measures held in the U.S. Effective management of the California swordfish fishery will benefit the coastal economy through supporting the livelihoods of the California swordfish fishermen, as well as benefit marine conservation through protecting sensitive species on a global scale.

INTRODUCTION

Fisheries: A Balance of Benefits and Environmental Impacts

Fisheries are critical to the development of coastal communities and are the sole source of income for many people around the world that rely on fishing for their livelihood. The benefits of fisheries include not only substantial contributions to global economies, but also the provision of a significant source of protein fundamental for feeding people around the world (FAO 2003). Over 1 billion people, mostly within developing countries and coastal areas, rely on seafood as their primary source of protein. In 2010, 2.9 billion people relied on seafood for 20% of their protein needs (MSC 2014). As global populations grow, food security will become an increasingly significant issue that will need to be met with a subsequent increase in seafood production. As a result, one of the most important aspects of fisheries is the renewable characteristic of the resources, allowing future generations to be supported by seafood as a source of income and protein as long as fisheries are managed effectively (FAO 2003).

Fishing also causes considerable direct and indirect ecological impacts. One direct impact of fishing is the potential to reduce stocks beyond the level at which they can regenerate to support future fish populations. Worldwide more than 25% of assessed stocks are overfished, depleted, or in recovery, and another 60% are fully or heavily exploited (FAO 2014b). An even larger proportion of quantitatively unassessed stocks appear overfished (Costello et al. 2012). Many indirect ecological impacts exist as well, with the incidental catch, or “bycatch[3]”, of non-target species or undersized individuals being one of the most substantial problems. This bycatch may include species that are abundant and do not have population concerns; however some fisheries may interact with species that are highly endangered and are at risk of extinction, such as sea turtles and whales.

Effective management of fisheries must consider the biological and ecological characteristics of the target species. For example, many high value fishes have extensive migration patterns throughout the world’s oceans. These highly migratory species cross domestic and international boundaries, making the stocks especially

[3] The Magnuson-Stevens Fishery Conservation and Management Act defines bycatch 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.”

difficult to manage effectively due to differences in fishing practices, abundance and distribution patterns, and regulatory standards between nations.

As a result of these ecological concerns and the complexity of international seafood resources, fisheries managers must evaluate significant tradeoffs between profit and environmental externalities. To ensure that future generations can be supported by the benefits of seafood production worldwide, fisheries should to be managed in a way that is sustainable, and that effectively balances biological impacts, national and international policies, socioeconomic considerations, and uncertainty.

The California Swordfish Fishery: A Case Study of Fisheries Tradeoffs

Our project used the California swordfish fishery as a case study to investigate the tradeoffs inherent to fisheries management due to concerns of declining profit and the environmental externalities associated with bycatch. Once economically valuable for the state and profitable for fishermen along the West Coast, the California swordfish fishery has since experienced significant declines in participation and profit. While the global production of swordfish has been increasing over time, the California drift gillnet swordfish catch has decreased 96% since 1985, from 3,000 metric tons (mt) to 120 mt in 2013, with an associated value decline from $11.9 million to 717,000 U.S. dollars (NMFS 2014b). As a result, the California swordfish fishery supplies only 4% of all swordfish consumed in the United States (NMFS 2014b). This decline is mostly due to an increase in regulations aimed at reducing bycatch, and the subsequent decline in fishing participation. Bycatch regulations were established to reduce the incidental catch of sea turtles, whales, juvenile sharks, and pinnipeds that has historically occurred within the fishery.

Consuming approximately 25% of global swordfish landings, the United States has a stable and high demand for swordfish (Asche et al. 2005). Coupled with the decline in California swordfish catch, this results in a growing reliance on imported swordfish to meet demand, which may have unintended consequences for marine ecosystems and sensitive species globally (Bartram et al. 2010; Rausser et al. 2009). When compared to the relative amount of bycatch to swordfish caught by domestic fisheries, swordfish imported to the U.S. are from countries that have a higher rate of bycatch (Chan and Pan 2012). Therefore, by meeting consumer demand with imported swordfish instead of California-caught swordfish, many have hypothesized that there is an induced overall increase in the amount of bycatch caught on a global scale (Mukherjee 2015). This theory is based on evidence that declining swordfish catch by the U.S. is inducing greater effort in foreign fleets to meet the demand, corresponding to greater bycatch on a global scale. In economic terms, this is referred to as the market transfer effect (Rausser et al 2009).

Project Objectives and Research Questions

Given the assumption that the primary countries from which the United States imports swordfish have less stringent marine conservation regulations than U.S. fisheries – and therefore higher bycatch rates – and that the West Coast has an underexploited domestic swordfish stock, the California swordfish fishery should be managed to increase the sustainable domestic swordfish supply – or catch – while limiting bycatch. How bycatch is limited depends on the gear type used, and when and where fishing occurs. The goal of our project was to evaluate different management strategies for enhancing local California productivity while adhering to Federal laws governing marine conservation such as the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). Our project explored various tradeoffs between different fishing scenarios and presents future management options that could improve economic performance and increase the catch under conservation constraints that benefit the marine ecosystem, fishers, coastal communities, and consumers.

Our project investigated various aspects of the fishery, such as the cost and efficiency for catching swordfish and other market species for the different gear types, associated bycatch rates of different gear types and if these factors vary temporally. We developed a model to evaluate a range of management scenarios composed of different gear types and fishing effort. The results of the model allowed us to analyze the most effective management strategies to increase fleetwide profit and domestic swordfish production in California. Our model assumed that an increase in local swordfish supply potentially leads to a reduced reliance on imported swordfish to meet consumer demand.

The three main objectives of our project were:

1. Develop a concise regulatory history of the fishery through the year of 2014, to include a timeline complete with management changes and environmental regulation changes, as well as a comparison of the California swordfish fishery to other domestic swordfish fisheries.
2. Create a model to evaluate management scenarios that will serve as a decision-support tool for the Pacific Fishery Management Council (PFMC) regarding policy and management options within the California swordfish fishery.
3. Explore and qualitatively address future management strategies to improve the economic and conservation performance of the California swordfish fishery such as incorporating buoy-gear, utilizing electronic monitoring, implementing bycatch individual transferable quotas (ITQs), using Exempted Fishing Permits (EFPs) for longline, and opening the Pacific Leatherback Conservation Area (PLCA) earlier in the fishing season.

To satisfy the second objective, we addressed four research questions:

1. Is there intra-annual variation in swordfish catch and/or bycatch interactions among gear types?
2. Does profit vary temporally and spatially by gear type?
3. How do bycatch hard caps impact swordfish catch and fleetwide profit?
4. Which management scenarios increase total swordfish catch and fleetwide profit under a bycatch hard cap?

BACKGROUND

Biology of Swordfish

Some characteristics of swordfish biology, such as its size and fecundity, make it an ideal target species for fisheries. However, its broad geographic range and daily water column distribution can make swordfish a very difficult species to locate and to manage.

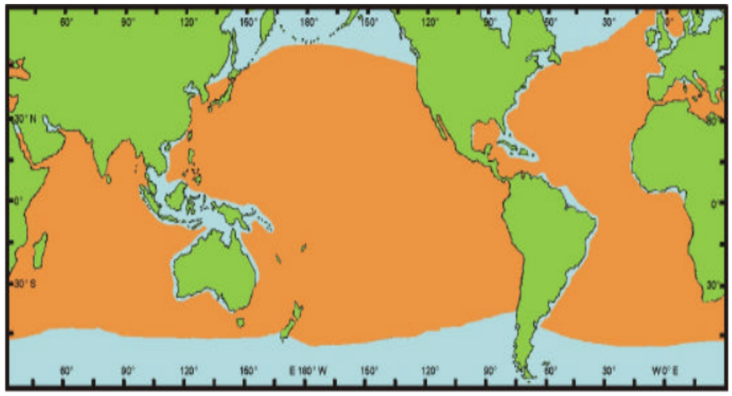

Figure 1. Global distribution of Swordfish. Source: van der Elst and Govender 2003, Nakamura 1985 --- Nakamura, I. 1985. Billfishes of the world. FAO Fish. Synop. 125, Vol. 5. 65 p.

Swordfish are found throughout the world's tropical and temperate oceans (Figure 1), with latitudinal ranges extending from 50°N to 45°S in the western Pacific, from 50°N to 35°S in the eastern Pacific, from 25°N to 45°S in the Indian Ocean, from 50°N to 40°-45°S in the western Atlantic and from 60°N to 45°-50°S in the eastern Atlantic (van der Elst and Govender 2003). With a maximum length of 14 feet and weighing up to 1,200 pounds, the swordfish is one of the fastest predatory fishes, swimming at speeds up to 50 mph (NOAA 2014b). Although swordfish are known to travel long distances, little is known about their extensive migration patterns. The movement of swordfish between the Exclusive Economic Zones (EEZ) of different countries and into the high seas makes this species a difficult fish to manage effectively (van der Elst and Govender 2003; Ward and Elscot 2000).

Swordfish fishing is affected by the daily and annual movement patterns of the fish. Swordfish tend to be found around sharp gradients of temperature and salinity, such as ocean fronts, as these areas have high numbers of forage fish congregated due to increased productivity (PFMC 2003). Swordfish migrate diurnally throughout the water column, feeding at the surface at night and in deeper waters during the day, preying mainly on pelagic fishes and invertebrates, favoring squid (Ward and Elscot 2000). This species is generally located in waters with surface temperatures of at least 13°C, however they have a broad temperature range, tolerating waters from 5° to 27°C (van der Elst and Govender 2003). Swordfish within the California bight have been recorded to reach depths of over 670m and are able to tolerate rapid changes in temperature during these diurnal movements due to the presence of a specialized muscle that heats the eye and brain to keep it at a near-constant temperature of 28°C (van der Elst and Govender 2003; Sepulveda et al. 2010; Ward and Elscot 2000).

Swordfish are naturally resilient to fishing pressure because they mature at an early age (5-6 years), have a moderate life longevity, high individual growth rates, and high fecundity, all contributing to a moderately high population growth rate (Marsh and Stiles 2011). The Western and Central North Pacific stock is estimated to be healthy because: 1) biomass is above that at which maximum sustainable yield (MSY) is produced, 2) overfishing is not occurring, and 3) there is no evidence of declining abundance (Marsh and Stiles 2011). This is confirmed by recent assessments indicating that the swordfish stock off the coast of California is healthy and annual catch rates of 10,000 mt in 2011-2012 are well below the estimated exploitable biomass of ~70,000 mt (Hinton and Maunder 2011; ISC 2014). Furthermore, the reproducing population (spawning biomass) is 50% above the carrying capacity with a spawning biomass ratio of 1.45 (Hinton and Maunder 2011). The harvest rate is well below the MSY target level, therefore the stock is considered largely underutilized despite significant national and global demand.

Demand for Swordfish

Swordfish have been harvested for centuries, with evidence of swordfish fishing dating to 3000-4000 BCE in Japan and 384-322 BCE in the Mediterranean (van der Elst and Govender 2003). The global fishing effort and subsequent catch of swordfish has risen progressively since the 1950s, with dramatic increases in the early 1980s linked to increased demand driven by the expansion of the swordfish market (Figure 2) (SWFSC 2010). As of 2012, 106 countries worldwide reported fishing for swordfish commercially, contributing to the total global capture of 114,300 mt (FAO 2012; FAO 2014a). The global leaders in terms of highest weight landed (in metric tons) in 2012 were as follows: Spain (22%), Taiwan Province of China (13%), Japan (9%), Indonesia (7%), Chile (6%), Philippines (4%), the United States (4%), Italy (4%), Sri Lanka (3%), and China (3%) (FAO 2014a). Within these fisheries, pelagic longline is the most widespread fishing gear for landing swordfish globally (Watson and Kerstetter 2006).

The U.S. and European Union (E.U.) have a strong influence on the global swordfish market and tend to dictate trends in swordfish prices due to high consumer demand (van der Elst and Govender 2003; Ward and Elscot 2000) (See Appendix A). The U.S., which only contributed 4% of all swordfish landings in 2012 (NMFS 2014b; FAO 2014a), is the world's largest swordfish market on an individual country basis, consuming approximately 25% of world landings (Asche et al. 2005). However, when taking into account the E.U. as a single entity, the E.U. consumes more swordfish than all other countries combined (SWFSC 2010). The demand for swordfish in the U.S. has been fairly high on a consistent basis over the last few decades; however, it did experience a drop in the mid-1990s. In 1997, the consumption of domestic swordfish declined due to a successful campaign called “Give Swordfish a Break” (Martin 2012). This campaign aimed at relieving market pressure on the North Atlantic swordfish stock because it was considered overfished at the time, although the National Marine Fisheries Service (NMFS) has since determined that the North Atlantic swordfish population has been successfully rebuilt. The campaign affected the consumption and domestic production of swordfish nationwide (Martin 2012). Peak swordfish consumption occurred in the late 1990s through 2004. The consistently high national demand is enough to consume almost all domestic catch (Crowder and Myers 2002); however, United States swordfish fisheries have exported an average of 270 metric tons from 2007 to 2013 (NMFS 2014b). Further, there is little demand for

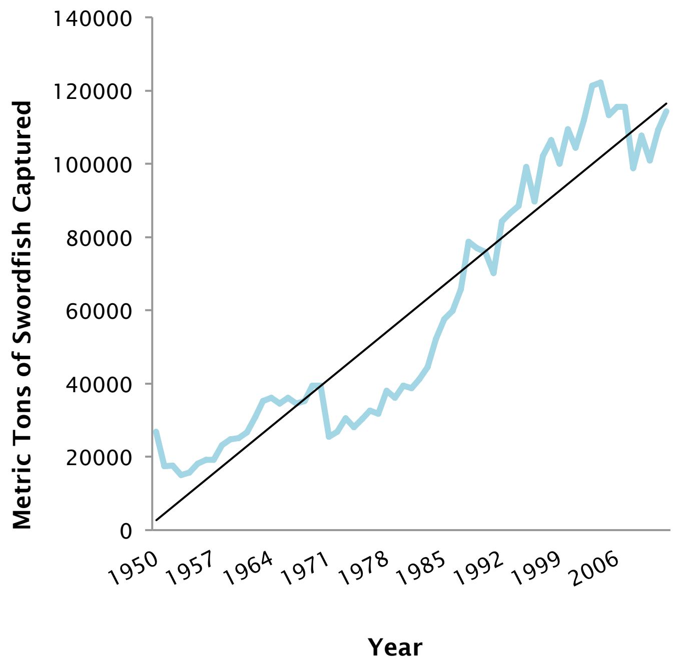

Figure 2. Total global catch of swordfish in metric tons from 1950 to 2012. Data: FAO 2014a

swordfish in Hawaii, and the majority of Hawaii landings are exported to the large, established markets on the U.S. mainland (WPRFMC).

During the 1980s and into the mid-1990s, domestically-caught swordfish generally supplied U.S. demand (Figure 3). Since 1997, however, the proportion of imported swordfish to all swordfish consumed has increased, with U.S. importing on average 75% of the swordfish consumed. The highest proportion imported was 81% in 2002 and 2004, making the U.S. one of the largest markets for foreign-caught swordfish (Table 1) (SWFSC 2010; NMFS 2014b). Importing such a large proportion of swordfish to meet the high demand in the U.S. is partially a result of a decline in domestic swordfish fishing effort (PFMC 2011b) and may have unintended consequences for marine ecosystems and sensitive species globally (Bartram et al. 2010; Rausser et al. 2009).

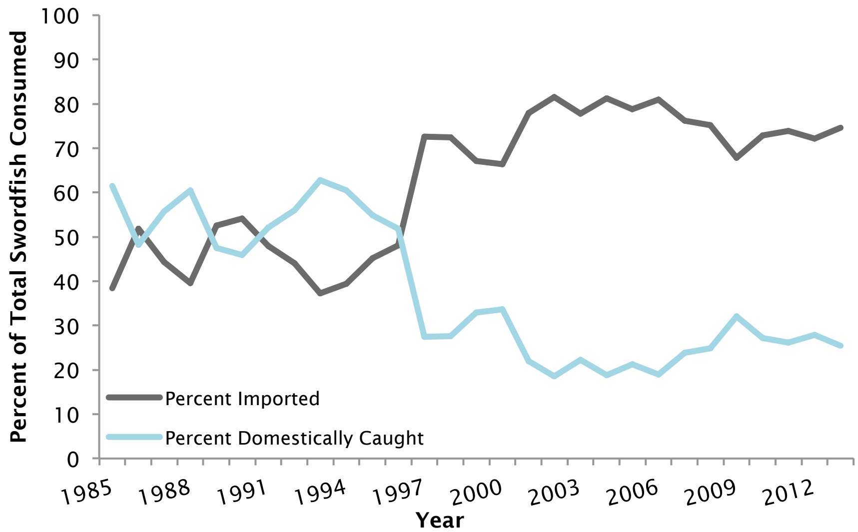

Figure 3. Comparison of imported and domestic swordfish as a percentage of all swordfish consumed in the U.S. from 1985-2013. Data: NMFS 2014b.

Table 1. Average imported compared to domestic swordfish consumed as a percentage of total swordfish consumed in the United States from 1985-2013. Data: NMFS 2014b.

Decade	Average Tons of Swordfish Consumed in U.S.	Average Percent Imported	Average Percent Domestic
1985-1994	13741	45%	55%
1995-2004	19205	69%	31%
2005-2013	13368	75%	25%

Regulatory History of the California Swordfish Fishery

The California swordfish fishery has a long and complex management history in terms of the gears used within the fishery, regulations and restrictions introduced and implemented over time, and agencies responsible for management (See Appendix B for regulatory history timeline). The fishery began as a state managed fishery; it is now managed as part of a federal highly migratory species (HMS) but the permitting authority still lies with the State of California.

The diverse gears used to catch swordfish in California waters vary significantly with regards to fleet size, vessel and crew size, effort, price received per pound, length of trip at sea, locations fished, and non-target species caught. Therefore, each gear type has incurred very different restrictions over time based on the significant differences in impact to swordfish stocks, populations of sensitive non-target species, and competition with recreational fishermen. (See Appendix C for comparison of domestic swordfish fisheries; Appendix D & E for management history of the California swordfish fishery; and Appendix G for information on how the North Atlantic swordfish fishery differs from the California fishery).

The complex political and management history that has influenced the structure of the California swordfish fishery today includes the initial development of gears and fishing techniques to increase the swordfish catch and profit of the fishery, followed by years of experimental and innovative gear alterations, seasonal and area closures, and limits on permits. Permits were limited mainly in order to reduce the impact of the fishery on sensitive marine species caught as bycatch, including sea turtles and marine mammals.

California's modern harpoon fishery targeting swordfish developed in the early 1900s and was modeled after the East Coast harpoon fishery, which began almost 70 years earlier (Coan et al. 1998). The harpoon swordfish fishery catch peaked in 1978, when an estimated 2.6 million pounds were landed by over 300 harpoon fishing vessels from San Diego to Point Conception, California, and fishing effort peaked in 1979 (12,700 days fished) (Coan et al. 1998). At that time, harpoon-caught swordfish accounted for the majority of swordfish landed to California ports. Harpoon fishing continued as the only commercial fishery that harvested swordfish within the EEZ off of California until 1980, when drift gillnet fishing began (Coan et al. 1998).

Drift gillnet fishing developed in southern California in 1977 for thresher sharks, and in 1979, the Fish and Game Commission authorized the sale of swordfish incidentally caught in the growing shark fishery. Swordfish replaced thresher shark as the primary target species of the drift gillnet fishery in 1981 because of the fourfold higher price per pound of swordfish (NOAA 2014b). The competition created by the more efficient drift gillnet fishery resulted in many harpoon fishers transitioning to drift gillnet gear or obtaining permits to use both gear types (Coan et al. 1998). Drift gillnet quickly replaced harpoon as the primary method for catching swordfish due to the greater catch per unit of effort (CPUE) (drift gillnet has a swordfish catch rate about 2-3 times higher), and thus reduced cost of fishing (Coan et al. 1998). The number of harpoon permits subsequently decreased from a high of 1,223 permits in 1979 to a low of 25 permits in 2001 (PFMC 2015a). Currently, only a few vessels continue to participate in the harpoon swordfish fishery, with only six vessels catching 6 mt in 2013 (PFMC 2015a).

Despite the efficiency and profitability of drift gillnet, one significant problem is that drift gillnet indiscriminately entangles non-target fish, marine mammals, sea turtles, and sharks (Hanan et al. 1993). During the early and mid-1980s, multiple regulations, mainly seasonal area closures, were instated to reduce the overall impact of the fishery on sensitive species such as pinnipeds, migrating gray whales, and sharks (Hanan et al. 1993). In 1990, California established an official drift gillnet observer program to document the mammal, sea turtle, seabird, and target and non-target fish species takes (Hanan et al. 1993).

In 1991, the California longline fishery was developed and the State Legislature permitted targeting swordfish using longline outside of the EEZ off of California (Holts 2001). In 1992, a proposal to allow longline inside of the California EEZ to target tuna, swordfish, and shark, was rejected by the CDFW over concern for longline not being as size selective as drift gillnet and the uncertainty of the swordfish population that has since been determined that the swordfish stock is healthy (Hinton and Maunder 2011; FAO).

Swordfish landings by longline outside the EEZ increased in the late 1990s and landings peaked in 2000, when 2,084 metric tons were caught (PFMC 2005). When the Hawaii longline fishery closed due to sea turtle bycatch concerns in 2000, twenty Hawaiian longline fishing vessels relocated to southern California to join the fishing fleet (Holts 2001; PFMC 2005).

In 2001, the California swordfish longline observer program was developed to document incidental takes. As concerns over the take of sensitive species by longline vessels increased, the drift gillnet fishery also experienced a significant temporal and area restriction. Due to recorded interactions with endangered species, the Pacific Leatherback Conservation Area (PLCA) was implemented in 2001. This time-area closure is in effect annually from August 15 to November 15 – the prime foraging period off the California and Oregon coasts for Leatherback sea turtles – and covers an area greater than 213,000 square miles. The area closed adjacent fishing grounds from the ports of Morro Bay, California, to the mid-Oregon coast, and westward beyond the EEZ to 129° W longitude with additional area closures in the Southern California Bight put into place when an El Niño event is forecast between June and August (Drift gillnet fishery 2007; PFMC 2011b). Members of the fishing industry believed that the implementation of the PLCA put many fishermen out of business (NMFS 2008), resulting in a significant decline in total catch, participation, and revenue for the drift gillnet fishery (NOAA 2011b). Despite the decline in participation and profit in the drift gillnet swordfish fishery, many proposals that were brought forward in the following years failed in attempt to introduce longline fishing within the EEZ (see Appendix D for more details).

Gear improvements such as transitioning from J hooks to circle hooks combined with new legislation in Hawaii such as the requirement of using mackerel instead of squid bait decreased sea turtle bycatch by 86% (Finkbeiner 2011) (See Appendix H for comparison of bycatch mitigation strategies for domestic swordfish fisheries). Due to these changes, the Hawaiian longline fishery reopened in 2004. Despite these improvements to the fishing gear, the California longline fishery was not authorized as part of the newly implemented Highly Migratory Species (HMS) Fishery Management Plan (FMP) (PFMC 2005; OPC 2008). The prohibition of shallow-set longline in California resulted in a transfer in fishing effort for this gear type to Hawaii (PFMC 2005).

Due to the participation and economic decline within the fishery as a result of the establishment of the stringent regulations of the early 2000s, the Council has since attempted to improve opportunities in the fishery. This has been in the form of proposed modifications to the PLCA closure, experimental fishing permits (EFPs) to reintroduce longline vessels outside the EEZ, and EFPs for a limited number of longline vessels to begin fishing within the EEZ using the gear modifications required in Hawaii (PFMC 2014c). These attempts to revitalize the fishery, however, have all failed to pass, resulting in the continual decline in participation and catch in the fishery.

Additional regulations being considered is the implementation of protected species bycatch hard caps on the California Drift gillnet fishery (PFMC 2015b). Currently, the MMPA and the ESA federal processes determine the fishery's management of protected species bycatch (PFMC 2014e). The PFMC is deciding if hard caps should be based on mortality/serious injury (M/SI) or a bycatch interaction (PFMC 2015b). The fishery would close immediately when estimated M/SI or the number of interactions equals the bycatch hard cap for any of the species for which there is a set cap. The Council's preliminary preferred hard cap alternative includes a 1-year sub-option based on the incidental take statement (ITS) in the 2013 drift gillnet fishery Biological Opinion (BiOp) with increases for selected species. These bycatch hard caps are as follows (PFMC 2015b):

Fin whale: 2
Humpback whale: 2
Sperm whale: 2
Leatherback sea turtle: 3
Loggerhead sea turtle: 3
Olive Ridley sea turtle: 2
Green sea turtle: 2
Short-finned pilot whale: 5

Participation within the California Swordfish Fishery

Despite the growing global demand for swordfish and high demand for swordfish in the U.S., participation in the domestic California swordfish fishery has been declining over the years. Increased regulations and management have been effective at reducing sensitive species interactions and maintaining a healthy swordfish stock over time, but have resulted in a significant decline in active California drift gillnet fishermen and total California swordfish landings (Figure 4) (Hellmers 2014). Over the past two decades, the number of drift gillnet vessels participating in the fishery dropped from 139 vessels in 1990 to 16 vessels in 2014 (NMFS 2014b). Since 1985, catch has plummeted 96% from 3,073 metric tons at a value of 11.9 million dollars to just 120 metric tons valued at 717,000 dollars in 2013 (NMFS 2014b). At the current annual attrition rate of 10%, it is expected that the fishery will disappear and with it, years of knowledge and experience, as well as harvest potential from a healthy fishery resource (SWFSC 2010; NMFS 2014b).

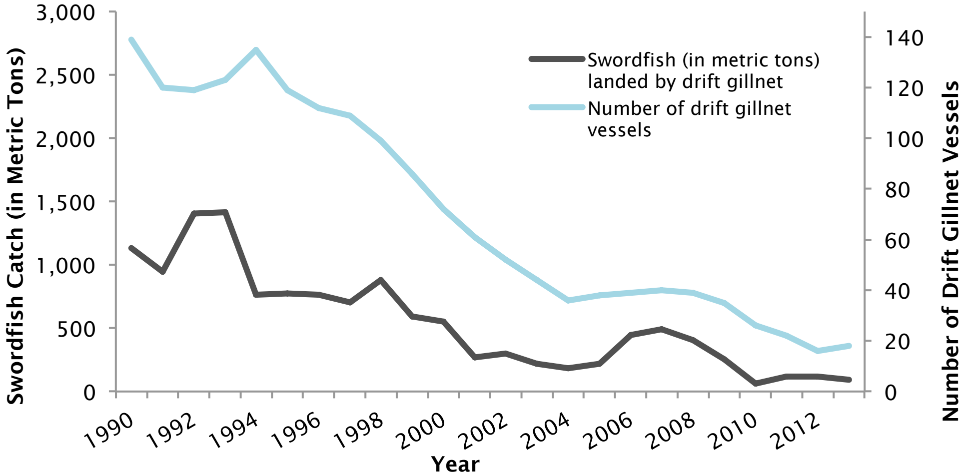

Figure 4. Decline in participation and catch of swordfish by drift gillnet in metric tons in California compared to the decline in the number of active drift gillnet vessels from 1990 to 2014.

Longline landings in California have also been influenced by changes in regulations (Figure 5). Longline landings for swordfish were substantial from 1999 to 2003 – at around 2,000 metric tons each year and valuing on average $6 million a year – likely due to an influx of twenty longline fishing vessels from Hawaii during the period when the Hawaii longline fishery closed (PFMC 2005; Holts 2001). This peak in catch and profit for longline was followed by a steep drop in total catch by hand line and longline gear from around 2,000 metric tons to 0.9 metric tons in 2005. This drop is due to the closing of the California longline fishery and the reopening of the Hawaii longline fishery in 2004.

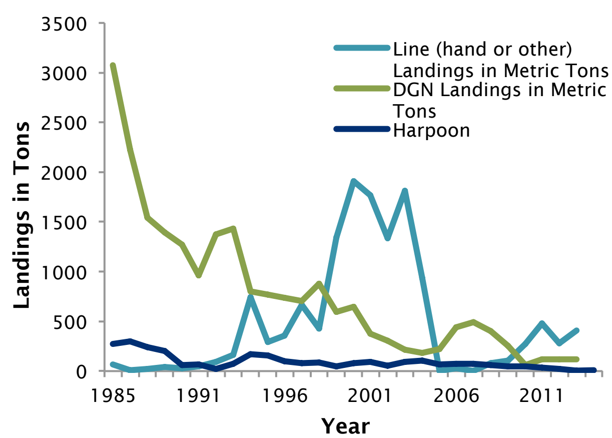

Figure 5. The amount of swordfish landed to California in metric tons by gear type, handline and longline, drift gillnet, and harpoon, from 1985 to 2013.

One consequence of the diminishing California swordfish fishery is evidenced by the fact that California only supplied 4% of all swordfish consumed in the United States in 2013. Because this fishery is underutilizing the swordfish stock, the fishery is not achieving its potential yield and profit (Hilborn 2013). This causes the California swordfish fishery to be economically unsustainable wherein potential net national benefits are lowered due to the decline in contribution to GDP. Furthermore, the domestic fishery is at a large disadvantage due to strict regulations, as compared to more loosely regulated foreign fleets (NOAA 2011a). Therefore, although the ecosystem-based fishery management strategies of the past have decreased the local environmental impacts of the fishery, the California fishery now plays a much smaller role in providing swordfish to meet U.S. consumer demand, and sensitive species bycatch still remains a global issue of concern (SWFSC 2010).

Bycatch Comparison between Gear Types

Sea Turtles

Conservation Status

The four species of sea turtles that have been recorded as bycatch in the California drift gillnet and historical longline fishery include the loggerhead, leatherback, olive ridley and green sea turtles, all of which are listed as federally endangered. Individuals are typically caught where fishing efforts overlap with the sea turtle species' distributions in the tropics and sub-tropics (Gilman and Lundin 2009; Gilman et al. 2006; Lewison et al. 2004a,b; Crowder and Murawski 1998).

Drift gillnet

Drift gillnets, along with other net fisheries, are a large source of anthropogenic mortality to sea turtles globally (Lewison and Crowder 2006). Sea turtles can swim into and get caught within drift gillnets that have been set within their range. Depending on the time between when they are caught and when the drift gillnet is hauled out of the water, caught individuals may drown. In France and Italy, the probability of mortality of sea turtles captured in gillnets has been reported to be as high as 50% (Argano et al. 1992; Laurent 1991).

However, data are lacking regarding the amount and size of turtles caught relative to the amount of gillnet gear deployed globally (Lewison and Crowder 2006). Despite preliminary evidence that drift gillnet fisheries may have bycatch equal to or greater than longline, there are a lack of innovative gear modifications to reduce sea turtle capture and mortality in drift gillnet fisheries compared pelagic longlines and coastal trawl fisheries (Gilman and Lundin 2009; Lewison and Crowder 2006).

Longline

Sea turtles are caught on longlines by biting baited hooks, and some are hooked on the body and then entangled. Longline has historically been under the most scrutiny for causing declines in sea turtle populations. However, there has been significant progress in reducing sea turtle bycatch in U.S. Fisheries (Finkbeiner 2011). With regulations requiring bycatch mitigation for sea turtles, such as the use of circle hooks and mackerel bait, the catch and mortality rates have significantly decreased. Within pelagic longline fisheries targeting swordfish, the change in fishing methods to reduce sea turtle mortality has had no impact on the amount of swordfish caught (Watson et al. 2005).

Hawaii's pelagic longline fishery reduced its sea turtle bycatch by 86% after bycatch mitigation regulations were instituted in 2004 (Finkbeiner 2011). The cumulative estimate of sea turtle bycatch and mortality in the historical California pelagic longline fishery was not affected as bycatch regulations were instituted around the same time the fishery was banned in 2004. However, the amount of sea turtles caught by the historical California longline fishery was very low on average at less than 10 turtles per year (Finkbeiner 2011). The estimated average probability of mortality of sea turtles captured in longline is about 25% (Gilman 2011) but has been noted to be as low as 4% (Lewison and Crowder 2007).

Cetaceans

Conservation Status

The three species of whales that have been recorded to have had an interaction with the California drift gillnet and historical longline fisheries include humpback, fin, and sperm whales. All three species of whales have been listed as federally endangered under the ESA since 1970 and protected under the MMPA.

Drift gillnet

On rare occasions, whales can become entangled in a California drift gillnet fishery. The most recent whale interaction in the California drift gillnet fishery occurred in 2010 when two sperm whales were caught. Before 2010, a whale interaction had not occurred since 2004 when one humpback whale was caught. Prior to 2004, the fishery caught one fin whale and one minke whale in 1999 (Carretta and Enriquez 2012a; NMFS 2010a; NMFS 2000). The introduction of acoustic pingers in 1996 resulted in a 50% decline in the overall cetacean entanglement rate (Carretta and Barlow 2011; Carretta et al. 2008; Barlow and Cameron 2003).

Controversy over reported whale bycatch in the California drift gillnet fishery stems from the relatively low observer coverage in the fishery, ranging from 4% to 20% between 1990 and 2012 (Carretta and Enriquez 2012b). Because there is not 100% observer coverage, the amount of bycatch individuals caught by the fishery is extrapolated to determine an estimate of total bycatch interactions in the fishery (Carretta and Enriquez 2012b). This extrapolation method assumes that the number of bycatch individuals recorded in a given year under 20% observer coverage would be exactly 1/5 of the total bycatch interactions recorded had there been 100% observer coverage. For example, in 2010, the 2 Sperm whale interactions observed were extrapolated to estimate a total of 16 whale interactions that year due to the 11.9% observer coverage (Carretta and Enriquez 2012a).

The relatively low observer coverage in the California drift gillnet fishery is partially due to a lack of funding to pay, feed, and host observers by federal and state agencies (Carretta and Enriquez 2012b). There is also a physical constraint of hosting an observer, and some California drift gillnet vessels are deemed ‘unobservable’ because they lack additional berthing space (Carretta and Enriquez 2012b). An experiment was done to determine the viability of video monitoring as an alternative to onboard observers; however, the technology was unable to sufficiently identify bycatch species and did not reduce costs (Carretta and Enriquez 2012b).

Longline

The incidental longline entanglement and hooking of large whales has occasionally been reported due to whales swimming into the fishing gear (Forney & Kobayashi 2007). However, the bycatch of whales is a larger problem in fisheries using gillnets and trawls compared to longline (Perrin et al. 1994). Due to the confidentiality of the historical California longline fishery there are no available estimates of whale bycatch. The Hawaii longline fishery, which has 100% observer coverage, had one humpback whale interaction between 2006 and 2014 (Jantz 2015).

Sharks

Conservation Status

In 2010 and 2011, Hawaii and California passed legislation banning shark finning. Shark finning is the practice of cutting off the fin of a caught shark and discarding the remaining carcass into the ocean. The mandate required fishers to retain the entire shark carcass when landing. This regulation was effective in decreasing the total catch and landings of all shark species (Gilman 2008).

The total biological impacts of fisheries on blue shark populations are unknown due to the lack of population analyses (Gilman 2008).

Drift gillnet

Blue shark represents a significant quantity of the bycatch caught in the California drift gillnet fishery. When the California drift gillnet fishery started in the late 1970s it originally targeted the common thresher shark (Hanan et al. 1993). After 1985, swordfish replaced thresher shark as the primary target species because there was a greater demand for swordfish which commanded a higher price-per-pound. This transition to targeting swordfish was possibly also due in part to the 1986 establishment of a shark conservation measure (PFMC 2012a).

Longline

Blue shark also represents a significant quantity of the bycatch in the Hawaii longline fishery. Interactions with sharks in longline fisheries cause significant ecological, economic and social challenges (Gilman 2008). Sharks, along with cetaceans, are primarily responsible for the depredation of bait off longline fisheries (Gilman 2008). This is a concern for shark populations because this behavior may cause changes in shark foraging behavior and distribution. This also results in the injury and mortality of sharks when they are incidentally caught on longline hooks and are intentionally harmed by fishers in attempts to prevent future depredation (Gilman 2006a).

The banning of shark finning in Hawaii did significantly decrease the landing of sharks in the longline fishery. Prior to the regulation, the Hawaii longline fishery finned 64% to 76% of caught sharks and 50% of the individuals caught were recorded as bycatch. Post-regulation, the Hawaii longline fishery released alive 93% of caught sharks (Gilman 2008). However, the development of methods to reduce the incidental catch of sharks in longline fisheries has been minimal compared to efforts to develop bycatch reduction measures for other species other species such as seabirds and sea turtles (Gilman 2006a). The Hawaii swordfish longline fishery doesn't employ shark bycatch mitigation practices that are found in other swordfish fisheries. Practices that are not utilized by the Hawaii swordfish fishery but used by other international fisheries include the avoidance of the following: use of lightsticks, wire traces, chumming, setting in specific sea temperatures, and avoiding fishing in areas with high shark abundance from past experience or communication with other vessels (Gilman 2006a).

Sea Birds

Conservation status

The two seabird species that have been recorded as bycatch in the U.S. pelagic longline fishery include the laysan and black-footed albatrosses. In 2003, the black-footed albatross was listed as endangered by the International Union for the Conservation of Nature and Natural Resources (IUCN) because it was predicted that the species would experience a population decline of more than 60% over the next three generations (56 years). This was partially due to the high rate of incidental mortality caused by longline fisheries, which was 2,000 birds per year in the U.S. and 6,000 birds per year in Japanese/Taiwanese fleets (International Union for the Conservation of Nature and Natural Resources 2004; Lewison and Crowder 2003). The number of birds killed per year by longline has since then been reduced as a result of mandatory seabird bycatch mitigation methods. Currently, both species are now listed as "near threatened" by the

IUCN (IUCN 2014). Additionally, a population analysis of both species performed by the U.S. Geological Survey (USGS) confirmed that breeding populations of the laysan albatross are stable, and populations of black-footed albatross are probably stable and therefore not threatened by U.S. pelagic fisheries (Arata 2009).

Drift gillnet

Sea bird interactions are rare within the California drift gillnet fishery (Carretta and Enriquez 2012b). If interactions do occur, they typically do not involve endangered species of sea birds (Carretta et al. 2014; Carretta and Enriquez 2012a; Carretta and Enriquez 2012b).

Longline

Longline fisheries impact 61 species of sea birds and 26 of these species are threatened with extinction, including 18 albatross species (Brothers et al. 1999; Gales 1998). Sea birds attracted to the bait can be hooked and entangled on longline equipment when the gear is being set (Gilman 2011). Birds caught are then at risk of drowning while gear sinks below the surface (Gilman 2011).

Regulations mandating bycatch mitigation practices used in the Hawaii longline fishery reduced the number of seabird interactions from 92 to 99% annually since 2004 compared to pre-regulations estimates (Bigelow 2011). These estimates are considered to be accurate due to the 100% observer coverage in Hawaii's shallow-set longline fishery.

The Market Transfer Effect

International trade chains, heightened by the increasingly globalized economy, connects markets, therefore local threats to species are driven by consumer demand around the world (Lenzen 2012). Because of this, policies with the goal of reducing local impacts to sensitive species should consider the global perspective instead of the direct local impact in isolation (Mukherjee 2015; Lenzen 2012). This issue is applicable to the global commercial swordfish industry, which is comprised of various fisheries internationally, each with different levels of impact to swordfish stocks and bycatch species.

Despite the decline in domestic swordfish production, U.S. consumer demand for swordfish remains high. Due to the decline in domestic landings of swordfish, imports have increased in order to compensate for the lowered domestic supply of swordfish. As fisheries operate in the global market, it is estimated that reducing catch in one part of the world results in a transfer of increased catch to another region in the world in order to meet consumer demand (NOAA 2011b). It is theorized that reducing bycatch due to a decline in domestic fishing will not cause an overall reduction in bycatch, but rather that this bycatch will be transferred to swordfish fisheries in other regions of the world where from which the swordfish demand will need to be met (Chan and Pan 2012).

Foreign fishing fleets that fill the demand gap that is present due to a decrease in the domestic supply of swordfish have higher bycatch rates and may impart a greater impact on sensitive species because of less stringent and enforceable regulations in these countries as compared to U.S. fisheries (SWFSC 2010; Santora 2003; Bartram and Kaneko 2004; Gilman et al. 2006; Sarmiento 2006; Rausser et al. 2009; Bartram et al. 2010). It is estimated that the U.S. swordfish fisheries have the lowest calculated bycatch-to-fish-catch ratios among other major Pacific longline fisheries – especially after the 2004 management measures took effect for the Hawaii shallow-set longline swordfish fishery (Chan and Pan 2012). Bartram et al. (2010) determined that for every

190 metric tons of swordfish caught in the Hawaii shallow-set longline fishery, 3.7 sea turtles were caught. To catch the same amount of swordfish – 190 metric tons – in the Australia swordfish fishery, 9.5 sea turtles were caught, and 13.7 sea turtles were caught in the Taiwan tuna fishery, which catches 93% of all swordfish landed by Taiwan (Crowder and Myers 2002). This could be because foreign fleets have not adopted fishing methods that reduce the catch of sea turtles and birds like circle hooks and mackerel bait, which are now required in most U.S. longline fisheries (Watson and Kerstetter 2006; Benson et al 2008). These bycatch rates can also be compared to the California drift gillnet fishery, which, catches an average estimated 2.9 sea turtles for every 190 metric tons of swordfish caught annually (Stohs 2014).

Additionally, the U.S. government does not enforce the receipt of information from importing countries regarding fishing practices, take of marine mammals, or additional information to satisfy the requirements of the MMPA or the ESA (CBD & TIRN 2008). Therefore, increasing swordfish imports from these foreign sources is expected to result in a net increase in the overall impact to sensitive species globally (SWFSC 2010).

Economically, relying on imported swordfish instead of domestically caught swordfish to meet consumer demand lowers national net benefits (NOAA 2011a). U.S. fishers who invest in innovative fishing methods to reduce bycatch and who adhere to federal and state standards have a disadvantage in the market as compared to foreign fleets exporting to the U.S. that are not held to the same conservation standards (Smith 2014). Further, a decline in domestic swordfish landings reduces the employment and incomes of local fishers and crew (Squires 2013). From a conservation perspective, any transfer effect of sea turtle bycatch as a result of decreased domestic swordfish supplied to meet national demand is expected to reduce U.S. consumer welfare due to the loss in existence value of sea turtles (Squires 2013).

Foreign Fleets

Of the major fishing areas in the world, the region where the most swordfish is caught is within the East Pacific Ocean (EPO), where most longline vessels are exempted from conservation regulations and where leatherback stocks are most fragile (WPRFMC 2011; Wallace et al. 2010; Shillinger 2008; Martinez et al 2008; Spotila et al. 2000). Additionally, the EPO experiences foreign competition over fishing grounds and markets, increasing the pressure on sensitive populations (NOAA 2011b). In 2012 and 2013, 56% and 51%, respectively, of swordfish imported to the U.S. were from countries within the EPO (Ecuador, Costa Rica, Chile, Panama, and Mexico) (Figure 6).

Over the last decade, the U.S. has consistently imported large proportions of its swordfish from Singapore. From 1997 through 2010, Singapore was the top importer of swordfish to the United States. In 2011 and 2012, Singapore provided the second highest proportion of imported swordfish, and in 2013 provided the fourth highest proportion of imported swordfish (NMFS 2014b). Despite this large influx of swordfish imported into the U.S., Singapore reports zero swordfish catches (FAO 2014a). Instead, Singapore acts mainly as a transshipper to the global import-export market for swordfish, re-exporting fish between large-scale exporting countries and large-scale importing countries (Folsom 1997). This transshipping of swordfish reduces the transparency of the supply chain, thereby decreasing the potential for ensuring that fishers are held accountable to the fishing practice standards enforced in the U.S. The lack of transparency and accountability within this trading system may lead to unreported interactions with marine mammals and other sensitive stocks.

Evidence shows that the primary source for Singapore's swordfish transshipments to the U.S. is from Taiwan, which exhibits fishing practices far below U.S. standards for the protection of fish stocks and sensitive species (Crowder and Myers 2002). Researchers, using approximations for incidental catch from vessels in two East Coast harbors of Taiwan alone, have estimated an annual take of 27,000 to 41,000 cetaceans (Perrin et al 2002). The Taiwan Fishery Agency regulates fisheries through two national legislations: the Fisheries Act and the Fishing Port Act. These Acts do not reference any specific provisions to prevent bycatch or provide standards for the protection of marine mammals (FA.COA 2014). Furthermore, Taiwan tuna and swordfish fishers are believed to operate in waters beyond Taiwanese authority with no monitoring or regulations (Perrin et al 2002). It is important to note that Taiwan catches a large proportion of global swordfish catches (13% in 2013); however, the majority of this catch is as bycatch from the tuna fisheries (Crowder and Myers 2002).

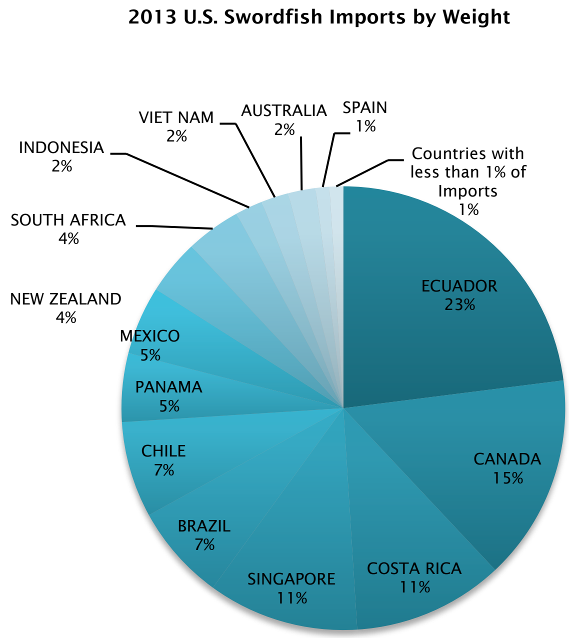

Figure 6. Percentage of imported swordfish to the U.S. in 2013 from countries as a percentage of total imported swordfish Data source: NMFS 2014b.

Due to the lack of transparency within the supply chain and the strong evidence of less stringent fishing and conservation standards within the foreign fleets from which the U.S. imports swordfish, it is likely that the U.S. indirectly contributes to global take of marine mammals, sea turtles, and other sensitive species. It can therefore be assumed that by importing from these countries without ensuring they meet standards similar to those required for U.S., the U.S. may jeopardize the protection of sensitive species globally, and place U.S. fishers at a significant disadvantage in the market due to the price differential previously mentioned. An alternative policy option that is being considered is the banning of imports from countries that do not meet these conservation standards (See Appendix K).

Hawaii Case Study

Evidence shows the market transfer effect occurred when the Hawaii longline swordfish fishery was closed from 2001 to 2004 (Rausser et al. 2009) (See Appendix F for History of Hawaii Swordfish Fishery). That closure resulted in a transfer of fishing effort to foreign fleets, which provided an increase of 1,602 metric tons of foreign swordfish imports to meet demand in the U.S. (Rausser et al. 2009). The short closure of the Hawaii fishery, implemented in an attempt to improve the protection of endangered sea turtles, resulted in an estimated market transfer of sea turtle bycatch, where an additional 2,882 sea turtle interactions occurred in foreign fleets (Rausser et al. 2009). Sarmiento (2006) estimated a "trade leakage" due to the Hawaii shallow-set longline swordfish fishery closure in 2000 by applying an econometric model that incorporated U.S. fresh swordfish imports, time lags, and other variables impacting U.S. fresh imports. This research determined that fresh imports to the U.S. increased significantly from Ecuador and Panama a year after the closure of the Hawaii fishery. Furthermore, the research concluded that the closure resulted in the transfer of fishing effort to some foreign fleets, and likely did not lead to an overall reduction in sea turtle interactions. This study, however, did not estimate specific changes in the number of bycatch interactions associated with increased imports (Sarmiento 2006).

It has also been determined that the closure of the Hawaii longline swordfish fishery likely caused a “spillover” (market transfer) effect of increased foreign production effort in the same fishing area where the Hawaii shallow-set longline swordfish fishery operated (Chan and Pan 2012). Thus Chan and Pan concluded that the reduction in U.S. production due to regulatory changes did not reduce overall sea turtle bycatch in the North and central Pacific because foreign fleets production occurred in the same area to maintain overall production levels and these fleets had higher bycatch rates. The study also projected that the inverse would be true: increasing effort in the U.S.-based Hawaii longline swordfish fishery would displace production by foreign fleets in the North and central Pacific, thus reducing bycatch.

Prior work is based on a number of important assumptions, and the magnitude of any market transfer effect depends on how the domestic swordfish production is linked to worldwide swordfish production. Assumptions related to the Hawaii fishery, which could be considered as relevant assumptions concerning a market transfer effect within the California swordfish fishery, are as follows (Chan and Pan 2012):

1. The domestic fresh swordfish production would replace fresh swordfish imports to the U.S. one-for-one. This would be supported by:
    a. The preference by U.S. consumers of domestic swordfish due to quality, freshness, and/or support of local fisheries. This has been observed historically during the peak Hawaii swordfish production when the U.S. domestic market absorbed the entirety of the supply.
    b. A one-for-one product displacement was observed during and after the Hawaii longline swordfish fishery closure.
    c. Demand for swordfish price is inelastic, meaning consumers are relatively insensitive to prices changes (Rausser et al. 2009). Therefore, any change in swordfish price would have a relatively minor impact on the quantity demanded.
    d. The U.S. price elasticity of swordfish demand impacts the extent to which a domestic swordfish fishery closure would lead to an increase in U.S. imports. A price inelastic demand increases the potential for a market transfer effect to occur, which was determined to be the case for the U.S. (-0.40 from 1990-2005) by Rausser et al. (2009). This assumption is further supported by several other studies of seafood demand, which found the demand for high-value fresh fish in the U.S. and Japan to be price inelastic (Cheng and Capps 1988, Eales et al. 1997, Wessells and Wilen 1994, Johnson et al. 1998).
2. If higher domestic swordfish production completely displaces the production of foreign fleets, a reduction of bycatch interactions would occur.

With these assumptions and the previous research conducted, it can be estimated that an increase in domestic swordfish production would result in lower foreign imports.

Market Transfer Effect for the California Swordfish Fishery

Our project operated without sufficient global data to conclude with certainty that a closure of the California swordfish fishery would result in the direct increase of swordfish imports from foreign fleets and that the global bycatch would increase as a result of any transfer. However, there is substantial evidence for the potential for this unintended impact to occur, and that an increase in domestic supply to meet national demand is an improvement in many ways for national net benefit (NOAA 2011a).

Therefore, our project operated under the assumption that there is the potential for a market transfer to occur wherein a decline in U.S. fishing effort would result in an increase in foreign fisheries effort that are assumed to have higher bycatch rates. Case studies of market transfer effects in domestic fisheries have provided evidence that a similar effect could be observed if the domestic California swordfish fishery participation declines. These studies also provided evidence for the potential for a reverse market transfer effect if the domestic swordfish fishery were able to increase fishing effort at a low bycatch rate, thereby resulting in fewer bycatch caught globally (Chan and Pan 2012). Our project did not, however, take into consideration how incidentally caught swordfish in global fisheries could reduce the strength of the transfer argument.

One argument against the potential for the occurrence of a market transfer effect in the case of the California swordfish fishery is that alternative swordfish harvesting gear types such as hand hook and line and harpooning are viable and could reproduce the current supply of swordfish (Scorse 2014). This argument can be refuted by the evidence that these techniques do not have a high enough catch rate to generate commercial volumes of swordfish landings (SWFSC 2010). Furthermore, revealed preferences of fishermen have shown a decline in these fishing techniques in recent decades despite the lack of fishing restrictions; therefore, it is unlikely that hand hook and line and harpoon gears will have sufficient increases in effort or catch volume to meet the current supply (SWFSC 2010).

Another argument made against the market transfer effect occurring due to changes in catch from the California swordfish fishery is that there is no empirical evidence to substantiate the existence of a transfer effect (Scorse 2014). This argument ignores the multiples studies, such as Rausser et al 2009, Sarmiento et al 2006, and Chan and Pan 2012 that document a transfer effect in foreign fleets as a result of the closure of the Hawaii shallow-set longline fishery in 2001. During this closure, a transfer was estimated wherein the increased imports to Hawaii were from increased foreign production relative to what would have occurred had the Hawaii fishery remained open (Rausser et al 2009).

The market transfer effect highlights the uncertainty of the effectiveness of imposing conservation policies on domestic fisheries when the U.S. competes with foreign fisheries in the national market (Mukherjee 2015; Mukherjee 2013). For these reasons, it is essential to consider the alternative management strategies to the full closure of the California swordfish fishery in order to avoid the potential for increased global bycatch as a result of national consumption of swordfish. Through modeling management alternatives and analyzing policy initiatives for the California swordfish fishery, it is possible to identify management strategies that increase profit and swordfish catch under conservation regulations and constraints, and therefore, allow for a decreased reliance on imported swordfish in order to protect sensitive species on a global scale.

METHODS

Model Overview

To generate and compare different management scenarios for a productive California swordfish fishery we developed a model using inputs and outputs calculated in Excel. The objective of the model was to analyze a range of management scenarios for the California commercial swordfish fishery. The management scenarios explored different combinations of three gear types – drift gillnet, harpoon, and longline – at various fishing effort allocations, in two areas – inside and outside the Exclusive Economic Zone (EEZ) off of California. Other gear types, such as deep-set buoy gear and deep-set longline were not incorporated into this analysis due to the lack of sufficient data.

We used four model input parameters: swordfish catch per unit effort (CPUE), cost of fishing per unit effort (cost of fishing/effort), revenue per swordfish catch (revenue/catch), and bycatch per unit effort (BPUE). Our analysis considered the following four bycatch species of concern: humpback whale, sperm whale, leatherback sea turtle, and loggerhead sea turtle. Our analysis focused on these four species because they are federally listed as endangered under the ESA, and are known to be impacted by fisheries. These four species were the only endangered species that had recorded interactions with drift gillnet or longline fleets during the time period of our analysis. We calculated all parameters as a monthly average, based on data availability (See Appendix I for data description).

In regards to effort allocation, our analysis explored changing the effort of each gear type individually, transferring effort from one gear type and adding it to another gear type, as well as increasing or decreasing the total fleetwide effort of all three gear types. Our model analyzes 252 management scenarios. There are three model outputs associated with each management scenario: total swordfish catch (metric tons), total profit (2013 dollars), and total bycatch (number of individuals) – all of which we calculated as an annual average. We ran the model with harpoon effort constant at the status quo effort level and changing effort allocations between drift gillnet and longline, as harpoon effort is determined by weather conditions and swordfish behavior and not by State or federal regulations; therefore, it is assumed that harpoon fishers are already fishing at the maximum effort level feasible. To explore the feasibility of a harpoon-only fleet, we modeled one management scenario based on the maximum catch by the harpoon fleet since 1981, as this timeframe is most representative of the harpoon fleet effort. This management scenario represents a saturation of the niche market demand for harpoon-caught swordfish.

We conducted tradeoff analyses based off of the model outputs from all of the management scenarios. In each tradeoff analysis, we plotted profit or swordfish catch against a bycatch index. The tradeoff analyses graphically present the range of possible management scenarios to inform management and policy decisions regarding the best and worst alternatives for the fishery with respect to sustaining economic profitability and conservation goals.

It is our hope that our model and tradeoff analyses will serve as decision-support tools for the Pacific Fishery Management Council (PFMC), the CDFW and NMFS, regarding the management decisions for the California swordfish fishery. These tools could also assist the PFMC's decision regarding various proposed bycatch hard caps for the fishery. Overall, the model will allow decision-makers to explore a range of possible management scenarios that consider catch, profit, and bycatch within the California commercial swordfish fishery.

Model Inputs

This subsection describes methods for the four model input parameters: CPUE, cost of fishing/effort, revenue/catch, and BPUE. We calculated these four parameters as a monthly average for each of the three gear types – drift gillnet, harpoon, and longline. The methods are organized first by gear type, and then by parameter.

Drift gillnet

The model input parameters for drift gillnet[4] were calculated as follows:

1. Swordfish CPUE

We calculated this parameter by dividing the total swordfish catch (metric tons) by the total effort (vessel days). Both catch and effort were obtained from logbook data from the CDFW (Childers 2015b). Swordfish catch was recorded in “number of individuals” in the logbook, which is a self-reporting requirement for drift gillnet fishery participants. We converted catch to metric tons using a “metric ton per fish”, or “metric ton per individual” dressed weight value (Hellmers 2014). The “metric ton per individual” weight was given by month and number of fish from 2006 to 2011. We averaged the “metric ton per individual” by month across the timeframe of 2006 to 2011. We also averaged the catch in “number of individuals” by month across the timeframe of 2006 to 2011. The catch in metric tons by month was obtained by multiplying the “monthly average metric ton per individual” by the “monthly average number of individuals.” The catch equation is shown below:

$$Swordfish\ catch_{month} = Average\left(\frac{metric\ ton}{individual}\right)_{month} \times Average\ individuals_{\ month}$$

The monthly average catch calculation is based off of 708 entries in the logbook from 2006 to 2011. Stipulations regarding the use of logbook data in this analysis may be found in the Data Caveats section. From the timeframe of 2006 to 2011, one individual swordfish that was caught in July of 2006 was excluded because there was no “metric ton per individual” weight conversion for individuals caught in July. This was the only swordfish caught in July from 2006 to 2011. Additionally, 8 other individual swordfish were excluded from the catch calculation – 7 swordfish that were less than 1 pound, and 1 swordfish that was 1500 pounds were excluded. These weights represent unrealistic weights for swordfish and are attributed to data input or a recording error. The individual swordfish weights in the catch calculation range from 3.2 pounds to 501 pounds, with a mean of 150 pounds and a standard deviation of 56 pounds.

Effort was recorded in “vessel days” in the logbook data. Therefore effort was obtained by averaging the vessel days by month from 2006 to 2011.

The CPUE parameter for drift gillnet was thus calculated for each month by dividing the monthly catch in metric tons by the number of vessel days in each month. The CPUE

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[4] The drift gillnet gear type refers to large-mesh drift gillnet, meaning a gillnet greater than 14 inch mesh size.

parameter was calculated for the following months: January, August, September, October, November, and December. The CPUE equation is shown below:

$$Swordfish\ CPUE_{month} = \frac{Swordfish\ catch_{month}\ (mt)}{Effort_{month}\ (vessel\ days)}$$

2. Cost of fishing/effort

We calculated this parameter by dividing the total cost of fishing (2013 dollars) by the total effort (vessel days). The cost of fishing for drift gillnet was obtained from a Cost and Earnings Survey Report, which was conducted for the 2008-2009 and 2009-2010 fishing seasons (Stohs 2010b). This report included both fixed and variable costs. Fixed costs included mooring (slip/berth) fees, fishing association membership dues, license fees, travel, office expenses, storage expense, county vessel and berth taxes. Fixed costs were not included for any of the three gear types because the magnitude of the fixed costs were about equal – ranging from $150 to $450 – at which magnitude will not significantly affect the profit of each management scenario in the model.

Variable costs included fuel, bait, and gear and are consistent with harpoon and longline variable costs. The variable costs were provided as an average aggregated cost per set in 2009 dollars. This variable cost was calculated as an average across the timeframe from 2008 to 2010. We converted the variable cost in 2009 dollars to 2013 dollars using the Consumer Price Index (CPI) inflation calculator (CPI Inflation Calculator 2015). The variable cost of fishing per set in 2013 dollars is $1,011. Observer costs were not included in this parameter because currently NMFS funds observers for the drift gillnet fishery, thus, this cost is not incurred by the fishermen. Due to data availability for this parameter, we were unable to calculate this parameter at a monthly temporal resolution. Therefore, this variable cost value was used for each of the drift gillnet fishing months.

Effort was recorded in “vessel days” in the logbook data (Childers 2015b). Therefore effort was obtained by averaging the vessel days by month from 2008 to 2010, in order to be consistent with the timeframe of the cost of fishing for drift gillnet.

The cost of fishing/effort parameter for drift gillnet was thus calculated for each month by dividing the cost of fishing in 2013 dollars by the number of vessel days in each month. The cost of fishing/effort parameter was calculated for the following months: January, August, September, October, November, and December. The cost of fishing/effort equation is shown below:

$$Cost\ of\ fishing/effort_{month} = \frac{Cost\ of\ fishing_{month}\ (2013\ dollars)}{Effort_{month}\ (vessel\ days)}$$

3. Revenue/catch

We calculated this parameter by dividing the revenue (2013 dollars) by the swordfish catch (mt). The average revenue was calculated by multiplying the average catch by the average price per pound. The average catch used in the revenue calculation was the same as detailed above in the CPUE parameter subsection, where the catch was averaged by month over the timeframe from 2006 to 2011. The average price per pound data was obtained from Southwest Fisheries Science Center (SWFSC) (Stohs 2015a). This price per pound value was based off HMS SAFE reports data summaries regarding total swordfish revenues and total swordfish landings, averaged across the timeframe from 2001 to 2012. The HMS SAFE reports reported landings in round weights (in pounds); therefore, these weights were converted to landed weights (in pounds) by using a round weight to dressed weight conversion factor of 1.45 to account for all onboard processing of swordfish before it is landed. The average price per pound was given as an annual average in 2012 dollars from SWFSC. This price per pound was converted to 2013 dollars using the CPI inflation calculator (CPI Inflation Calculator 2015). Due to data availability, we were unable to calculate the average price per pound at a monthly temporal resolution. Therefore, the average price per pound value was the same for each of the drift gillnet fishing months in the revenue calculation. For drift gillnet, the average price per pound in 2013 dollars was $3.85.

The above detailed monthly average catch values in metric tons were converted to pounds. Revenue was then calculated by multiplying the catch in pounds by the average price per pound to obtain the revenue in 2013 dollars. The revenue equation is shown below:

$$Revenue_{month} = Average\ catch_{month}\ (lbs.) \times average\ \frac{price}{lb.}\ (2013\ dollars)$$

The revenue/catch parameter for drift gillnet was thus calculated for each month by dividing the revenue in 2013 dollars by the swordfish catch in metric tons – as calculated above in the CPUE subsection – for each month, based off averaging across the timeframe from 2006 to 2011.The revenue/catch parameter was calculated for the following months: January, August, September, October, November, and December. The revenue/catch equation is shown below:

$$Revenue/catch_{month} = \frac{Revenue\ (2013\ dollars)}{Swordfish\ catch\ (mt)}$$

4. BPUE

We calculated this parameter for 4 species – humpback whale, sperm whale, leatherback sea turtle, and loggerhead sea turtle – by dividing the total bycatch (number of individuals) by the total effort (vessel days). The number of individuals were obtained from the drift gillnet observer record (Stohs 2014c). Both bycatch and effort were calculated as a monthly average across the timeframe from 2001-2013. The BPUE equation is shown below:

$$BPUE_{species\ (sp.)} = \frac{Bycatch_{sp.,month}\ (individuals)}{Effort_{sp.,month}\ (vessel\ days)}$$

Table 2 depicts all four drift gillnet monthly average parameters, units, and the timeframe over which each parameter was averaged.

Table 2. Drift gillnet monthly average parameters.

Parameter	Units	Timeframe
Catch per Unit Effort (CPUE)	Metric tons/vessel day	2006-2011
Cost of fishing/effort	2013 dollars/vessel day	2008-2010
Revenue/catch	2013 dollars/vessel day	2006-2011
Bycatch per Unit Effort (BPUE) ▪ **Loggerhead sea turtle** ▪ **Leatherback sea turtle** ▪ **Sperm whale** ▪ **Humpback whale**	Individuals/vessel day	2006-2011

Harpoon

The model input parameters for harpoon were calculated as follows:

1. Swordfish CPUE

We calculated this parameter by dividing the total swordfish catch (metric tons) by the total effort (vessel days). Both catch and effort were obtained from logbook data from the CDFW (Childers 2015b). Swordfish catch was recorded in “number of individuals” in the logbook. We first converted catch from number of individuals to pounds using an “average weight per individual”, given in pounds per individual per month and per year (Childers 2015a). The average weights were only from landed fish and are estimated dressed weights recorded in the logbook by the captain. The numbers of fish that accompany the average weights in this dataset were the number of fish from which the average weight was calculated, not the total number of fish caught.

We averaged the “average weight per individual” in pounds by month across the timeframe of 2006 to 2013. We also averaged the catch in “number of individuals” by month across the timeframe of 2006 to 2013. The catch in pounds by month was obtained by multiplying the “monthly average pounds per individual” by the “monthly average number of individuals.” The catch equation is shown below:

$$Swordfish\ catch_{month} = Average\left(\frac{pounds}{individual}\right)_{month} \times Average\ individuals_{\ month}$$

The monthly average catch calculation was based off of 234 entries in the logbook from 2006 to 2013. Stipulations regarding the use of logbook data in this analysis may be found in the Data Caveats section. From the timeframe of 2006 to 2013, there was catch data for the month of May (1.88 individuals caught); however, there was no average weight value for May. In order to fill in this data, we calculated the annual average pounds per individual and used this value as the average pounds per individual in May in order to calculate the swordfish catch in May. The swordfish catch in pounds was then converted to catch in metric tons. The individual swordfish weights in the catch calculation range from 80 pounds to 340 pounds, with a mean of 189 pounds and a standard deviation of 35 pounds.

Effort was recorded in “vessel days” in the logbook data. Therefore effort was obtained by averaging the vessel days by month from 2006 to 2013. Vessel days for harpoon include days where searching occurred but no swordfish were sighted.

The CPUE parameter for harpoon was thus calculated for each month by dividing the monthly catch in metric tons by the number of vessel days in each month. The CPUE parameter was calculated for the following months: January, May, June, July, August, September, October, November, and December. The CPUE equation is shown below:

$$Swordfish\ CPUE_{month} = \frac{Swordfish\ catch_{month}\ (mt)}{Effort_{month}\ (vessel\ days)}$$

2. Cost of fishing/effort

We calculated this parameter by dividing the total cost of fishing (2013 dollars) by the total effort (vessel days). The cost of fishing for harpoon was obtained from a Cost and Earnings Survey Report, which was conducted from 2008 to 2010 (Stohs 2010b). This report included both fixed and variable costs. Fixed costs included mooring (slip/berth) fees, fishing association membership dues, license fees, travel, office expenses, storage expense, county vessel, and berth taxes. Fixed costs were not included for any of the three gear types because the magnitude of the fixed costs were about equal – ranging from $150 to $450 – at which magnitude will not significantly affect the profit of each management scenario in the model.

Variable costs included fuel, bait, and gear and are consistent with harpoon and longline variable costs. The variable costs were provided as an average aggregated cost per set in 2009 dollars. This variable cost was calculated as an average across the timeframe from 2008 to 2010. We converted the variable cost in 2009 dollars to 2013 dollars using the Consumer Price Index (CPI) inflation calculator (CPI Inflation Calculator 2015). For harpoon, the variable cost of fishing per day in 2013 dollars is $254. Due to data availability for this parameter, we were unable to calculate this parameter at a monthly temporal resolution. Therefore, this variable cost value was used for each of the harpoon fishing months. The cost of using spotter planes to target swordfish is based off altering the revenue/catch parameter, which is explained in the next subsection.

Effort was recorded in “vessel days” in the logbook data (Childers 2015b). Therefore effort was obtained by averaging the vessel days by month from 2008 to 2010, in order to be consistent with the timeframe of the cost of fishing for harpoon.

The cost of fishing/effort parameter for harpoon was thus calculated for each month by dividing the cost of fishing in 2013 dollars by the number of vessel days in each month. The cost of fishing/effort parameter was calculated for the following months: January, May, June, July, August, September, October, November, and December. The cost of fishing/effort equation is shown below:

$$Cost\ of\ fishing/effort_{month} = \frac{Cost\ of\ fishing_{month}\ (2013\ dollars)}{Effort_{month}\ (vessel\ days)}$$

3. Revenue/catch

We calculated this parameter by dividing the revenue (2013 dollars) by the swordfish catch (mt). The average revenue was calculated by multiplying the average catch by the average price per pound. The average catch used in the revenue calculation was the same as detailed above in the CPUE parameter subsection, where the catch was averaged by month over the timeframe from 2006 to 2013. The average price per pound data was obtained from the SWFSC (Stohs 2015a). This price per pound value was based off HMS SAFE report data summaries regarding total swordfish revenues and total swordfish landings, averaged across the timeframe from 2001 to 2012. The HMS SAFE reports reported landings in round weights (in pounds); therefore, these weights were converted to landed weights (in pounds) by using a round weight to dressed weight conversion factor of 1.45 to account for all onboard processing of swordfish before it is landed. The average price per pound was given as an annual average in 2012 dollars from SWFSC. This price per pound was converted to 2013 dollars using the CPI inflation calculator (CPI Inflation Calculator 2015). Due to data availability, we were unable to calculate the average price per pound at a monthly temporal resolution. Therefore, the average price per pound value is the same for each of the harpoon fishing months in the revenue calculation. For harpoon, the average price per pound in 2013 dollars was $7.09.

The above detailed monthly average catch values in metric tons were converted to pounds. We then calculated revenue by multiplying the catch in pounds by the average price per pound to obtain the revenue in 2013 dollars. The revenue equation is shown below:

$$Revenue_{month} = Average\ catch_{month}\ (lbs.) \times average\ \frac{price}{lb.}\ (2013\ dollars)$$

The revenue/catch parameter for drift gillnet was thus calculated for each month by dividing the revenue in 2013 dollars by the swordfish catch in metric tons – as calculated above in the CPUE subsection – for each month, based off averaging across the timeframe from 2006 to 2013. We calculated the revenue/catch parameter for the following months: January, May, June, July, August, September, October, November, and December. The revenue/catch equation is shown below:

$$Revenue/catch_{month} = \frac{Revenue\ (2013\ dollars)}{Swordfish\ catch\ (mt)}$$

About 20% of the harpoon effort utilized spotter planes to target swordfish. The use of spotter planes results in an added cost of fishing/effort. We incorporated this added cost of fishing/effort based on expert knowledge that harpooners pay for the use of a spotter plane by contributing 50% of their catch revenues. For the harpoon catch that used a spotter plane, we divided this catch in half and then calculated a new revenue value to represent the revenue that the fishers retained after paying for the use of the spotter plane. We then calculated the difference in revenue between revenue resulting from the use of a spotter plane and revenue resulting from no use of a spotter plane. This difference in revenue was divided by the average vessel days per month to obtain the average added cost of fishing/effort by month for the use of a spotter plane. These monthly values are then added to the monthly cost of fishing/effort of $254.38 for harpoon. For example, the average cost of using a spotter plane in July was $117.74. Therefore, the cost of fishing/effort for July was $254.38 plus $117.74, which equals $372.12.

4. BPUE

It is assumed that HPN has no bycatch; therefore, there was no BPUE parameter for HPN.

Table 3 depicts all three harpoon monthly average parameters, units, and the timeframe over which each parameter was averaged.

Table 3. Harpoon monthly average parameters.

Parameter	Units	Timeframe
Catch per Unit Effort (CPUE)	Metric tons/vessel day	2006-2013
Cost of fishing/effort	2013 dollars/vessel day	2008-2010
Revenue/catch	2013 dollars/vessel day	2006-2013

Longline

The model input parameters for longline[5] were calculated for two areas – both inside and outside EEZ off the coast of California, as follows:

1. Swordfish CPUE

We calculated this parameter by dividing the total swordfish catch (metric tons) by the total effort (vessel days). Both catch and effort data were obtained from the Pacific Islands Fisheries Science Center (PIFSC) (Jantz 2015). The Hawaiian longline fleet that operates outside the EZZ and lands swordfish to California has 100% observer coverage for the timeframe from 2006 to 2014. The year 2007 was excluded from this analysis because no data for 2007 were included within the PIFSC dataset. The year 2014 was also excluded in order to be consistent with the timeframe used for the effort calculation.

We used landings data, which included every species brought on the vessel (bycatch species and market species) during fishing operations. Therefore, all species of fish, shark, sea turtles, seabirds and marine mammals were included in this data. The data also included the trip identification code, the time of the "haul in," or when the fishing set was brought onboard the vessel, and the port of arrival. Data indicating the day, month and year, and begin and end hauling time identified the set when an individual swordfish was captured. The number of hooks was provided for each set. Individuals were coded as "kept" or "returned", and "alive" or "dead". In order maintain consistency of CPUE calculations across gear types, only "kept" swordfish were included in our analysis, as these are the swordfish landed, brought to port, and sold in the market. Observers measured every third swordfish in accordance with reporting regulations; therefore, about two thirds of the swordfish length data was not provided in the data. Length measurement procedures varied across individuals, and our analysis only considered "eye to fork" (EF) and "out of protocol eye to fork" (OEF)[6] length measurements, which are lengths in centimeters. "Approximate length in feet" (AL) measurements were also included in the PIFSC data; however, these measurements were excluded from our analysis because the dressed weight values once converted were small and inconsistent in comparison to the EF and OEF converted dressed weights. A total of 90 out of 7,000 AL swordfish length measurements were excluded across the timeframe from 2006 to 2013. In order to calculate the dressed weight of the individuals, the following length-weight conversion was used (Western and Central Pacific Fisheries Commission 2014):

$$Dressed\ weight\ (kg) = (1.37 \times 10^{-5}) \times EF\ of\ OEF\ Length\ (cm)^{3.04}$$

We performed bootstrapping to assign weight values to the swordfish individuals that were not measured by observers. The dressed weight was converted from kilograms to metric tons by multiplying by 0.001.

Total swordfish catch in metric tons was calculated by month across the entire timeframe from 2006 to 2013 (excluding 2007). We calculated the total number of hooks per month and divided by the average number of hooks per set across the entire timeframe in order to calculate the number of sets per month from 2006 to 2013. It was assumed that one

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[5] The longline gear type refers to shallow-set longline, meaning a longline with set buoys less than 15 feet deep.

[6] Out of protocol eye to fork length measurements are when observers take a length measurement for a fish that is not for the protocol of every third fish (meaning it may be the "first" or "second" fish in the series of every third fish.

longline set is equivalent to one longline vessel day. Finally, CPUE was calculated by dividing the total swordfish catch by the total number of vessel days for each month. The values for this parameter were the same for both inside and outside the EEZ. We calculated the CPUE parameter for the following months: January, February, March, April, September, October, November, and December. The CPUE equation is shown below:

$$Swordfish\ CPUE_{month} = \frac{Swordfish\ catch_{month}\ (mt)}{Effort_{month}\ (vessel\ days)}$$

2. Cost of fishing/effort

Inside the EEZ

We calculated this parameter by dividing the total cost of fishing (2013 dollars) by the total effort (vessel days). The cost of fishing for longline was calculated as an average across the timeframe from 2009 to 2014 (confidential data). Fixed costs were not included for any of the three gear types because the magnitude of the fixed costs were about equal – ranging from $150 to $450 – at which magnitude will not significantly affect the profit of each management scenario in the model. Variable costs included fuel, bait, and gear and are consistent with drift gillnet and harpoon variable costs. Observer costs were not included in this parameter because currently NMFS funds a proportion of observer coverage for the longline fishery (WPRFMC 2010).

The data indicated depart and return dates, and total number of days per trip. Fishing operations inside the EZZ included three days of transit or travel time. This travel time was not included in the calculation for cost of fishing in order to be consistent with calculations for drift gillnet and harpoon, which only accounted for days fished and not traveled. Days fished were assumed to be equivalent to vessel days. For some of the trips, fishing days included days with two different months in the same trip. We divided the total trip cost by the fishing days per each month. For example, if fishing occurred between January and February, the respective fishing days cost was allocated for each month. There were no individual fishing trips that allocated fishing days between different years. The sum of the cost for each month by year was calculated and then divided by the total of fishing days for the same month. Finally, we calculated the average cost for each month across the timeframe of 2009 to 2014 to obtain the cost of fishing/effort for longline inside the EEZ. The cost of fishing/effort parameter was calculated for the following months: January, February, March, April, September, October, November, and December. The cost of fishing/effort equation is shown below:

$$Cost\ of\ fishing/effort_{month} = \frac{Cost\ of\ fishing_{month}\ (2013\ dollars)}{Effort_{month}\ (vessel\ days)}$$

Outside the EEZ

We calculated this parameter by dividing the total cost of fishing (2013 dollars) by the total effort (vessel days). The cost of fishing for longline was obtained from the PIFSC (Pan 2015). Cost data was differentiated by landings to Hawaii or landings to California; therefore, cost data for landings to California were used to calculate the cost of fishing outside of the EEZ.

Fixed costs included mooring fees, bookkeeping fees, insurance, dry dock and engine overhaul, major repair and routine repair, and loan payments (which do not account for depreciation of the fishing vessel). Fixed costs were not included for any of the three gear types because the magnitude of the fixed costs were about equal – ranging from $150 to $450 – therefore, including fixed costs would not significantly affect the profit of each management scenario in the model. Observer costs were not included in this parameter because currently NMFS funds a proportion of observer coverage for the longline fishery (WPRFMC 2010).

Variable costs included fuel, oil, ice, bait, fishing gear, equipment resupply (trip base), provisions, communication, and lightsticks. These variable costs were consistent with drift gillnet and harpoon variable costs. The variable costs were provided as an average aggregated total trip cost per trip by month in 2013 dollars. This cost value was provided as a weighted average. The days fished per month was also provided.

The cost of fishing/effort parameter for longline outside the EEZ was thus calculated for each month by dividing the total trip cost per trip in 2013 dollars by the number of days fished in each month. This resulted in the total trip cost per fishing days, where a fishing day is assumed to be equivalent to a vessel day because it does not include travel days. The cost of fishing/effort parameter was calculated for the following months: January, February, March, April, September, October, November, and December. The cost of fishing/effort equation is shown below:

$$Cost\ of\ fishing/effort_{month} = \frac{Trip\ cost\ per\ trip_{month}\ (2013\ dollars)}{Days\ fished_{month}\ (vessel\ days)}$$

3. Revenue/catch

We calculated this parameter by dividing the revenue (2013 dollars) by the swordfish catch (mt). Revenue for the Hawaiian longline fishery was obtained from the West Coast PacFIN landings data (Stohs 2015b). Revenue data was aggregated by month for landings to the California from 2006 to 2013. Data only includes months when there were 3 or more vessels in order to maintain with the “Rule of 3” for the release of confidential data. Revenue values were adjusted to 2013 dollars using the Implicit Price Deflator for GDP. One observer trip was omitted due to no reported swordfish landings or revenues, which was assumed to be a deep-set longline tuna trip. The monthly aggregated revenue values were divided by 8 in order to obtain the average monthly revenue value that a one year average across the timeframe from 2006 to 2013.

The average catch used in the revenue/catch calculation was the same as detailed above in the CPUE parameter subsection, where the catch was averaged by month over the timeframe from 2006 to 2013. We obtained catch data from the Pacific Islands Fisheries Science Center (PIFSC) landings data. There was catch data for September; however, there was no revenue value for September in the PacFIN data. The October catch was approximately 10 times larger than the September catch; therefore, in order to not exclude catch data, we assumed that September revenues were 10 times lower than in October to fill the data gap.

We thus calculated the revenue/catch parameter for longline for each month by dividing the revenue in 2013 dollars by the swordfish catch in metric tons – as calculated above in the CPUE subsection – for each month, based off averaging across the timeframe from 2006 to 2013. The values for this parameter were the same for both inside and outside the EEZ. The revenue/catch parameter was calculated for the following months: January, February, March, April, September, October, November, and December. The revenue/catch equation is shown below:

$$Revenue/catch_{month} = \frac{Revenue\ (2013\ dollars)}{Swordfish\ catch\ (mt)}$$

4. BPUE

We calculated this parameter by dividing the total bycatch (number of individuals) by the total effort (vessel days). BPUE was calculated for the following four species of concern: humpback whale, sperm whale, leatherback sea turtle, and loggerhead sea turtle. We obtained these data from the PIFSC observer data (Jantz 2015). We calculated average numbers of individuals across the timeframe from 2006 to 2013 (excluding 2007) and divided by the average fishing effort in vessel days, as described and calculated in the CPUE section. The values for this parameter were the same for both inside and outside the EEZ. The BPUE parameter was calculated for the following months: January, February, March, April, September, October, November, and December. The BPUE equation is shown below:

$$BPUE_{species\ (sp.)} = \frac{Bycatch_{sp.,month}\ (individuals)}{Effort_{sp.,month}\ (vessel\ days)}$$

Table 4 depicts all four longline monthly average parameters, units, and the timeframe over which each parameter was averaged.

Table 4. Longline monthly average parameters.

Parameter	Units	Timeframe
Catch per Unit Effort (CPUE)	Metric tons/vessel day	2006-2013
Cost of fishing/effort	2013 dollars/vessel day	2009-2014 (inside) 2006-2013 (outside)
Revenue/catch	2013 dollars/vessel day	2006-2013
Bycatch per Unit Effort (BPUE) ▪ **Loggerhead sea turtle** ▪ **Leatherback sea turtle** ▪ **Sperm whale** ▪ **Humpback whale**	Individuals/vessel day	2001-2013

Table 5 depicts the annual average swordfish CPUE and BPUE for loggerhead and leatherback turtles and sperm and humpback whales for drift gillnet, longline, and harpoon, including units.

Table 5. Annual average swordfish CPUE, loggerhead BPUE, leatherback BPUE, sperm whale BPUE, and humpback whale BPUE values for drift gillnet, longline, and harpoon.

Parameter	Drift gillnet	Longline	Harpoon
Swordfish CPUE (mt/vessel day)	0.17748	0.65361	0.11361
Loggerhead Turtle BPUE (individuals/vessel day)	0.00269	0.02107	0
Leatherback Turtle BPUE (individuals/vessel day)	0.00260	0.00704	0
Sperm Whale BPUE (individuals/vessel day)	0.00047	0	0
Humpback Whale BPUE (individuals/vessel day)	0.00004	0.00037	0

Model Framework

This section explains the methods for the model framework.

As motivation for our analysis and model framework, we first conducted a cost-benefit analysis (CBA) that explored the tradeoffs between 3 management scenarios of different fleet compositions in order to determine which scenario resulted in the greatest fleetwide profits, as indicated by a larger benefit-cost (B/C) ratio and/or net present value (NPV) (Appendix L for complete CBA description). The 3 scenarios were: (1) a fleet comprised of all drift gillnet vessels (100% drift gillnet), (2) a fleet comprised of all longline vessels (100% longline), and (3) a fleet composed of both drift gillnet and longline vessels (50% drift gillnet and 50% longline). Our CBA informed our model framework, particularly with respect to the management scenarios that explored the reincorporation of longline or the scenarios that were composed of a mixed fleet portfolio.

The four model input parameters – CPUE, cost of fishing/effort, revenue/catch, and BPUE – that we calculated as monthly averages for each of the three gear types – drift gillnet, harpoon, and longline – were entered into the model as monthly constants for each gear type. It is important to note that longline parameters were calculated for both inside and outside of the EEZ; therefore, longline had a second set of constant parameters. Two spatial strata for longline – inside and outside the EEZ off of California – were incorporated in the model in order to explore the viability of re-incorporating LL into the California swordfish fishery.

Monthly temporal resolution of parameters were important because swordfish catch varies throughout the year, due in part to management decisions (drift gillnet is permitted from August 15 to January 31 during non-El Niño years), and to the highly migratory nature of the swordfish stock (swordfish are more abundant in certain areas in during certain times of the year). A model that incorporates monthly temporal resolution will more precisely capture the variability of catch and bycatch in the California swordfish fishery; thus informing higher accuracy in model outputs. It is important to note that data for the 4 parameters were obtained at various temporal resolutions due to data limitations and availability; therefore, certain parameters – such as drift gillnet and harpoon cost of fishing per unit effort – were the same for each month.

Each gear type also had a constant effort proportion for each month – meaning each gear type had a constant amount of fishing effort that the model incorporates in the total effort calculation for each month. Effort varied significantly throughout the year; therefore, it was important to calculate these constants at a monthly temporal resolution. For each gear type, the effort proportion values were calculated by dividing the average number of vessel days in that month by the total number of vessel days in that year. For drift gillnet, we calculated the effort proportion as monthly averages across the timeframe from 2006 to 2011. For harpoon, we calculated the effort proportion as monthly averages across the timeframe from 2006 to 2013. For longline, we calculated the effort proportion as monthly averages across the timeframe from 2006 to 2013. We also calculated the status quo vessel days as the total annual vessel days per gear type: 760 vessel days for drift gillnet, 469 vessel days for harpoon, and 247 vessel days for longline[7]. We ran the model with harpoon effort constant at the status quo effort level and changed effort allocations between drift gillnet and longline. The model explored different allocations of vessel days among drift gillnet and longline, while maintaining harpoon effort constant at the status quo effort level. The model considered harpoon as a recreational gear type rather than a commercial gear type because of the relatively low swordfish catch and fleetwide profit compared to drift gillnet and longline.

The model explored 36 different management scenarios grouped into 4 management scenario categories: (1) status quo, (2) 100% effort for the three gear types, (3) longline transferred to drift gillnet, and (4) drift gillnet transferred to longline with harpoon (Appendix J). The same 36 management scenarios were repeated and calculated based on decreasing the drift gillnet and longline effort by 25%, 50%, and 75%, and increasing the drift gillnet and longline effort by 25%, 50%, and 75%.

To simulate a harpoon niche-market saturation scenario with a total swordfish catch of approximately 204 mt based on the maximum historical catch since 1981, the harpoon effort was increased from 463 vessel days in the status quo to 1,845 vessel days when all drift gillnet and longline effort is transferred to harpoon. This harpoon effort accounted for a 290% increase in harpoon effort from the status quo. This management scenario represented a 25% increase in total effort from the status quo.

For each management scenario, the model calculated the effort (vessel days) per month per gear type (and per spatial area for longline). We calculated the effort by multiplying the constant effort proportion per month and gear type by the total number of vessel days per gear type. The effort per month and gear type was used to calculate the model outputs for each scenario.

Uncertainty Analysis

Swordfish catch and bycatch rates (leatherback and loggerhead sea turtle, and humpback and sperm whale) varied between months and across years as a result of changes in environmental conditions or other dynamic and complex behaviors. A sensitivity analysis was therefore incorporated into our model to account for uncertainty in the swordfish CPUE and the four BPUE parameters, which were calculated as monthly averages for both drift gillnet and longline gear types.

Uncertainty was incorporated into the four BPUE parameters by modeling a two-step random process that first determined whether a bycatch event occurred, and then selected the number of individuals caught if a bycatch event occurred. The occurrence of a bycatch event was assumed to follow a Bernoulli process with the probability of occurrence equal to the monthly probability that bycatch occurred. This was calculated for both drift gillnet and longline by dividing the total number of months in which a bycatch event occurred by the total number of active fishing months for that gear type across the entire time frame (2001-2011 for drift gillnet and 2006-2013 for longline). The distribution of the number of individuals caught conditional upon a bycatch event occurring was taken to be lognormal, with the mean and variance determined by the historical number of individuals caught in months during which bycatch was observed.

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[7] The status quo longline vessel days were calculated from the annual average vessel days of Hawaii longline vessels that land swordfish to California ports.

The number of individuals caught was converted to a BPUE by dividing by the average number of vessel days for the gear type in that month.

Uncertainty was also incorporated into the swordfish CPUE parameter for each active fishing month. A monthly CPUE value was drawn from a uniform distribution spanning a standard deviation both below and above the mean CPUE for the given month and gear type across the entire time frame.

A macro was developed to draw 500 random values for the swordfish CPUE parameter and the four BPUE parameters for each gear. The macro then calculated swordfish catch, fleetwide profits, and the total number of individuals caught for each bycatch species for each of the 500 runs. The average swordfish catch, profit and the average number of bycatch species were calculated across the 500 runs.

Model Outputs

The model has three outputs: total swordfish catch, total fleetwide profit, and total bycatch in individuals (for loggerhead sea turtles, leatherback sea turtles, sperm whales, and humpback whales) for each management scenario. We calculated the outputs at a monthly temporal resolution (and inside and outside the EEZ for longline), similar to the input parameters calculations. However, we focused our analysis on the annual values of the model outputs.

For each scenario, the total annual swordfish catch was calculated using the following equation:

$$\boldsymbol{Annual\ Catch} = \sum_{months} \frac{Catch}{Effort} \times \frac{Effort}{Month}$$

For each scenario, the total annual profit was calculated using the following equation:

$$\boldsymbol{Annual\ Profit} = \sum_{months} \left(\frac{Catch}{Month} \times \frac{Revenue}{Catch}\right) - \left(\frac{Effort}{Month} \times \frac{Cost\ of\ Fishing}{Effort}\right)$$

Because revenue/catch was calculated based only on the amount of swordfish caught (in metric tons), it was important to incorporate the additional revenue from other market species caught by both drift gillnet and longline[8]. For drift gillnet, we incorporated revenue from the following other market species: “Common thresher shark”, “non-highly migratory species (HMS) FMP sharks”, “Shortfin mako shark”, and “tunas”. We used the PacFIN data (Stohs 2015b) to calculate the average annual revenue for these market species over the timeframe from 2006 to 2013, which was 193,130 U.S. dollars. For longline, we incorporated revenue from the following groups of species: “tuna”, “other HMS species”, and “other species.” We used the Hawaii shallow-set longline revenue data (Pan 2015) to calculate the average annual revenue over the timeframe from 2006 to 2013, which was 37,378 dollars.

[8] Data used for harpoon fishers was for targeting swordfish only; therefore additional revenue for other market species is not applicable for harpoon.

The revenue from the other market species for drift gillnet and longline were added to the profit output for each of the scenarios, incorporating the different percentages of effort with the revenue. For example, when 25% of drift gillnet was transferred to longline, then:

$$Total\ profit\ (including\ other\ market\ species) = Profit\ output + \$193{,}130 \times .25 + \$37{,}378$$

For each scenario, the total annual bycatch was calculated using the following equation:

$$\boldsymbol{Annual\ Bycatch} = \sum_{months} \left(\frac{Bycatch}{Effort}\right) \times \frac{Effort}{Month}$$

The annual bycatch was calculated for each of the four bycatch species of concern. All calculations used the following units: swordfish catch (metric tons); effort (vessel days); revenue (2013 dollars); cost of fishing (2013 dollars); profit (2013 dollars); and bycatch (number of individuals).

Model Assumptions

Our model had the following assumptions:

- Assumed 20% observer coverage for drift gillnet was characteristic of the entire drift gillnet fleet's BPUE. (See Data Caveats for methods determining if and how the 20% observer coverage for drift gillnet was assumed to be characteristic of the entire drift gillnet fleet).
    - Harpoon was assumed to have no bycatch. It is important to note that all longline data has 100% observer coverage. Therefore, it was important to determine if the 20% observer coverage for drift gillnet was characteristic of the entire drift gillnet fleet's BPUE in order normalize the bycatch calculations across gear types.
- The Hawaii longline landings to California ports represented the potential California longline fleet outside the EEZ.[9]
    - The CPUE, revenue/catch, and BPUE parameters for inside and outside of the EEZ were the same.
    - The cost of fishing/effort parameter for inside and outside of the EEZ was different because of the difference in fuel costs, as fishing outside of the EEZ requires more fuel compared to fishing inside the EEZ.
- Bycatch species were considered to be any non-market, protected species that was incidentally caught.
    - For our analysis, the bycatch species included: leatherback and loggerhead sea turtles, and humpback and sperm whales.

[9] Because there was not sufficient data for longline fishing outside of the EEZ off the coast of California, Hawaii longline data was used in this analysis. Using Hawaii longline landings to California ports, rather than to Hawaii ports was more representative of a potential California longline fleet due to differences in oceanographic conditions. The Hawaii longline fleet that landed swordfish to California ports fish immediately outside the EEZ off California, closer to California Current waters. Swordfish caught inside the EEZ off Hawaii and landed to Hawaii ports occur in the North Equatorial Current (MarineBio 2015). As oceanographic conditions may influence swordfish behavior and bycatch migration patterns (Block 2011), we assumed Hawaii longline data for swordfish landed to California ports was more representative of a potential California longline fleet that lands swordfish, as well as the bycatch interactions that are associated with this fishing fleet.

- The fishing season for each gear type was solely based on when there were data present for each month and averaged over the specified timeframe.
- Data received as a subset or sample of the entire fleet were assumed to be representative of the entire fleet.
- Bycatch hard caps were analyzed over a one year timeframe.
- To compare effort across the three gear types, vessel days were used for the unit of effort; therefore, we assumed that one harpoon vessel day is equivalent to one drift gillnet vessel day, which is equivalent to one longline vessel day.
    - One longline set and one drift gillnet set occurred overnight and for about the same number of hours.
    - The average number of longline hooks per set was incorporated in order to normalize a longline set or vessel day.
    - Vessel days are the days actively targeting swordfish; therefore travel days are not included.
    - Vessel days for harpoon included days where searching occurred but no fish were sighted.
- The Pacific swordfish fishery is a healthy stock.
- The model assumed a multiple gear bycatch cap in that there were the same hard caps for the entire swordfish fleet even with the addition of longline gear type.
- Bycatch hard caps were based on takes or interactions, not mortality or serious injury.

Data Caveats

The following caveats regarding data used in our analysis were:

Determining if 20% drift gillnet observer coverage was representative of the entire drift gillnet fleet

Both logbook data and the observer record were required to calculate the drift gillnet parameters in the model. This was because the logbook data for drift gillnet did not include catch information for protected species (because interactions with non-market species are rarely reported in logbooks). The observer record was needed to calculate the BPUE parameter for drift gillnet. Because the observer record had a range of 12-20% observer coverage over the time period being considered in this analysis, we needed to determine if the 12-20% observer coverage was representative of the entire fleet and if not, a method to calculate a reasonable average BPUE from the observer record. It is important to note that by performing an uncertainty analysis, we tested the sensitivity of this calculation with regards to the BPUE parameter.

To determine if the observer record was representative of the entire drift gillnet fleet, we compared every month for every year from 2006 to 2011 (the years used for the drift gillnet calculations) in the drift gillnet logbook data with the drift gillnet observer record. Ultimately, we wanted to determine if an observer was present for every month in every year considered in this analysis because if so, it would not be necessary to calculate a reasonable average BPUE in order to fill in any discrepancies between the logbook data and the observer record.

By comparing the drift gillnet logbook with the observer record, we found that there were months in which no observers were present but when swordfish were caught. Table 6 highlights these months.

Table 6. Months in which there was no record of any event for bycatch species (green), months in which observers were present, and months in which observers were present but swordfish were caught (grey).

Year	Months
2006	1,6,7,8,9,10,11,12
2007	1,3,6,7,8,9,10,11,12
2008	1,2,4,5,8,9,10,11,12
2009	1,2,3,8,9,10,11,12
2010	1,3,6,8,9,10,11,12
2011	1,8,9,10,11,12

In Table 6, the months in green represent no record of any event for bycatch species during that month; these were filled in as 0 for the BPUE. The months that are not highlighted represent months when observers were present as indicated in the observer record. The months in grey, which are only for the month of August, represent the months when no observers were present but when swordfish were landed. In order to fill in data for these 3 August months, we calculated an average BPUE for each of the bycatch species based on a three month range (averaging the BPUE from July through September and using this value for the August BPUE). We performed this calculation for the 3 August months, rather than extrapolating the BPUE to represent 100% observer coverage as we determined this to be a more reasonable method for the timeframe of our analysis. Furthermore, we tested the sensitivity of the BPUE parameter in our model by performing an uncertainty analysis.

Using the logbook database instead of the landings database for drift gillnet and harpoon catch and effort data to calculate CPUE and BPUE parameters

In Hawaii, landings data referred to everything brought onto the vessel including market species, turtles, other protected species, etc. In California, landings data referred *only* market species that were brought and sold at port. Drift gillnet and harpoon logbook data were self-reported data and there was no modification factor to account for the percentage of unreported fish caught. Therefore, accuracy of these data was uncertain, and we took the data at face value. The logbook data for drift gillnet was used in this analysis instead of the landings data because the landings data did not have any effort associated with the total swordfish catch, and our analysis required data where total effort can be related to total swordfish caught. To be consistent with total catch associated with the total effort used to actually catch swordfish, we had to use logbook data as it would be inaccurate to compute the swordfish catch from the landings data and to compute the effort from the logbook data.

Comparing drift gillnet and harpoon logbook data with longline landings data

There is an implicit difference in accuracy between the California drift gillnet and harpoon logbook data and the Hawaii longline landings data because the former was self-reported and the latter had 100% observer coverage. In order to account for the known differences between the drift gillnet and harpoon logbook data and the Hawaii longline landings data, we included within the analysis only the swordfish that were kept and actually brought to port (landed). Therefore, in the Hawaii longline landings data, only the swordfish coded as “kept” were included in this analysis. No adjustments were needed for the drift gillnet and harpoon logbook data because only swordfish that were brought to port were included in this data. The Hawaii longline landings data included all catch and bycatch information within the same database (unlike drift gillnet) and the fishery had 100% observer coverage; therefore no calculations were performed in regards to the longline bycatch.

Harpoon Caveats

The California harpoon swordfish fishery was considered a recreational gear type in the model because of the relatively low swordfish catch and fleetwide profit compared to drift gillnet and longline. Because of data limitations, the harpoon fishery in the model had the following caveats:

1. *Discrepancy in profit:* The profit model outputs differed from the HMS SAFE report summaries for the California harpoon fishery. The current analysis calculated a positive profit for the harpoon fishery from the time period 2006 – 2013, while the HMS SAFE reports found a negative profit. The discrepancy in profits could be explained by any one of the following:

    A. The current study calculated profits based on catch rates and average swordfish weights reported in trip logs from 2006 – 2013 and a price per pound of $7.09 averaged over the 2001 – 2012 period. As a result, this may have had an upward bias in the profit calculation due to matching costs from 2008 – 2010 to revenues representative of a longer time period. The HMS SAFE report was based on the costs and revenues reported in the survey, which may have been downwardly biased because of the poor swordfish fishing conditions in most recent years.
    B. The HMS SAFE report incorporated both fixed and variable costs to estimate annual profits per vessel while the model included only variable costs to estimate annual profits per vessel.
    C. Overall, the differences in profit between the model output and the HMS SAFE reports were due to different types of data representative of different time periods.

2. *Matching of costs to revenues:* The revenue used in the analysis was averaged over a longer time period than the cost data because there were no cost data for the entire period.
3. *Linearity assumption:* Assuming linearity in profits may only be reasonable when the increase in effort or number of harpoon vessels is small. With a significantly large increase in harpoon effort compared to the status quo, there was a diminishing return to effort in profits because of the nonlinear change in revenues and costs on the margin.
4. *Revealed preference:* The recent harpoon effort is representative of harpoon fisher's choice for participating in this fishery because the fishery is an open access fishery. Thus, any significant increase in harpoon fishing effort is questionable. For example, after the California longline fishery shut down in 2004, there was no increase in harpoon effort and with the decrease in drift gillnet effort over the past couple of decades, harpoon effort did not significantly change.
5. *Economic profit considerations:* In our harpoon-saturation scenario, we did not consider the economic costs of harpoon fishery participation if drift gillnet was not an allowable gear type and if targeting swordfish was limited to harpoon only. If other fishing or non-fishing employment opportunities resulted in higher profits for the drift gillnet fishers, then it would not be feasible to induce over 100 fishers to participate in the harpoon-only fishery, as modeled in the harpoon-saturation scenario.
6. *Scalable profits assumption:* The model assumed that the profits were infinitely scalable which may be incorrect at significantly higher levels of harpoon effort compared to the status quo.

RESULTS

We conducted a cost-benefit analysis (CBA) to inform our model that explored the tradeoffs between 3 management scenarios of different fleet compositions in order to determine which scenario resulted in the greatest fleetwide profits, as indicated by a larger benefit-cost (B/C) ratio and/or net present value (NPV). The 3 scenarios were: (1) a fleet comprised of all drift gillnet vessels (100% drift gillnet), (2) a fleet comprised of all longline vessels (100% longline), and (3) a fleet composed of both drift gillnet and longline vessels (50% drift gillnet and 50% longline). Overall, our analysis demonstrated that both drift gillnet and longline are profitable under bycatch hard caps. Drift gillnet profits would likely decline in the future due to the projected decline in catch revenue, while longline profits would increase with projected revenue growth based on current and past fishing levels (See Appendix L for further details).

Within our model, we first analyzed an ideal scenario to increase domestic California swordfish supply and decrease reliance on foreign swordfish imports. Because previous studies showed a quantifiable market transfer effect of swordfish catch and bycatch when the Hawaii longline fishery closed from 2001 – 2004, we are assuming that an increase in domestic swordfish production will result in a decrease in imported swordfish by the same amount, assuming a constant demand for swordfish. We first analyzed whether swordfish catch, bycatch interactions, and profit varied temporally and then we modeled a range of management scenarios that resulted in different swordfish catch, profit, and bycatch for the four following species: leatherback and loggerhead sea turtles and sperm and humpback whales. These management scenarios, under different bycatch constraints, helped to answer the overarching question for how different combinations of effort and gear types increased swordfish catch and profit. The specific research questions in order of relevance were as follows:

1. Intra-annual variation in swordfish catch and bycatch interactions among gear types

A. Does swordfish catch vary within the year among gear types?

We wanted to understand the seasonal variation of the gear types to explore the possibility of having a swordfish fishery that operates year-round because consumers demand swordfish throughout the year. The analysis did not change the fishing seasons or the times of the year when fishermen fished using the three gear types based on the assumption that fishermen fish during times of the year when the swordfish are most abundant, and thus when the fishery is most profitable, under the constraints of the time and area closures of the fishery. However, the following results showed changes in magnitude of how much swordfish were caught for drift gillnet, longline, and harpoon each month (Figure 7). Drift gillnet had the highest swordfish catch between the months September to January, while harpoon caught the most swordfish in the summer months (July, August, and September), and longline caught the most swordfish over a longer monthly range compared to the other two gear types from October to March. The longline data used were from the Hawaii longline fleet for swordfish landings specifically to California ports.

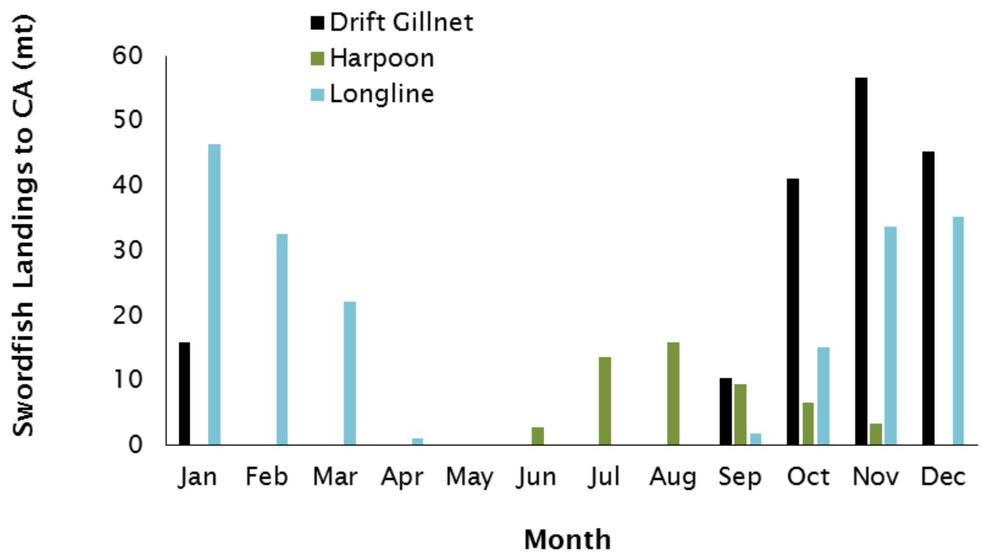


Figure 7. Swordfish catch varies within the year for drift gillnet, harpoon, and longline.

B. Do bycatch interactions vary within the year among gear types?

Historical bycatch for drift gillnet summed over the time frame from 2001 – 2013 varied slightly within the year with the only observed bycatch interactions occurring from August through December (Table 7). Our analysis considered the following four bycatch species of concern: humpback whale, sperm whale, leatherback sea turtle, and loggerhead sea turtle. Our analysis focused on these four species because they are federally listed as endangered under the ESA, and are known to be impacted by fisheries. These four species were the only endangered species that had recorded interactions with drift gillnet or longline fleets during the time period of our analysis. During that period, four observed turtle interactions or takes (2 loggerhead turtles and 2 leatherback turtles) and 3 whale interactions occurred (1 humpback whale and 2 sperm whales) with the drift gillnet gear type over the 13-year time period. Drift gillnet had an average of 18% +/- standard deviation of 3.5% observer coverage for bycatch over this time period.

Historical bycatch for longline summed over the time frame from 2006 – 2013 varied significantly within the year with observed bycatch interactions occurring from October through April, with the majority of the interactions (not necessarily mortalities) occurring from October to December (Table 8). The number of bycatch interactions appeared greater for longline than drift gillnet, likely because longline had 100% observer coverage. In total, 24 turtles (7 loggerhead and 17 leatherback turtles) and 1 humpback whale interactions occurred over the 8-year time period. The condition of the sea turtles and whale after interacting with the gear type is unknown.

Harpoon was assumed to have no bycatch interactions.

Table 7. Historical bycatch for drift gillnet from 2001 – 2013 with ~20% observer coverage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Loggerhead Turtle								1 (2001)		1 (2006)		
Leatherback Turtle									1 (2009)	1 (2012)		
Humpback Whale											1 (2004)	
Sperm Whale												2 (2010)

Table 8. Historical bycatch for longline from 2006 – 2013 with 100% observer coverage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Loggerhead Turtle	2 (2011)	1 (2013)		1 (2011)								1 (2010); 2 (2013)
Leatherback Turtle			1 (2011)							1 (2010); 2 (2011)	1 (2010); 2 (2011); 1 (2012); 2 (2013)	2 (2009); 1 (2010); 4 (2013)
Humpback Whale											1 (2011)	
Sperm Whale												

2. Does profit vary temporally and spatially by gear type?

A. Does profit vary within the year?

Profit varied within the year for all three gear types analyzed (Figure 8). Most of the profit generated by drift gillnet fishermen occurred from October through January, whereas harpoon was most profitable from June to November, and longline was most profitable from December through April. Drift gillnet showed a negative profit in August, while longline had a profit loss in October and November. The most profitable fishing months generally corresponded to the months with the highest swordfish catch because profit was a function of total catch (Figure 9). Discrepancies between profit and swordfish catch were apparent because profit included revenue from swordfish and other market fish species. The price of swordfish does not decrease with an increase in swordfish supply because the model assumes a constant price per pound of swordfish sold.

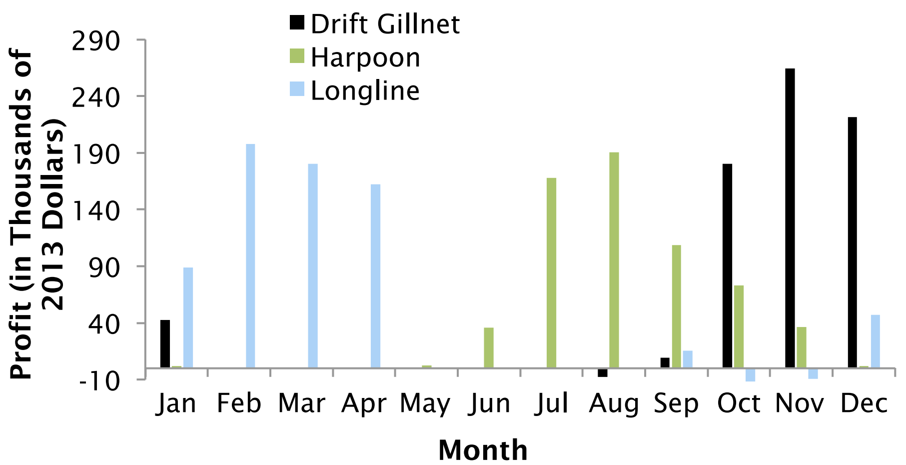


Figure 8. Profit varies within the year for drift gillnet, harpoon, and longline.

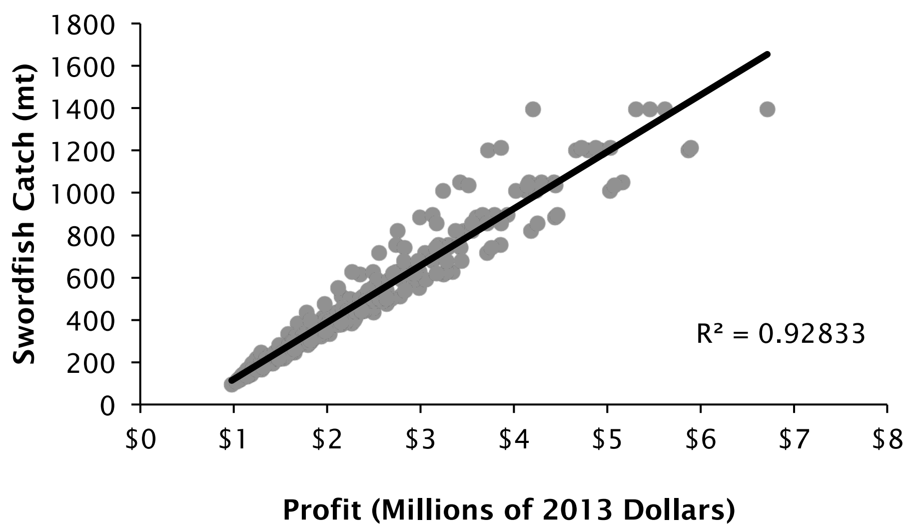


Figure 9. Profit and swordfish catch are positively correlated. Profit includes revenue generated from both swordfish and other market species catch.

B. Does profit vary spatially for longline?

The longline fishery inside of the EEZ had a higher profit than the longline fishery outside of the EEZ (Figure 10). This was likely because the longline fishery inside of the EEZ had lower fuel costs compared to fishing outside of the EEZ as the fishermen had to travel a shorter distance. The only difference in the data parameters used for the longline gear type was the cost of fishing/effort parameter. The CPUE, BPUE, and the revenue/catch parameters were the same for fishing inside and outside of the EEZ.

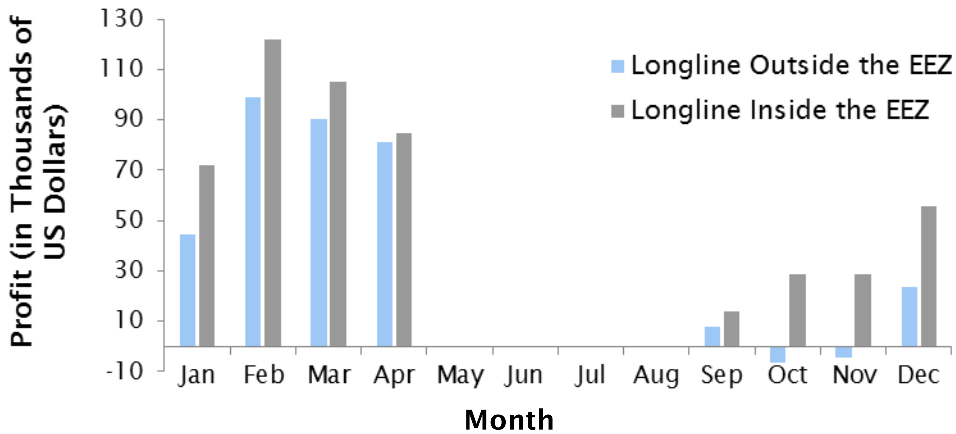


Figure 10. Profit varies spatially for longline fishing inside and outside of the EEZ.

3. How do different bycatch hard caps impact swordfish catch and fleetwide profit?

One major output from the model was 252 management scenarios composed of drift gillnet and longline with varying levels of effort and harpoon with a constant level of effort based on the average harpoon effort from 2006 - 2013. All possible management scenarios representing all four of the bycatch species as a function of profit is represented in Figure 11. The number of humpback and sperm whale interactions was significantly lower than loggerhead and leatherback turtle interactions. Thus, the main driver of the bycatch problem within the California swordfish fishery consisting of drift gillnet, harpoon, and/or longline was due to turtle interactions, not whale interactions. A management scenario with more longline effort than drift gillnet effort had a higher sea turtle bycatch rate than a management scenario with more drift gillnet effort because the turtle interaction rate is higher with longline. Loggerhead turtle interactions were generally greater than leatherback turtle interactions.

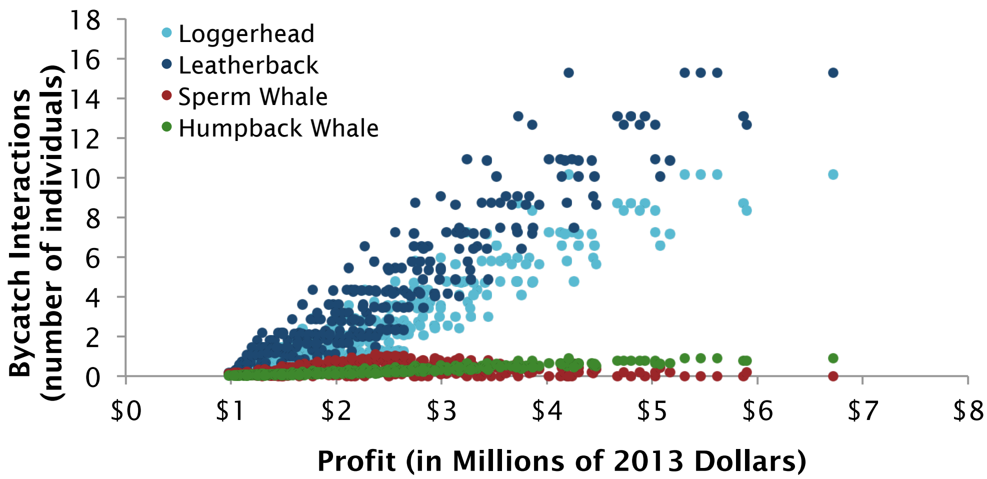


Figure 11. All possible management scenarios by bycatch species (individual interactions) as a function of profit (n = 252 scenarios).

The Pacific Fishery Management Council is considering setting hard caps for loggerhead and leatherback turtles and humpback and sperm whales (along with other species) based on the Incidental Take Statement (ITS) and the Biological Opinion 2013 (BiOp) (Table 11). The Council preferred bycatch hard cap levels are as follows: loggerhead sea turtle: 3; leatherback sea turtle: 3; sperm whale: 2; humpback whale: 2. Our analysis considered how fleetwide profit and swordfish catch varied with different bycatch constraints. Drift gillnet and longline have relatively low sea turtle and whale bycatch rates compared to other swordfish fisheries worldwide; however, among the bycatch interactions with drift gillnet and longline gear types, leatherback turtles have a relatively higher bycatch rate than loggerhead turtles and sperm and humpback whales. As a result of the relatively higher bycatch rate, the leatherback sea turtles hard cap of 3 individuals was reached before any of the other bycatch hard caps; thus, the number of leatherback turtles determined when the fishery shut down, and consequently the maximum fleetwide profit was attained in the model. Our analysis evaluated how fleetwide profit and swordfish catch changed by increasing and decreasing the leatherback hard cap by one individual.

Because the leatherback turtle hard cap was the limiting factor and the hard caps of loggerhead turtles and humpback and sperm whales were not exceeded, the remainder of the results only display the total number of leatherback interactions. All of the dots shown in Figure 12 are the total number of management scenarios that have a higher fleetwide profit than status quo and that do not exceed the hard cap of 4 leatherback turtles. With a leatherback hard cap of 4 individuals (dashed gray line), the number of potential management scenarios was reduced from 252 possible scenarios under no bycatch hard cap to 92 scenarios (Figure 12). The number of potential management scenarios is further reduced to 74 scenarios, and then 36 scenarios when the leatherback hard cap is decreased to 3 individuals (solid black line) and then to 2 individuals (dotted blue line), respectively.

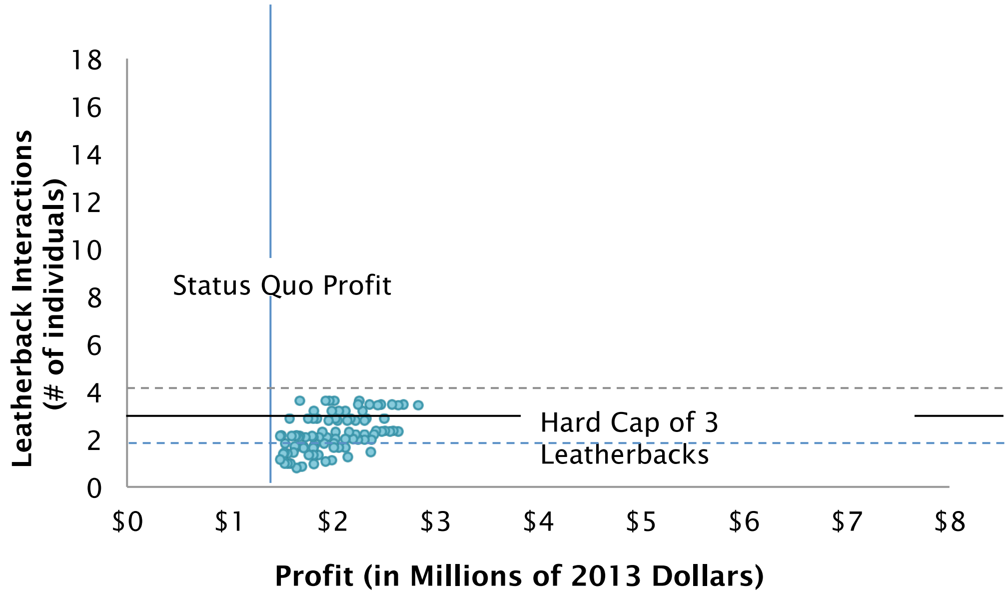


Figure 12. Management scenarios under the conservation constraint of a leatherback hard cap of 2, 3, and 4 individuals and the economic constraint of a fleetwide profit greater than the status quo.

By increasing the leatherback turtle bycatch constraint from 2 to 3 individuals, swordfish catch increased by 64 mt. By increasing the constraint from 3 to 4 individuals, swordfish catch increased by 35 mt (Figure 13). The fleetwide profits increased by $260,000 and $190,000 when increasing the leatherback bycatch constraint from 2 to 3 and then 3 to 4 individuals, respectively (Figure 13).

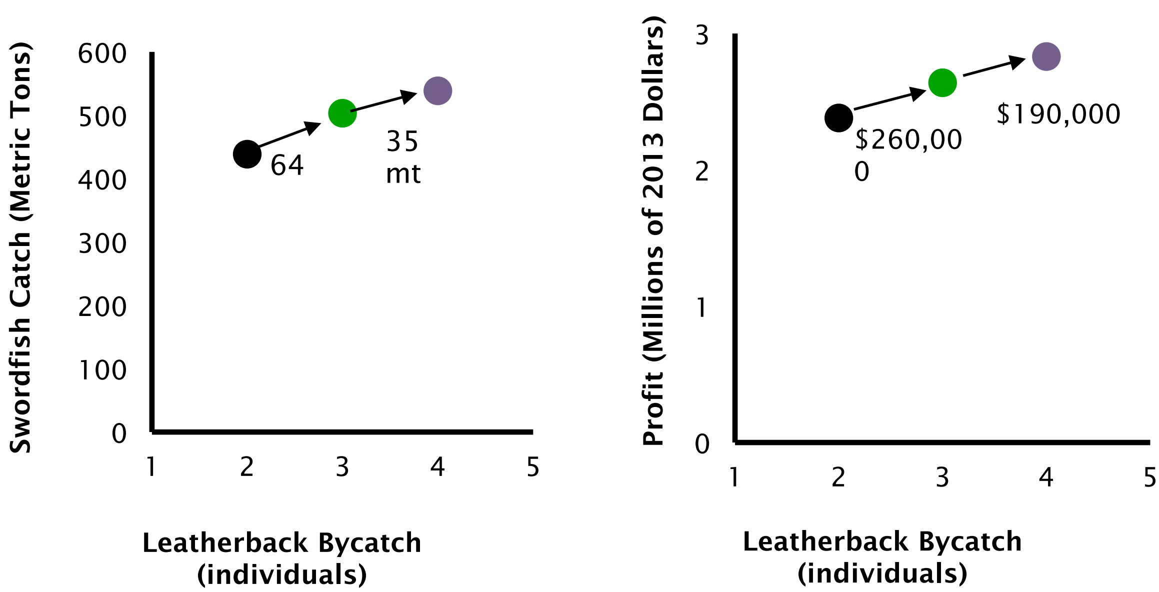


Figure 13. Quantified increases in swordfish catch (mt) and fleetwide profit (millions of 2013 dollars) for three different leatherback bycatch constraints: 2, 3, and 4 leatherback turtle individuals.

4. Which management scenarios increase the total swordfish catch and the total fleetwide profit under the bycatch hard cap?

Six of the most interesting management scenarios we further explored that did not exceed the Council-preferred hard cap of 3 leatherback turtles include: 1) status quo with constant drift gillnet and harpoon effort, 2) top profit and catch, 3) reincorporating longline with constant harpoon and drift gillnet effort, 4) increase harpoon effort to saturate the harpoon-caught swordfish niche market, 5) removal of drift gillnet permits while reincorporating longline and maintaining constant harpoon effort, and 6) activating drift gillnet latent permits (Table 9). The total fleetwide profit and the total bycatch interactions (which sum the interactions of the 4 bycatch species) varied with each of these six management scenarios (Figure 14).

Table 9. Six Gear Portfolio Recommendations to the Pacific Fishery Management Council[10].

Scenario Descriptions	Profit (in millions)	Total Bycatch Interactions	Total Fleet Swordfish Catch (mt)	Drift Gillnet Catch (mt)	Harpoon Catch (mt)	Longline Inside Catch (mt)	Longline Outside Catch (mt)	# of Drift Gillnet Vessels	# of Harpoon Vessels	# of Longline Vessels Inside	# of Longline Vessels Outside
Status Quo (simulated from 2006-2011)	$1.48	1.4	222	169	52	0	0	35	24	0	0
Top profit and catch under hard cap	$2.64	4.8	503	369	52	82	0	76	24	3	0
Reincorporating longline with constant harpoon and drift gillnet	$2.22	5.1	410	169	52	141	47	35	24	5	2
Increase harpoon to saturate market	$7.09	0	403	0	400	0	0	0	187	0	0
Removal of drift gillnet vessels with reintroduced longline	$1.50	3.8	244	0	52	108	84	0	24	4	3
Drift gillnet latent permits filled	$1.66	1.8	265	383	52	0	0	79	24	0	0

[10] Within our analysis, the average annual vessel days per vessel for drift gillnet was 21.75 vessel days; for harpoon was 19.50 vessel days, and for longline was 42.13 vessel days.

A visual representation of these six management scenarios is displayed in Figure 14, followed by individual descriptions of each scenario. Reincorporating longline with constant drift gillnet and harpoon effort has the greatest total number bycatch interactions, while harpoon had the least with zero bycatch interactions. The top profit and swordfish catch management scenario has the highest total fleetwide swordfish catch, while harpoon has the lowest. The management scenario that activates all of the drift gillnet latent permits represents a scenario that a has a higher total fleetwide swordfish catch compared to harpoon-only fishery, while a lower total bycatch interaction than a fishery reincorporating longline.

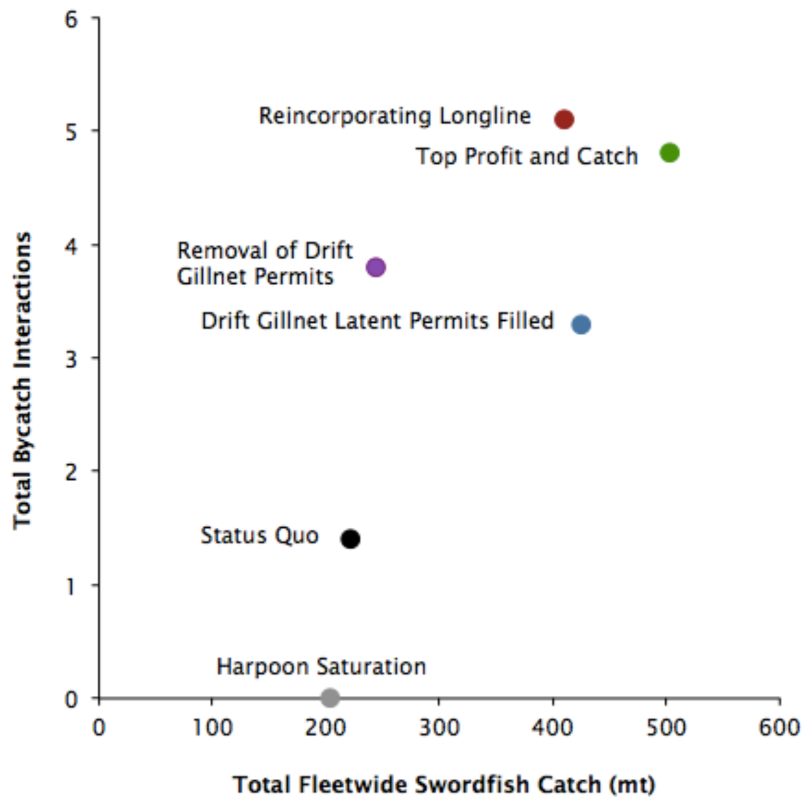


Figure 14. Six management scenarios with different gear portfolios result in different swordfish catch.

Top profit and swordfish catch under the bycatch hard cap

Compared to the status quo, the management scenario with the highest fleetwide profit and swordfish catch under the leatherback turtle hard cap of 3 individuals included the reintroduction of longline and increasing the drift gillnet effort by more than double (Figure 15). The total bycatch interactions more than doubled compared to the status quo, however.

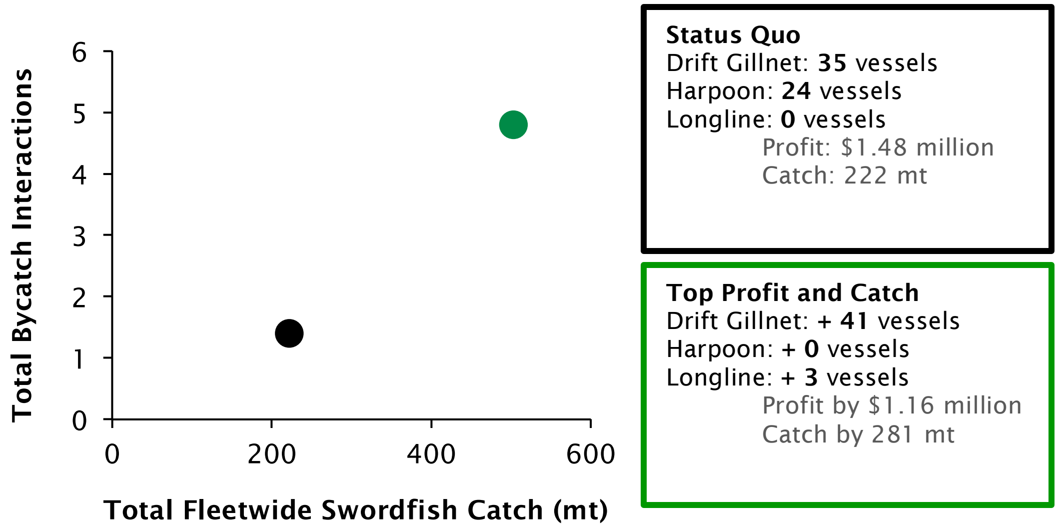


Figure 15. Comparison of the number of vessels, fleetwide profit, and swordfish catch for the management scenario with the highest fleetwide profit and swordfish catch and the status quo scenario under the leatherback hard cap of 3 individuals.

Reincorporating longline with constant harpoon and drift gillnet effort under the bycatch hard cap

Under the leatherback turtle hard cap of 3 individuals, reincorporating longline as an allowable gear type while maintaining a constant drift gillnet and harpoon effort increased the fleetwide profit compared to the status quo, which only had drift gillnet and harpoon (Figure 16). The total bycatch interactions more than doubled compared to the status quo, however.

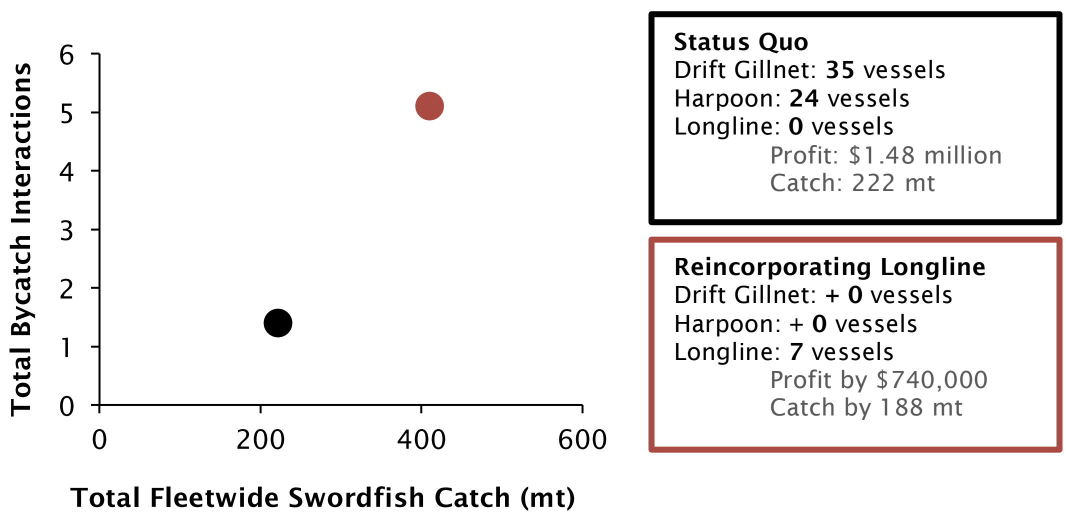


Figure 16. Comparison of the number of vessels, fleetwide profit, and swordfish catch for the management scenario that reincorporates longline keeping drift gillnet and harpoon effort constant and the status quo scenario under the leatherback hard cap of 3 individuals.

Increase harpoon to saturate the market

To explore the saturation of the harpoon-caught swordfish market, this management scenario modeled the maximum catch by the harpoon fleet since 1981, which was 204 mt (Figure 17). The total bycatch interactions decreased to zero because harpoon was assumed to have no observed bycatch interactions. The total swordfish catch decreased slightly compared to the status quo. This management scenario is important because harpoon-caught swordfish is a niche market, meaning a higher price is demanded for the luxury good because it is fresh and of higher quality compared to drift gillnet and longline-caught swordfish.

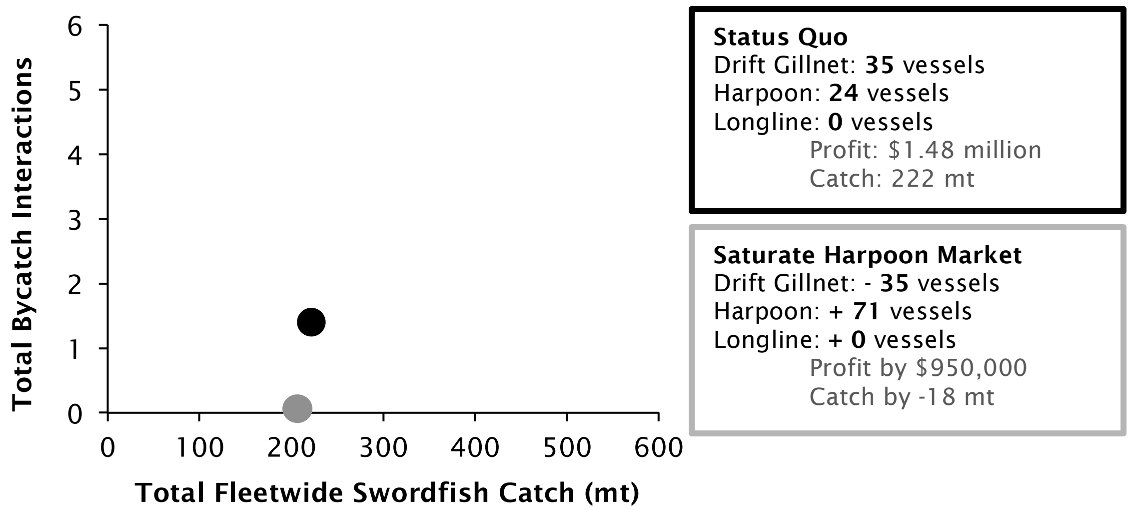


Figure 17. Comparison of the number of vessels, fleetwide profit, and swordfish catch for the management scenario that would saturate the harpoon-niche market and the status quo scenario under the leatherback hard cap of 3 individuals.

Removal of drift gillnet permits with reincorporated longline under the bycatch hard cap

Because the PFMC requested NMFS and CDFW to evaluate methods for reducing drift gillnet capacity, we included a management scenario that modeled the transfer of effort from the 16 active drift gillnet permits to the longline gear type (Figure 18). The total bycatch interactions roughly doubled and the total fleetwide swordfish catch increased slightly compared to the status quo.

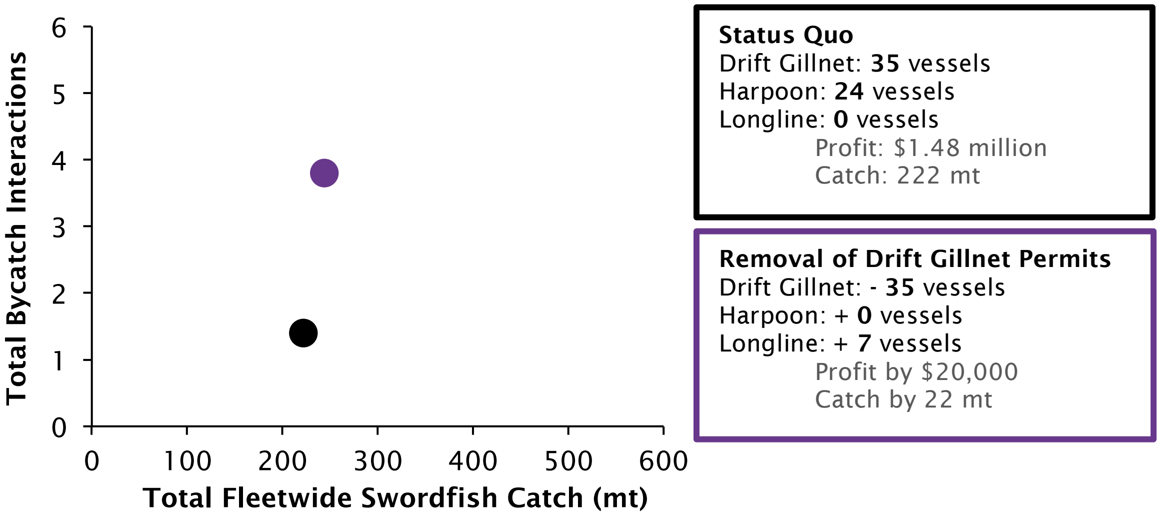


Figure 18. Comparison of the number of vessels, fleetwide profit, and swordfish catch for the management scenario that would buy out drift gillnet vessels and the status quo scenario under the leatherback hard cap of 3 individuals.

Filling of drift gillnet latent permits under the Bycatch Hard Cap

In our analysis we assumed there were 44 drift gillnet latent permits within the California commercial swordfish fishery, based on 35 active permits as the status quo averaged from 2006 to 2013. In this management scenario, we modeled the filling of all of these drift gillnet latent permits. Compared to the status quo, the total bycatch interactions doubled, however, the total swordfish catch also doubled (Figure 19).

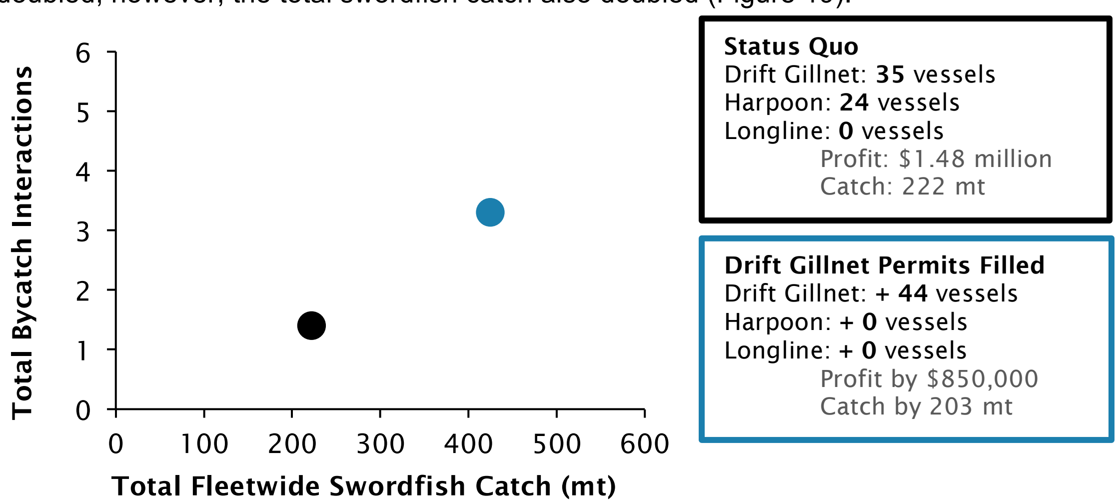
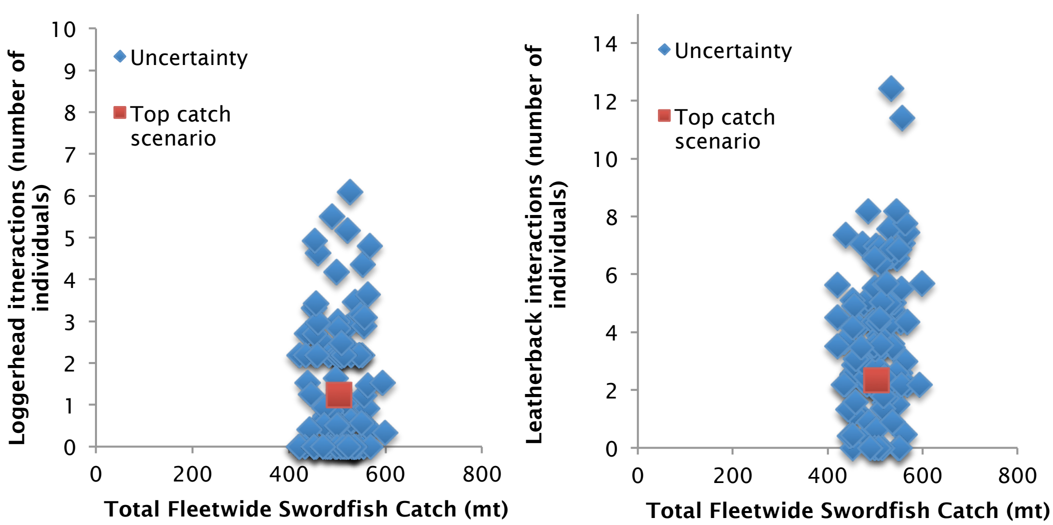


Figure 19. Comparison of the number of vessels, fleetwide profit, and swordfish catch for the management scenario that would fill the latent drift gillnet permits and the status quo scenario under the leatherback hard cap of 3 individuals.

Uncertainty Analysis

We incorporated uncertainty into the top profit and top swordfish catch model scenario by performing a sensitivity analysis for the CPUE parameter and four BPUE parameters (Figure 20). The 500 random values for the CPUE parameter and the four BPUE parameters that were calculated in our uncertainty model resulted in an average total swordfish catch of 504 mt, an average fleetwide profit of $2.65 million, and an average bycatch of 1.56 loggerhead sea turtles (A), 3.94 leatherback sea turtles (B), 1.57 sperm whales (C), and 0.32 humpback whales (D) in number of individuals. The probability of exceeding the bycatch hard caps was also calculated under uncertainty for each species of concern. Out of 500 runs of random CPUE and BPUE parameters, the loggerhead sea turtles remained under a hard cap of 3 individuals 82.2% of time, and the leatherback sea turtles remained under a hard cap of 3 individuals 40.4% of the time. Sperm whales remained under a hard cap of 2 individuals 69% of the time, and humpback whales remained under a hard cap of 2 individuals 86.6% of the time. As expected, the leatherback sea turtle was the limiting bycatch species that reached hard cap first. If the leatherback sea turtle hard cap were increased from 3 to 4 individuals, the probability of not exceeding a hard cap would increase to 52.6%.

A. B.



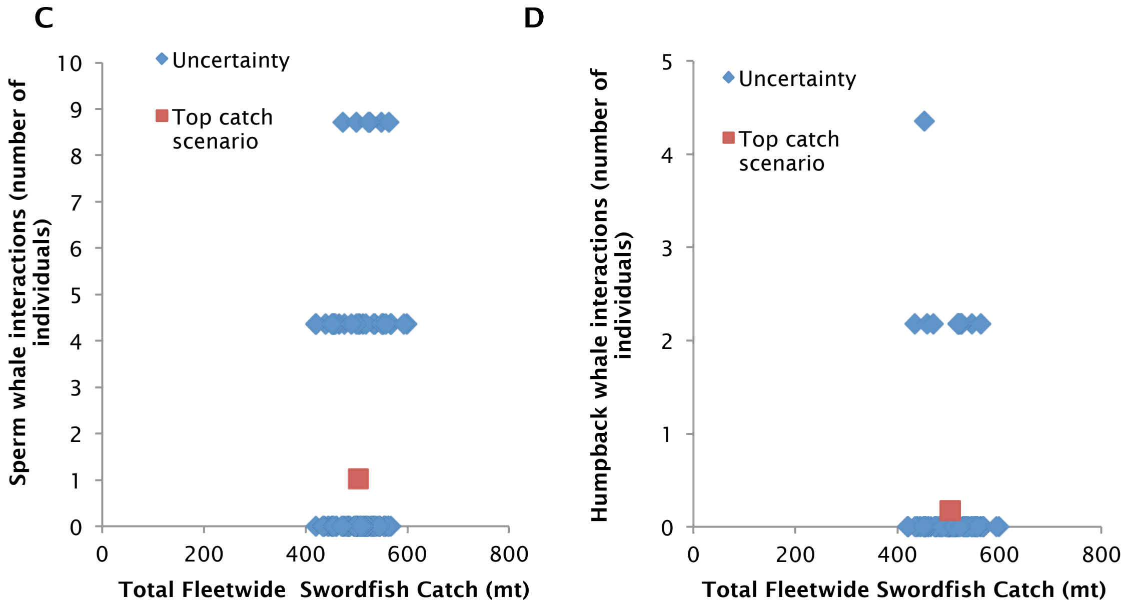


Figure 20. Sensitivity analysis for total fleetwide swordfish catch and bycatch interactions for loggerhead (A) and leatherback turtles (B) and sperm (C) and humpback whales (D).

Thought experiment: displacing foreign imports by simulating an increase in domestic catch by the California swordfish fishery

Under the assumption of the potential of a one-to-one market transfer of catch, a thought experiment was conducted to explore the economic, catch, and bycatch consequences of a complete displacement of imported swordfish with domestically-caught swordfish through an increase in California fishing effort and swordfish supply (Figure 21). An increase in the California drift gillnet, longline, and harpoon effort were simulated within the model wherein there was an increase in total catch by 8,919 mt in order to eliminate the amount of imported swordfish. This complete displacement of imported swordfish would result in a total California catch of 9,141mt (with a domestic catch of 12,149 mt), increasing the California fleetwide profit by $36 million compared to the status quo. This would require an additional 44 drift gillnet vessels to fill the latent permits, an increase in harpoon vessels by 71 to saturate the harpoon-caught swordfish niche market, and an increase in 267 longline vessels. This experimental scenario resulted in a total of 164 sea turtle interactions, 5 humpback whale interactions, and 1 sperm whale interactions. When considering global interactions and assuming a market transfer effect, this experimental scenario resulted in a global net reduction in the number of bycatch interactions due to eliminating imports from countries with high bycatch rates. Considering the sea turtle bycatch rates and current amount of swordfish imported from Ecuador, Canada, Costa Rica, Singapore (bycatch rates from Taiwan), Chile, Panama, Brazil, and Mexico, we calculated the overall reduction of global sea turtle interactions if imports were eliminated from these countries. Incorporating the California sea turtle interactions within this scenario, the global net reduction in sea turtles was 8,861individuals, where loggerhead interactions are reduced by 1,921 individuals and leatherback interactions are reduced by 522 individuals.

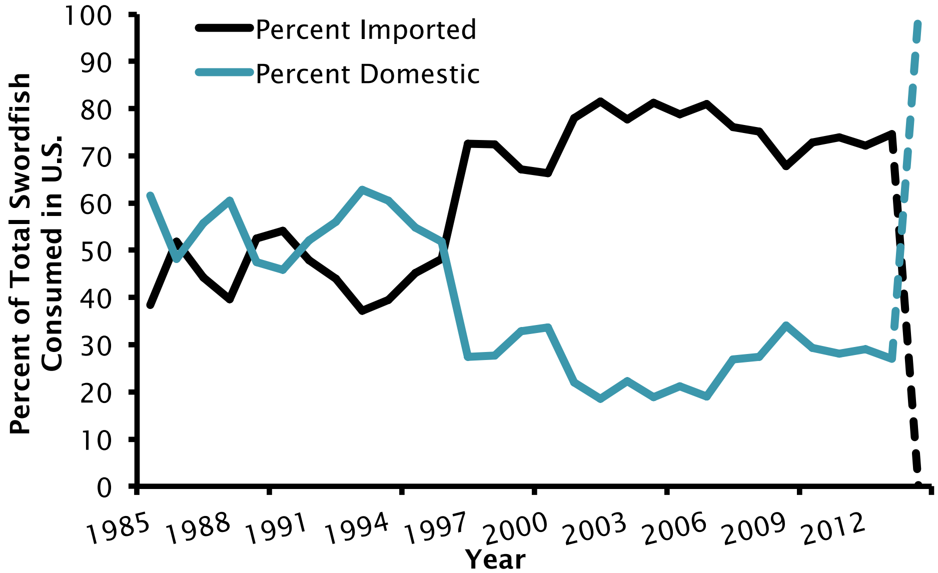


Figure 21. Percentage of imported versus domestic swordfish out of the total swordfish consumed in the U.S., including a complete displacement of imported swordfish by simulating an increase in catch by the California commercial swordfish fishery.

DICUSSION

This section explains the relevance of the results and the implications for management. Recommendations are provided regarding future management and policy options to improve the economic and conservation performance of the California swordfish fishery. We evaluated 252 management scenarios in the California commercial swordfish fishery by modeling different combinations of drift gillnet, harpoon, and longline effort both inside and outside of the U.S. EEZ. The results of our model indicated that some management scenarios for the California commercial swordfish fishery will increase both catch and profit, while not surpassing the Council preferred proposed bycatch hard caps for protected species. Of these 252 management scenarios six main management regimes, including status quo, are most relevant for the PFMC and NMFS as they face broad decisions regarding the management of the California commercial swordfish fishery. Although only six main management regimes are presented here, the model evaluated a suite of intermediary scenarios and incremental changes in effort between the various scenarios that the PFMC may use to inform policy decisions.

Top profit and swordfish catch: The top fleetwide profit and top swordfish catch management scenario demonstrates that a fishery with a gear portfolio composed of drift gillnet, longline, and harpoon resulted in the maximum profit and swordfish catch, subject to a bycatch hard cap of 3 leatherback sea turtles. Regardless of whether a hard cap is implemented, a mixed-gear fleet may result in the highest fleetwide profit and catch in the fishery. An additional advantage to a mixed-gear fleet is the potential to supply domestically caught, California swordfish more consistently throughout the year. The highest drift gillnet swordfish catch occurs during the months of September to January;

the highest harpoon swordfish catch occurs during July, August, and September; and the highest longline swordfish catch occurs over a longer monthly range during the months of October to March. Thus, the variation in swordfish supply from the different gear types could contribute toward a decreased reliance on foreign swordfish imports from countries with less stringent bycatch regulations.

Reincorporating longline: The management scenario composed of reincorporating longline within the fishery with constant drift gillnet and harpoon effort demonstrates that adding longline vessels to the California swordfish fishery may increase fleetwide profits and catch. However, it should be noted that the fixed costs associated with buying or retrofitting a vessel suitable for longline is not incorporated in this analysis. There may be some vessels already suitable for longline that would not have start-up costs, but would need to consider other costs, risks, market and other factors with shifting their operations to new fishing grounds. The use of Exempted Fishing Permits (EFPs) to allow a limited amount of longline fishing within the EEZ should be considered to determine if this scenario is viable from both an economic and bycatch performance perspective. It is important to reiterate that through permitting longline as an allowable gear type in the California swordfish fishery, the PFMC has the capability to permit a smooth supply of domestically caught California swordfish to meet the consistently high consumer demand for swordfish throughout the majority of months of the year. It is important to note that there is no swordfish catch in April and May because these months are not within the fishing season for drift gillnet and longline, and weather conditions and swordfish behavior may not be conducive for harpoon fishers to catch swordfish. Again, this management scenario regarding reincorporating longline is evaluated under a hard cap of 3 leatherback sea turtles for a multi-gear fishery. Therefore, regardless of how effort is allocated across the three gear types, the hard cap levels remain constant and apply to all three gear types in the fishery. As exemplified in the Results section, profit scales with the hard cap level in that higher profit is attained with a higher hard cap level.

Harpoon saturation: This management scenario demonstrates the potential to increase the amount of swordfish landed by harpoon fishers, and to market these harpoon-caught fish for a price premium in a niche market. If the estimated threshold of 204 mt for the harpoon-caught swordfish niche market is filled based on the historical maximum catch since 1981, this resulted in an increase in profit due to the price premium received; however, this resulted in a decrease in catch in the fishery compared to the status quo. Although it is not viable to increase the harpoon fleet by over 100 vessels as detailed in the Harpoon Caveats subsection, it is important to consider the niche market opportunity for harpoon-caught swordfish due to the price premium received and the associated no bycatch interactions with the harpoon gear type, which is of conservation importance.

Removal of drift gillnet permits, increase in longline effort: The Nature Conservancy has proposed, and the PFMC is considering a drift gillnet permit buyout (M. Stevens, personal communication, 2014). This management scenario illustrates that in this case, the fleetwide profit and catch would increase if effort from the active drift gillnet permits were transferred to the longline gear type. The increase in fleetwide profit and swordfish catch is $20,000 and 22 mt, respectively, in comparison to the status quo. This suggests that a fishery composed of just active drift gillnet vessels, or just active longline vessels – rather than a mixed-fleet – resulted in similar profit and swordfish catch outputs. The higher catch and profit of a fishery composed of just longline vessels in this management scenario may be attributed to the higher CPUE of the longline gear type. It is important to note that this scenario in the model uses 35 drift gillnet vessels as the status quo for active permit holders due to taking an average of active drift gillnet vessels over the timeframe from 2006 to 2013.

Latent drift gillnet permits filled: The converse management scenario to the removal of drift gillnet permits is if all latent, or inactive, drift gillnet permits were filled and actively fishing (adding 44 permits to the status quo of 35 in our model). Under this scenario, the fishery had the potential to increase both profit and swordfish catch without exceeding a bycatch hard cap of 3 leatherback sea turtles. It is important to note that there are currently 16 active drift gillnet vessels, and 63 latent drift gillnet permits (IATTC 2014). However, this scenario indicates that if the latent drift gillnet permits were filled, then there would be an increase in profit and swordfish catch in the fishery. In our model, drift gillnet is associated with a higher resultant profit outcome due to a higher price per pound for drift gillnet. Longline is associated with a higher resultant catch outcome due to the higher CPUE for longline. It is important to reiterate that our analysis focused on bycatch interactions for four bycatch species that are listed as federally endangered under the ESA and MMPA and that had historical interactions with drift gillnet and longline gear during the timeframe of our analysis. The drift gillnet and longline gear types have interactions with other cetaceans and pinnipeds; however, these species were not incorporated in our analysis.

Import displacement: Our thought experiment regarding the complete displacement of foreign imported swordfish with domestically-caught, California swordfish demonstrated that if a market transfer effect is assumed, increasing domestic fishing effort enough to meet all U.S. demand can remove the nation's reliance on foreign imports. This thought experiment illustrated the potential of a displacement of foreign imports using current levels of catch from other U.S. swordfish fisheries combined with an increase in California swordfish production under the assumption that the increased catch in California would displace an equal amount of swordfish catch by foreign fleets.

This analysis was done as a thought experiment to determine the potential global impact of increasing California swordfish production, with the results illustrating that by revitalizing the California swordfish fishery, there is potential for a considerable net reduction in interactions with sensitive species. Within the context of this analysis, and considering the U.S. demand for swordfish, and regulatory review of this fishery, the results of this thought experiment emphasize the importance of not limiting the considerations of impacts to marine ecosystems and sensitive species solely to California waters.

Within this simulation, however, the effort needed in the California fishery to displace all imported swordfish is unrealistic based off of regulations, revealed preferences of fishers, and historical fishing levels. Due to our data limitations, our analysis could only incorporate increases within the California fishery, however to represent a more realistic scenario, consideration should be made regarding displacing imports with increased effort and catch within all U.S. swordfish fisheries.

Uncertainty analysis: We use the Council proposed preferred bycatch hard cap levels in our analysis, which are based on mortality or serious injury. However, throughout this analysis our bycatch parameter has been based off of bycatch interactions or takes, not mortality. Therefore, our results represent a more conservative estimate of potential swordfish catch and profit outcomes, as well as potential bycatch interactions.
We incorporated uncertainty into our analysis to determine the sensitivity of our model parameters. Our model evaluates management scenarios that could simultaneously

increase swordfish catch and limit bycatch of sensitive species. Results are based on existing data, however, physical conditions and complicated species behavior can alter swordfish abundance of sensitive species' catch rates, ultimately affecting the total catch of swordfish or the number of bycatch interactions. Incorporating uncertainty in the model based on existing CPUE and BPUE values for swordfish and bycatch species, respectively, can predict a range of results that could help to adjust the level of effort for the drift gillnet and longline gear types, and thus reduce the risk of exceeding the bycatch hard caps. The top profit and swordfish catch scenario under uncertainty showed that leatherback sea turtle has a higher probability of reaching the bycatch hard cap before the other three species included in this analysis. This is likely due to higher interactions with the leatherback sea turtle when the longline gear is incorporated in fisheries management scenarios, as based on the historical data analyzed. The PFMC may consider a certain level of uncertainty in management decisions regarding proposed bycatch hard caps in order to adjust the level of effort for all gear types in the fleet to provide a buffer for uncertainty and reduce the risk of reaching an undesirable number of bycatch interactions.

Summary: Because recent assessments of the Pacific swordfish stock indicate that the stock is healthy and the annual catch rates of 10,000 metric tons are well below the estimated exploitable biomass of ~70,000 mt (Hinton and Maunder 2011; ISC 2014), the Pacific swordfish stock is considered an underutilized domestic, natural resource with the potential to be further exploited. Our analysis indicates six management regimes in particular that are of relevance to the PFMC and which result in higher profit and swordfish catch outcomes without surpassing the analyzed bycatch hard cap levels.

Future Management and Policy Options: There are other significant management and policy opportunities that the PFMC and NMFS may contemplate when determining the future of the California swordfish fishery. Management options include the incorporation of buoy gear, utilizing electronic monitoring (as a supplement or in lieu of human observer coverage), implementing individual transferable quotas for bycatch, using Exempted Fishing Permits (EFPs) for longline, and opening the Pacific Leatherback Conservation Area (PLCA) earlier in the fishing season. A policy option that NMFS may consider implementing is the banning of swordfish imports from countries that do not mandate the same bycatch mitigation regulation measures held in the U.S. Although data was not available to analyze these options, we addressed each qualitatively in the appendix (See Appendix K).

It is our hope that managers of the fishery (the PFMC and/or CDFW, NOAA) can use our model as a decision-making tool when considering the implementation of bycatch hard cap levels, the reincorporation of longline into the fishery, or the allocation of effort across a mixed-gear fleet. Our model framework is flexible in that it may be altered to address the addition of other gear types, such as deep-set buoy gear or deep-set longline.

CONCLUSION

The Pacific swordfish stock off the West Coast is an underutilized domestic resource. We modeled 252 management scenarios in the California commercial swordfish fishery, and revealed numerous options to increase the catch and profit in the fishery without exceeding the PFMC proposed bycatch hard cap levels for 4 bycatch species – leatherback and loggerhead sea turtle and humpback and sperm whale – that are federally listed as endangered under the ESA. There are tradeoffs between profit and catch, and bycatch interactions, which fisheries managers – particularly the PFMC and NMFS – must take into account when making management decisions for the fishery. We created a tradeoff analysis tool that can be adapted for other gear types – such as deep-set buoy gear and deep-set longline – and different effort levels, while considering bycatch interactions.

Our analysis demonstrated that reincorporating longline into the fishery could increase domestic swordfish catch and fleetwide profits without exceeding bycatch hard cap levels. Therefore, we recommend the PFMC consider approving EFPs for longline as a first step to assessing viability and bycatch performance of this gear off the West Coast. Overall, we recommend the Council consider a gear portfolio composed of a mixed-gear fleet of drift gillnet, longline, and harpoon as this results in the highest profit and catch outcomes and will provide a steady supply of domestically-caught, California swordfish throughout most of the year. We found that harpoon is not a viable gear type to increase catch on a commercial scale. The PFMC and NMFS should transition the fishery to 100% observer coverage through a combination of observers and electronic monitoring based on capacity of vessels and given innovations that allow electronic monitoring to be feasible on vessels. Transitioning to 100% observer coverage is of particular importance if bycatch hard caps are implemented, and the PFMC should consider whether these bycatch hard caps might be applied to a multi-gear fleet. If bycatch hard caps are implemented, the PFMC should implement bycatch hard caps that are based on scientific justification as proposed by NMFS. Attention should be paid to fishery participation and fisher behavior and overall domestic catch when considering the implementation of hard caps as an additional regulation.

Management decisions within the California commercial swordfish fishery have the potential to address unintended consequences associated with foreign imported swordfish. Assuming a market transfer effect, it is possible to reduce our reliance on foreign imports through an increase in California swordfish production, which will therefore decrease bycatch interactions on a global scale. The PFMC should put special emphasis on creating opportunities for local success in order to decrease reliance on imports. Through our analysis, we conducted a thought experiment that illustrated that if all imported swordfish were replaced with domestic swordfish, there is the potential to reduce global sea turtle interactions by about 9,000 individuals. Further management and policy options for the PFMC to consider include the incorporation of buoy gear as an allowable gear type, opening the PLCA earlier in the season and implementing a ban on swordfish imports from countries that do not mandate the same bycatch mitigation regulations as the U.S. Effective management of the California swordfish fishery will benefit the coastal economy through supporting the livelihoods of the California swordfish fishermen, as well as benefit marine conservation through protecting sensitive species on a global scale.

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REFERENCES

Abbot, J.K. and Wilen, J.E. (2009). Regulation of fisheries bycatch with common-pool quotas. *Environmental Economics and Management*, *57*(2), 195-204.

Arata, J.A., Sievert, P.R., and Naughton, M.B. (2009). Status assessment of Laysan and black-footed albatrosses, North Pacific Ocean, 1923–2005. *U.S. Geological Survey Scientific Investigations Report 2009-5131*, 1-80.

Argano, R., Basso, R., Cocco, M., and Gerosa, G. (1992). New data on loggerhead (Caretta caretta) movements within the Mediterranean. *Bollettino del Museo dell' Istituto di Biologia dell 'Universita di Genova,* 56-57, 137–164.

Asche, Frank, Guttormsen, A.G., Kristoferson, D., Roheim, C. A. (2005). Import Demand Estimation and the Generalized Composite Commodity Theorem. American Agricultural Organization Annual Meeting, Providence, Rhode Island, 1-22.

Assembly California Legislature. (2013). Letter from assemblyman Stone and state assembly members to federal agencies related to marine conservation and California drift gillnet fishery. Accessed online at: http://asmdc.org/members/a29/attachments/LettertoPFMC020614.pdf

Barlow, J., and Cameron, G. A. (2003). Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science*, *19*(2), 265-283.

Bartram, P. K., Kaneko, J.J. (2004). Catch to bycatch ratios: Comparing Hawaii's longline fisheries with others. *University of Hawaii-NOAA, Joint Institute for Marine and Atmospheric Research, 4*(352), 1-40.

Bartram, P. K., Kaneko, J. J., and Nakamura, K.K. (2010). Sea turtle bycatch to fish catch ratios for differentiating Hawaii longline-caught seafood products. *Marine Policy, 34,* 145-149.

Benson, S., Dewar, H., Dutton, P., Fahy, C., Heberer, C., Squires, D., and Stohs, S. (2008). Swordfish and Leatherback Use of Temperate Habitat (SLUTH). *NMFS and Southwest Fisheries Science Center: SLUTH Workshop Report.* Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/hms_program/sluth_workshop_report-final_8-25-09__2_.pdf

Bigelow, K. A. (2011). Seabird interaction rates estimated from observer data (2004-2011) in the Hawaii-based shallow and deep-set longline fisheries. *Western and Central Pacific Fisheries Commission: Scientific Committee Tenth Regular Session,* 1-13.

Block, B. A. (2011). Nature. Accessed online at: http://www.nature.com/news/2011/110622/full/news.2011.379.html

Blue Water Fishermen's Association (BWFA). (2014a). Choose American-Caught Swordfish. Accessed Online at: http://www.bwfa-usa.org/

Blue Water Fishermen's Association (BWFA). (2014b). Pelagic Longlining. Accessed Online at: http://www.bwfa-usa.org/our-fishery/pelagic-longlining

Blue Water Fishermen's Association (BWFA). (2014c). U.S. Regulation. Accessed Online at: http://www.bwfa-usa.org/our-fishery/fishery-management/us-regulation

Boyce, J.R. (1996). An economic analysis of the fisheries bycatch problem, *Journal of Environmental Economics and Management*, *31*(3), 314-336.

Brothers, N.P., Cooper, J., Lokkeborg, S. (1999). The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. *Food and Agriculture Organization of the United Nations*, FAO Fisheries Circular No. 937.

Burke, G. (2014). California Drift Gill Net Swordfish Fishery: One simple change could enhance fresh, local, sustainable landings by 25-30%. *Supplemental Public Comment PowerPoint*. Accessed online at: http://www.pcouncil.org/wp-content/uploads/K5c_SUP_PC_PPT_BURKE_MAR2014BB.pdf.

CA AB2019. 2013-2014. Regular Session. (2014, February 20). Accessed Online at: https://legiscan.com/CA/text/AB2019/id/1014279

California Seafood Council. (1998). The Truth About Swordfish: Californians love swordfish! Accessed online at: http://caseafood.californiawetfish.org/news/swftruth.htm

California Department of Fish and Wildlife: Marine Region. (2014). 2014 California Legislative Fisheries Forum: Annual Marine Fisheries Report, 1-31.

Carretta, J., Barlow, J., & Enriquez, L. (2008). Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. *Marine Mammal Science*, *24*(4), 956–961.

Carretta, J. V., & Barlow, J. (2011). Long-term effectiveness, failure rates, and "dinner bell" properties of acoustic pingers in a gillnet fishery. *Marine Technology Society Journal*, *45*(5), 7-19.

Carretta, J.V. & Enriquez, L. (2012a). Marine Mammal and Seabird Bycatch in California Gillnet Fisheries in 2010. *NOAA Administrative Report LJ-12-01*, 1-14.

Carretta, J.V. & Enriquez, L. (2012b). Marine Mammal and Seabird Bycatch in California Gillnet Fisheries in 2011. *NOAA Technical Memorandum NMFS,* 1-14.

Carretta, J. V., Enriquez, L., & Villafana, C. (2014). Marine Mammal, Sea Turtle and Seabird Bycatch in California Gillnet Fisheries in 2012. *NOAA Technical Memorandum NMFS,* 1-16.

Center for Biological Diversity (CBD) and Turtle Island Restoration Network (TIRN) (2008). Petition to Ban Imports of Swordfish from Countries Failing to Submit Proof of the Effects of Fishing Technology on Marine Mammals Pursuant to Marine Mammal Protection Act, Section 101. Accessed online at: http://www.biologicaldiversity.org/campaigns/fisheries/pdfs/Swordfish-PetitionL.pdf

Center for Biological Diversity (CBD). (2015). Feds Agree to Implement Seafood Import Ban to Protect Whales and Dolphins. Press Release. Accessed online at http://www.biologicaldiversity.org/news/press_releases/2015/marine-mammals-01-06-2015.html

Chan, H.L. and Pan, M. (2012). Spillover Effects of Environmental Regulation for Sea Turtle Protection: The Case of the Hawaii Shallow-set Longline Fishery. *NOAA Technical Memorandum NMFS-PIFSC, 30,* 1-37.

Cheng, H.T., and O. Capps, Jr. (1988). Demand analysis of fresh and frozen finfish and shellfish in the United States. *American Journal of Agricultural Economics*, *70*(3), 533-542.

Childers, J. (2015a). Average Swordfish Weights for Harpoon. Raw data. *California Department of Fish and Wildlife (CDFW).*

Childers, J. (2015b). CDFW Logbook Data. 2015. Raw data. *California Department of Fish and Wildlife (CDFW).*

Coan Jr. A. L., Vojkovich, M., & Prescott, D. (1998). The California harpoon fishery for swordfish, *Xiphias gladius. NOAA Technical Report NMFS, 142*, 37-49.

Collaborative Fisheries Research West. (n.d.). Alternative swordfish gear to reduce bycatch: alternative swordfish gear to reduce bycatch. Accessed online at: http://www.cfr-west.org/CFR_West/Projects/Pages/swordfish_research.html

Costello, C., Gaines, S., Lynham, J. (2008). Can Catch Shares Prevent Fisheries Collapse? *Science*, *321*, 1678-1681.

Costello, C., Ovando, D., Hilborn, R., Gaines, S. D., Deschenes, O., & Lester, S. E. (2012). Status and solutions for the world's unassessed fisheries. *Science, 338*(6106), 517-520.

CPI Inflation Calculator: Bureau of Labor Statistics. (2015).*U.S. Bureau of Labor Statistics.* Accessed online at: http://www.bls.gov/data/inflation_calculator.htm

Crowder, L. and R. Myers (2001). Report to Pew Charitable Trusts: A Comprehensive Study of the Ecological Impacts of the Worldwide Pelagic Longline Industry. *The Pew Charitable Trusts*, *143*.

Crowder, L. and Murawski, S. (1998). Fisheries bycatch: implications for management. *Fisheries, 23*, 8–17.

Dahl, K. (2013). PacFIN landings data relevant to proposed Pacific Leatherback Conservation Area modification. *Pacific Fishery Management Council: Agenda Item I.2.a: Attachment 1,* 1-4.

Drift gillnet fishery, 50 C.F.R. § 660.713 (2007). Accessed Online at: http://www.law.cornell.edu/cfr/text/50/660.713

Drift Gill Net Shark and Swordfish Fishery, Cal. S.B. 1478 (1994). Accessed Online at: http://www.leginfo.ca.gov/pub/93-94/bill/sen/sb_1451-1500/sb_1478_bill_940907_chaptered

Eales, J.E., Durham, C.A. and Wessells, C.R. (1997). Generalized models of Japanese demand for fish. *American Journal of Agricultural Economics*, *79*(4), 1153-1163.

Finkbeiner, E. M., Wallace, B. P., Moore, J. E., Lewison, R. L., Crowder, L. B., and Read, A. J. (2011). Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. *Biological Conservation*, *144*(11), 2719-2727.

FishChoice.com. (2014). Swordfish. Accessed online at: http://www.fishchoice.com/buying-guide/swordfish

FA.COA – Fisheries Agency, Council of Agriculture. (2014). Acts: Fisheries Act. Accessed online at: http://www.fa.gov.tw/en/LegalsActs/content.aspx?id=1&chk=F8CA5D8C-49DB-46B5-9839-43D955E36275&param

Fish2Fork.com (2014). Sri Lankan seafood imports to be banned in Europe in illegal fishing crackdown. Accessed online at http://fish2fork.com/en_GB/news/news/sri-lankan-seafood-imports-to-be-banned-in-europe-in-illegal-fishing-crackdown

Folsom, W.B. (1997). World Swordfish Fisheries: An Analysis of Swordfish Fisheries, Market Trends, and Trade Patterns. *NOAA Technical Memorandum NMFS,* 1-319.

Food and Agriculture Organization of the United Nations (FAO). (n.d.). A short description of gillnet and longline gears. Accessed online at: http://www.fao.org/docrep/005/x7788e/X7788E02.htm.

Food and Agriculture Organization of the United Nations (FAO). (2003). Fish Stock Assessment Manual: Chapter 1. *FAO Fisheries Technical Paper 393*. Accessed online at: http://www.fao.org/docrep/006/X8498E/x8498e08.htm

Food and Agriculture Organization of the United Nations (FAO). (2012). Fishery and Aquaculture Statistics, Capture Production: Tunas, bonitos, billfishes. Accessed online at: ftp://ftp.fao.org/FI/CDrom/CD_yearbook_2012/root/capture/b36.pdf

Food and Agriculture Organization of the United Nations (FAO). (2014a). Global Capture Production (FishStat) Dataset. Accessed online at: http://data.fao.org/dataset-data-filter?entryId=af556541-1c8e-4e98-8510-1b2cafba5935&tab=data

Food and Agriculture Organization of the United Nations (FAO). (2014b). The State of World Fisheries and Aquaculture. Accessed online at: http://www.fao.org/3/a-i3720e.pdf

Forney, K.A. & Kobayashi, D.R. (2007). Updated Estimates Of Mortality And Injury Of Cetaceans In The Hawaii-Based Longline Fishery, 1994-2005. *NOAA Technical Memorandum NMFS,* 1-30.

Gales, R., Brothers, N., & Reid, T. (1998). Seabird mortality in the Japanese tuna longline fishery around Australia, 1988–1995. *Biological Conservation*, *86*, 37–56.

Gilman, E., Brothers, N., McPherson, G., and Dalzell, P. (2006a). Review of cetacean interactions with longline gear. *Journal of Cetacean Research and Management*, *8*(2), 215–23.

Gilman, E., Zollett, E., Beverly, S. et al. (2006b). Reducing sea turtle bycatch in pelagic longline gear. *Fish and Fisheries, 7*, 2–23.

Gilman, E., Kobayashi, D., Swenarton, T., Brothers, N., Dalzell, P., and Kinan, K. I. (2007). Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. *Biological Conservation*, *139*(1-2), 19-28.

Gilman, E., et al. (2008). Shark interactions in pelagic longline fisheries. *Marine Policy*, *32*(1), 1-18.

Gilman, E. and Lundin, C. (2009). Minimizing bycatch of sensitive species groups in marine capture fisheries: lessons from commercial Tuna fisheries. *IUCN Global Marine Programme*, 1-22.

Gilman, E.L. (2011). Bycatch governance and best practice mitigation technology in global tuna fisheries, *Marine Policy*, *35*, 590-609.

Government Publishing Office (GPO). (2015). Electronic code of federal regulations. Accessed online at: http://www.ecfr.gov/cgi-bin/text-idx?SID=a47de6ab77468a437eb7cbdd9ea0b999&node=sp50.12.635.b&rgn=div6%20-%20se50.12.635_115.

Hanan, D.A., Holts D.B., and Coan, A.C. and Dalzell, P. (1993).The California drift gill net fishery for sharks and swordfish, 1981-82 through 1990-91. *State of California, Resources Agency, Department of Fish and Game: Fish Bulletin 175,* 1-95.

Hellmers, E. (2014). Unpublished data set provided by California Department of Fish and Wildlife.

Holland, D.S. (2010), Markets, pooling and insurance for managing bycatch in fisheries. *Ecological Economics*, *70,*121-133.

Holts, D. (2001). Swordfish. *California's Living Marine Resources: A Status Report*, *California Department of Fish and Game*, 322 -323.

Inter-American Tropical Tuna Commission (IATTC). (2014). California Regional Vessel Register List. Accessed online at: https://iattc.org//VesselRegister/VesselList.aspx?List=RegVessels&Lang=ENG#United_States.

International Commission for the Conservation of Atlantic Tunas (ICCAT). (2010-2011). 8.8 SWO-ATL-Atlantic Swordfish. ICCAT Correspondence & Reports. Accessed online at: http://www.nefmc.org/press/council_discussion_docs/January%202011/ICCAT/Doc%203_ICCAT_Atl%20Swordfish.pdf

International Council for the Exploration of the Sea (ICES). (2010). Report of the Study Group on Bycatch of Protected Species (SGBYC), 1-4, Copenhagen, Denmark. Accessed online at: http://www.ascobans.org/sites/default/files/document/ICES_SGBYC_final_2010.pdf

International Union for the Conservation of Nature and Natural Resources (IUCN), (2004). *The IUCN Red List of Threatened Species*. Accessed online at: http://www.redlist.org

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). (2014). North Pacific Swordfish *(Xiphiuaus gladius)* Stock Assessment in 2014, Report of the Billfish Working Group, 1-85.

Ito, R. Y. and Machado, W.A. (2001). Annual Report of the Hawaii-Based Longline Fishery for 2000. *Southwest Fisheries Science Center: Administrative Report H-01-07,* 1-56.

Jantz, L., and E. Forney. (2015). Hawaii Longline Observer Data. Raw data. *NOAA Pacific Islands Fisheries Science Center (PIFSC).*

Johnson, A.J., Durham, C.A. and Wessells C.R. (1998). Seasonality in Japanese household meat and seafood. *Agribusiness: An International Journal*, *14*(4), 337-351.

Laurent, L. (1991). Les tortues marines des cotes francaises mediterraneennes continentales. Faune de Provence (C.E.E.P.), *12*, 76–90.

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., & Geschke, A. (2012). International trade drives biodiversity threats in developing nations. *Nature*, *486*(7401), 109-112.
Lewison, R. L., & Crowder, L. B. (2003). Estimating fishery bycatch and effects on a vulnerable seabird population. Ecological Applications, 13(3), 743-753.

Lewison, R.L., Crowder, L.B., Read, A.J. and Freeman, S.A. (2004a). Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology and Evolution*, *19*, 598–604.

Lewison, R.L., Freeman, S.A. and Crowder, L.B. (2004b). Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecology Letters*, *7*, 221–231.

Lewison and Crowder. 2006. Putting Longline Bycatch of Sea Turtles into Perspective. Conservation Biology, 21, 1.

Lewison, R. L., and Crowder, L.B. (2007). Putting longline bycatch of sea turtles into perspective. *Conservation Biology*, *21*(1), 79-86.

MarineBio Conservation Society (MarineBio). (2015). Currents and Tides – MarineBio.org. Accessed online at: http://marinebio.org/oceans/currents-tides/

Marine Stewardship Council (MSC). (2014). Fish as food. Accessed online at: http://www.msc.org/healthy-oceans/the-oceans-today/fish-as-food

Marine Stewardship Council (MSC). (2015). MSC Assessment Status: SSLLC US North Atlantic swordfish Longline. Accessed online at: http://www.msc.org/track-a-fishery/fisheries-in-the-program/in-assessment/north-west-atlantic/ssllc-us-north-atlantic-swordfish-longline

Marsh, J., and Stiles,M. (2011). Seafood Report: Swordfish, *Xiphias gladius*. *Monterey Bay Aquarium Seafood Watch.*

Martin, D. (2012). Social Marketing: A Paradigm for Shifting Behavior. *NOAA, Understanding the Marketplace: Consumer Trends and Perceptions,* 39-40. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/hms_program/2011%20Swordfish%20workshop%20proceedings/understanding__marketplace_swordfishproceedings_v_25-final.pdf

Martinez, J. P., Marco, A., Quiñones, L. and Godley, B. (2008). Globally significant nesting of the leatherback turtle (Dermochelys coriacea) on the Caribbean coast of Colombia and Panama. *Biological Conservation*, *141*(8), 1982-1988.

Mukherjee, Z. (2013). Unilateral conservation policies and the magnitude of trade induced transfer of bycatch. *Simmons College Economics Department Working Paper*.

Mukherjee, Z. (2015). An economic approach to understanding the international transfer of bycatch from unilateral bycatch reduction policies. *Marine Policy*,*51*, 190-195.

National Marine Fisheries Service (NMFS). (2000). NMFS California/Oregon Drift Gillnet Observer Program Observed Catch - 1999/2000 Fishing Season May 1, 1999, through January 31, 2000. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/swr_observer_program/drift_gillnet_catch_summaries/observeddgn1990-2000.pdf

National Marine Fisheries Service (NMFS). (2008). Workshop Report: Swordfish and Leatherback Use of Temperate Habitat. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/swr_observer_program/drift_gillnet_catch_summaries/observeddgn2000-2010.pdf.

National Marine Fisheries Service (NMFS). (2010a). NMFS California/Oregon Drift Gillnet Observer Program Observed Catch - 2010/2011 Fishing Season May 1, 2010, through January 31, 2011. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/swr_observer_program/drift_gillnet_catch_summaries/observeddgn2000-2010.pdf.

National Marine Fisheries Service (NMFS). (2010b). Summary of Hawaii Longline Fishing Regulations. Accessed online at: http://www.nmfs.noaa.gov/pr/interactions/fkwtrt/meeting1/longline_fishery/regulation_summary.pdf

National Marine Fisheries Service (NMFS). (2011). Fisheries of the United States 2010. *NMFS Office of Science and Technology and Fisheries Statistics Division,* 1-103. Accessed online at: http://www.st.nmfs.noaa.gov/st1/fus/fus10/FUS_2010.pdf

National Marine Fisheries Service (NMFS). (2012). Fisheries of the United States 2012. *NMFS Office of Science and Technology and Fisheries Statistics Division,* 1-124. Accessed online at: http://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus12/FUS2012.pdf

National Marine Fisheries Service (NMFS). (2013). Fisheries of the United States 2013. *NMFS Office of Science and Technology and Fisheries Statistics Division,* 1-129. Accessed online at: http://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus13/FUS2013.pdf

National Marine Fisheries Service (NMFS). (2014a). CA Thresher Shark/Swordfish Drift Gillnet (≥14in. mesh) Fishery. Accessed online at: http://www.nmfs.noaa.gov/pr/pdfs/fisheries/lof2014/ca-thresher-shark-swordfish-drift-gillnet.pdf

National Marine Fisheries Service (NMFS). (2014b). Commercial Fisheries Statistics: Annual Commercial Landing Statistics. *NOAA.* Accessed online at: http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index

National Marine Fisheries Service (NMFS). (2014c). Current Fishery Statistics: Imports and Exports of Fishery Products Annual Summary, 2013. *NOAA Fisheries,* 1-28. Accessed online at: http://www.st.nmfs.noaa.gov/Assets/commercial/trade/Trade2013.pdf

National Oceanic and Atmospheric Administration (NOAA). (2011a). Social and Economic Factors: Influences on the Fishery and Coastal Communities. *NOAA West Coast Regional Office*, 19-25.

National Oceanic and Atmospheric Administration (NOAA). (2011b). The U.S. West Coast Swordfish Workshop: Working towards Sustainability. *Supplemental Swordfish Workshop Presentation, Agenda Item E.2.b.* Accessed online at: http://www.pcouncil.org/wp-content/uploads/E2b_SUP_WKSHP_PPT_SEPT2011BB.pdf

National Oceanic and Atmospheric Administration (NOAA). (2013). Final Environmental Assessment, Regulatory Impact Review, and Final Regulatory Flexibility Analysis for Amendment 8 to the 2006 Consolidated Atlantic Highly Migratory Species Fishery Management Plan: Commercial Swordfish Management Measures. Office of Sustainable Fisheries, 1 – 134.

National Oceanic and Atmospheric Administration (NOAA). (2013b). Regulation summary: Hawaii Pelagic Longline Fishing (revised August 2014). *NOAA Fisheries Pacific Islands Regional Office.* Accessed online at: http://www.fpir.noaa.gov/SFD/pdfs/hawaii-longline-reg-summary_%28rev.8-26-14%29.pdf

National Oceanic and Atmospheric Administration (NOAA). (2014a). Highly Migratory Species. *NOAA Fisheries: West Coast Region*. Accessed online at: http://www.westcoast.fisheries.noaa.gov/fisheries/migratory_species/highly_migratory_species.html

National Oceanic and Atmospheric Administration (NOAA). (2014b). North Atlantic Swordfish. *Fish Watch: U.S. Seafood Facts*. Accessed online at: http://www.fishwatch.gov/seafood_profiles/species/swordfish/species_pages/north_atlantic_swordfish.htm

Northeast Fisheries Science Center (NEFSC). (2014). Electronic Monitoring. Accessed online at: http://www.nefsc.noaa.gov/fsb/ems/

Pacific Fishery Management Council (PFMC). (2002a). Pacific Council News Brief: A Publication of the Pacific Fishery Management Council, 2002. Accessed online at: ftp://ftp.pcouncil.org/pub/Newsletters/2002_March_News.pdf

Pacific Fishery Management Council (PFMC). (2002b). Council Decisions at the November 2002 Meeting. Accessed online at: http://www.pcouncil.org/wp-content/uploads/1102decisions.pdf

Pacific Fishery Management Council (PFMC). (2003). Appendix F: U.S. West Coast Highly Migratory Species: Life History Accounts and Essential Fish Habitat Descriptions. *U.S. West Coast Highly Migratory Species Plan Development Team,* 1-57. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/habitat/essential_fish_habitat/highly_migratory_species_appendix_f.pdf

Pacific Fishery Management Council (PFMC). (2005). Management Regime for High Seas Longline Fishery. *PFMC Agenda Item E.6.* Accessed online at: http://www.pcouncil.org/bb/2005/0605/E.6_SS_June2005BB.pdf

Pacific Fishery Management Council (PFMC). (2006a). Decisions at the March 2006 Meeting. *PFMC,* 1-6. Accessed online at: http://www.pcouncil.org/wp-content/uploads/0306decisions.pdf

Pacific Fishery Management Council (PFMC). (2006b). Drift Gillnet Management. *PFMC Agenda Item J.3, Situation Summary,* 1-2. Accessed online at: http://www.pcouncil.org/bb/2006/0306/J3_SitSum_Mar06_BB.pdf

Pacific Fishery Management Council (PFMC). (2007). Issuance of an Exempted Fishing Permit to Fish with Longline Gear in the West Coast Exclusive Economic Zone: Environmental Assessment. *NMFS Department of Commerce and Southwest Fisheries Science Center,* 1-144. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/nepa/HMS/ea_longline_exemptfish_permit_eez_2007.pdf

Pacific Fishery Management Council (PFMC). (2008). Council Decisions - September 2008 Meeting. Accessed online at: http://www.pcouncil.org/wp-content/uploads/0908decisions.pdf

Pacific Fishery Management Council (PFMC). (2011a). Highly Migratory Species: Background. Accessed online at: http://www.pcouncil.org/highly-migratory-species/background/

Pacific Fishery Management Council (PFMC). (2011b). Status of the U.S. West Coast Fisheries for Highly Migratory Species Through 2010: Stock Assessment and Fishery Evaluation. *PFMC,* 1-164. Accessed online at: http://www.pcouncil.org/wp-content/uploads/HMS_SAFE_2011_FINAL.pdf

Pacific Fishery Management Council (PFMC). (2012a). Description of Fisheries and Statistical Summaries of Catch, Revenue and Effort. *PFMC,* 1-4. Accessed online at: http://www.pcouncil.org/wp-content/uploads/3.1-West-Coast-Commercial-HMS-Fisheries_final.pdf

Pacific Fishery Management Council (PFMC). (2012b). Highly Migratory Species Management Team Swordfish Management Data Report and Future Management Recommendations. *Supplemental HMSMT Report, Agenda Item B.3.b*. Accessed online at: http://www.pcouncil.org/wp-content/uploads/B3b_SUP_HMSMT_RPT_MAR2012BB.pdf

Pacific Fishery Management Council. (2014a). Decision Summary Document. *PFMC,* 1-6. Accessed online at: http://www.pcouncil.org/wp-content/uploads/0614decisions.pdf

Pacific Fishery Management Council (PFMC). (2014b). Highly Migratory Species Management Team Report on Drift Gillnet Fishery Transition Issues. *PFMC Agenda Item E.2.b*. Accessed online at: http://www.pcouncil.org/wp-content/uploads/E2b_SUP_HMSMT_Rpt_JUNE2014BB.pdf

Pacific Fishery Management Council (PFMC). (2014c). Highly Migratory Species Management Team Report on Drift Gillnet Management. *PFMC Agenda Item K.5.b.,* 1-15. Accessed online at: http://www.pcouncil.org/wp-content/uploads/K5b_HMSMT_DGN_MAR2014BB.pdf

Pacific Fishery Management Council (PFMC). (2014d). Highly Migratory Species Management Team Report on New or Routine Management Measures for 2015-2016 Fisheries. *PFMC Agenda Item G.4.b*. Accessed online at: http://www.pcouncil.org/wp-content/uploads/G4b_HMSMT_Rpt1_SEPT2014BB.pdf

Pacific Fishery Management Council (PFMC). (2014e). Highly Migratory Species Management Team Report on Routine Management Measures to Establish Hard Caps in the Drift Gillnet Fishery. *PFMC Agenda Item G.4.b*. Accessed online at: http://www.pcouncil.org/wp-content/uploads/G4b_HMSMT_Rpt3_DGN_SEPT2014BB.pdf

Pacific Fishery Management Council (PFMC). (2014f). Fact Sheet: Electronic Monitoring. Accessed online at: http://www.pcouncil.org/wp-content/uploads/Electronic-Monitoring-May-2014.pdf

Pacific Fishery Management Council (PFMC). (2014g). Groundfish: Trawl Catch Share Program Electronic Monitoring. Accessed online at: http://www.pcouncil.org/groundfish/trawl-catch-share-program-em/

Pacific Fishery Management Council (PFMC). (2015a). Current HMS SAFE Report: Commercial Fisheries Descriptions. Accessed online at: http://www.pcouncil.org/highly-migratory-species/stock-assessment-and-fishery-evaluation-safe-documents/current-hms-safe-document/commercial-fisheries-descriptions/

Pacific Fishery Management Council (PFMC). (2015b). Highly Migratory Species Management Team Report on Proposed California Drift Gillnet Fishery Management and Monitoring Plan Including Management Alternatives. *PFMC Agenda Item H.4.b*. Accessed online at: http://www.pcouncil.org/wp-content/uploads/H4b_HMSMT_Rpt_MAR2015BB.pdf

Pacific Fishery Management Council (PFMC) March Meeting. (2015c). Highly Migratory Species Management Team Meeting. *PFMC Agenda Item H.4.b*. Vancouver, Washington, USA. *In-person attendance.*

Pacific Fishery Management Council (PFMC). (2015d). Informational Report on Regional Electronic Technologies Implementation Plan for West Coast Marine Fisheries. Accessed online at: http://www.pcouncil.org/wp-content/uploads/IR6_WCR_ETPlan_MAR2015BB.pdf

Pacific Offshore Cetacean Take Reduction Plan Regulations; Taking of Marine Mammals Incidental to Commercial Fishing Operations, 50 C.F.R. §229 (1996-1997). Accessed Online at: http://www.nmfs.noaa.gov/pr/pdfs/fr/fr62-51805.pdf

P., Minling. (2015). Cost Data for Hawaii Shallow-set Longline Landings to California. Raw data. *NOAA PIFSC.*

Perrin, W.F., Donovan, G.P. and Barlow, J. (1994). Report of the International Whaling Commission (Special Issue 15): Gillnets and Cetaceans. *International Whaling Commission*, 1-629. https://archive.iwc.int/pages/search.php?search=%21collection34&k=

Perrin, W. F., Reeves, R. R., Dolar, M. L. L., Jefferson, T. A., Marsh, H., Wang, J. Y., and Estacion, J. (2002). Report of the Second Workshop on The Biology and Conservation of Small Cetaceans and Dugongs of South-East Asia. *Convention on Migratory Species (CMS): CMS Technical Series Publication No 9,* 1-161.

Rausser, G., et al. (2009). Unintended consequences: The spillover effects of common property regulations. *Marine Policy*, *33*(1), 24-39.

Santora, C. (2003). Management of turtle bycatch: Can endangered species be protected while minimizing socioeconomic impacts? *Coastal Management, 31*(4), 424-434.

Saving Seafood. (2013). Ray Hilborn on Magnuson: lost yield from fishing too hard is 3%, but from fishing too little is 48%. *Testimony, Committee on House Natural Resources Hearing*, September, 11, 2013. Accessed online at: http://www.savingseafood.org/washington/ray-hilborn-on-magnuson-lost-yield-from-fishing-too-hard-is-3-but-from-fishing-too-little-i.html

Sarmiento, C. (2006). Transfer function estimation of trade leakages generated by court rulings in the Hawaii longline fishery. *Applied Economics*, *38*, 183-190.

Scorse, J. (2014). Public Comment: Agenda Item E.2: Transitioning the Drift Gillnet Swordfish Fishery. Accessed Online at: http://www.pcouncil.org/wp-content/uploads/E2c_SUP_PubCom2_FULLELECTRICVERSION_JUNE2014BB.pdf

Sepulveda, C. A., Knight, A., Nasby-Lucas, N. and Domeier, M. L. (2010), Fine-scale movements of the swordfish Xiphias gladius in the Southern California Bight. *Fisheries Oceanography, 19*: 279–289.

Sepulveda, C.A., Aalbers, S.A., & Heberer, C. (2013) Development and Trials of Deep-set Buoy Gear Off the California Coast. NOAA PFMC Research Update 2013. PowerPoint Presentation. Accessed Online at http://www.pcouncil.org/wp-content/uploads/I1c_SUP_SWFSC_PPT2_CHUGEY_MAR2013BB.pdf

Sepulveda, C.A., Albers, S. A. and Heberer, C. (2014). Testing Modified Deep-Set Buoy Gear to Minimize Bycatch and Increase Swordfish Selectivity. *Pfleger Institute of Environmental Research (PIER) and NMFS,* 27-32. Accessed online at: http://www.nmfs.noaa.gov/by_catch/docs/brep_2014_sepulveda.pdf

Shillinger GL, Palacios DM, Bailey H, Bograd SJ, Swithenbank AM, et al. (2008) Persistent Leatherback Turtle Migrations Present Opportunities for Conservation. PLoS Biol 6(7): e171. doi:10.1371/journal.pbio.0060171

Smith, Z., Gilroy, M., Eisenson, M., Schnettler, E., and Stefanski, S. (2014). Net Loss: The Killing of Marine Mammals in Foreign Fisheries. *NRDC.* Accessed online at: http://big.assets.huffingtonpost.com/NRDC.pdf

Southwest Region and Southwest Fisheries Science Center, NOAA (SWFSC). (2010). Understanding Key Issues Facing U.S. West Coast Swordfish Fisheries and Consumers. *NOAA National Marine Fisheries Service White Paper*, 1-15. Accessed online at: http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/hms_program/2011%20swordfish%20workshop%20Background%20materials/understanding_swo_issues-_whitepaper.pdf

Spotila, J. R., Reina, R. D., Steyermark, A. C., Plotkin, P. T., and Paladino, F. V. (2000). Pacific leatherback turtles face extinction. *Nature*, *405*(6786), 529-530.

State of California Ocean Protection Council (OPC). (2008). Resolution of the California Ocean Protection Council on a Longline Exempted Fishing Permit and Potential Impacts to West Coast Sea Turtles. *CA.gov,* 1-2*.* Accessed online at: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/sea_turtle_reso_final_amended.pdf

State of California Ocean Protection Council (OPC). (2014). Swordfish, Pacific (Xiphias gladius). Accessed online at: http://opc.ca.gov/webmaster/ftp/project_pages/Rapid%20Assessments/Swordfish.pdf

Stohs, S. (2007). Which Swordfish Gear is Cleanest? *NMFS,* 1-33. Accessed online at: http://ageconsearch.umn.edu/bitstream/9766/1/sp07st01.pdf

Stohs, S. (2010a). Drift Gillnet and Harpoon Cost and Earnings Survey Report. 2010. Raw data. *NOAA SWFSC.*

Stohs, S. (2010b). U.S. and International Commercial Swordfish Fishery Background, and the Futility of Unilateral Conservation. *Southwest Fisheries Science Center (SWFSC)* (PowerPoint slides).

Stohs, S. (2014). Drift Gillnet Observer Record. Raw data. *NOAA SWFSC.*

Stohs, S. (2015a). Aggregated West Coast PacFIN Landings Data by Month for Hawaii Shallow-set Longline Trips with Landings to the West Coast from 2006-2013. Raw data. *NOAA SWFSC.*

Stohs, S. (2015b). Average Price per Pound. Raw data. *NOAA SWFSC.*

Squires, D., Campbell, H., Cunningham, S., Dewees, C., Grafton, R. Q., Herrick, S. F., and Vestergaar, N. (1998). Individual transferable quotas in multispecies fisheries. *Marine Policy*, *22*(2), 135-159.

Squires, D. (2013). Overview of Transfer Effects: What are they and why should we care? *NOAA Presentation Slides*. Accessed Online at: http://www.nmfs.noaa.gov/stories/2013/08/docs/transfer_effects_squires.pdf

Swordfish Buoy Gear. (n.d.).Accessed online at: https://www.lindgren-pitman.com/s-4-buoy-gear-swordfishing.aspx.

Wallace, B. P., Heppell, S.S., Lewison, R. L., Kelez, K. and Crowder, L.C. (2008). Impacts of fisheries bycatch on loggerhead turtles worldwide inferred from reproductive value analyses. *Journal of Applied Ecology*, 45(4):1076-1085.

Ward, P., and Elscot, S. (2000). Broadbill swordfish: Status of the world fisheries. *IOTC Proceedings* (3), 208-213.

Watson, J. W., Epperly, S. P., Shah, A. K., & Foster, D. G. (2005). Fishing methods to reduce sea turtle mortality associated with pelagic longlines. *Canadian Journal of Fisheries and Aquatic Sciences, 62*(5), 965-981

Watson, J. W., and D. W. Kerstetter. (2006). Pelagic longline fishing gear: a brief history and review of research efforts to improve selectivity. *Marine Technology Society Journal 40*(3): 6-11.

Watson, J.W., Epperly, S.P., Shah, A.K., Foster, and D.G. (2011). Fishing methods to reduce sea turtle mortality associated with pelagic longlines. *Canadian Journal of Fisheries and Aquatic Science*, *62*(5), 965-981.

Wessells, Cathy R., and James E. Wilen. 1994. Seasonal patterns and regional preferences in Japanese household demand for seafood. *Canadian Journal of Agricultural Economics 42*(1):87-103.

Western and Central Pacific Fisheries Commission. (2014). "North Pacific Swordfish (*Xipiaus gladius*) Stock Assessment in 2014."

Western Pacific Region Pacific Fishery Management Council (WPRFMC). (n.d.). Hawaii Seafood Market for Pelagic Fish. *WPRFMC,* 1-7. Accessed online at: http://www.wpcouncil.org/documents/pel_mrkt.pdf

Western Pacific Regional Fishery Management Council (WPRFMC). (2010). Fishery Ecosystem Plan for Pacific Pelagic Fisheries of the Western Pacific Region. *WPRFMC,* 1-249 http://www.wpcouncil.org/fep/WPRFMC%20Pelagic%20FEP%20(2009-09-21).pdf

Western Pacific Regional Fishery Management Council (WPRFMC). (2011). 107th Meeting of the Scientific and Statistical Committee. *WPRPFMC,* 1-11. Accessed Online at: http://www.wpcouncil.org/wp-content/uploads/2013/05/107-SSC-Report.pdf

Western Pacific Fishery Management Council (WPFMC). (2014). Hawaii longline electronic monitoring pilot study. Electronic Monitoring Workshop, Seattle, January 2014.

APPENDIX

A. Market Prices

Market prices for swordfish fluctuate significantly based on the supply and demand, gear type used, whether it is fresh or frozen, and between local and imported swordfish in a given year. Imported swordfish, depending on where it is imported from and when, generally sells for less than domestically caught swordfish (NOAA 2014b). From 2009 through 2013, swordfish fillets and steaks were priced on average at $6.58 per pound for swordfish landed in the U.S. compared to the $4.36 per pound for imported swordfish (Table 1).

Table 1. The price per pound of swordfish caught domestically compared to imported swordfish from 2009 through 2013. Data Sources: U.S. 2009-2010: NMFS 2011; U.S. 2011: NMFS 2012; U.S. 2012-2013: NMFS 2013; Import data: NMFS 2014c.

Year	U.S. average Fillets and Steaks	Imported Fillets and Steaks
2009	$5.82	$3.86
2010	$6.27	$4.29
2011	$6.64	$4.76
2012	$7.04	$4.87
2013	$7.15	$4.01

Within domestic swordfish fisheries, there is a large range of prices at which the fish is sold depending on the fishery and gear type. Between the gear types historically used in California (drift gillnet (DGN), shallow-set longline (SS LL), and harpoon (HPN)), Hawaii (SS LL and deep-set longline (DS LL)), and on the East Coast by the Atlantic Fishery (longline (ATL LL) and experimental deep-set buoy gear (ATL BG)), the Atlantic fishery's experimental deep-set buoy gear is projected to sell swordfish at the highest average price per pound. The historical California shallow-set longline fishery had the lowest average price per pound (Table 2). The CDFW also provides a comparison of the average price per pound of swordfish across gear types for California drift gillnet (DGN), longline (LL), and harpoon (HPN), where harpoon receives the highest price per pound, and longline receives the lowest price per pound out of the three (Table 3). Buyers describe the swordfish caught by drift gillnet and harpoon as being of high quality, a characteristic that has the potential to improve the marketing of swordfish from these gear types (FishChoice 2014; Stohs 2007). This is especially true for harpoon-caught swordfish, which is considered to be the freshest and of highest quality due to the length of the harpoon fishing trip and how the fish are handled and processed compared to fishing for swordfish with other gear types.

Table 2. Market price per pound of swordfish by gear type in California and Hawaii fisheries. Data Source: PFMC 2014b.

Fishery	Time period	Average price per pound of swordfish (2012 dollars)
CA DGN	2001-2012	$2.67
CA SS LL	1999-2004	$2.04
CA HPN	1995-2011	$4.77
HI SS LL	2005-2012	$2.33
HI DS LL	2005-2012	$2.66
ATL LL	2005-2012	$3.96
ATL BG	2007-2012	$5.33

Table 3. Comparison of 2013 price per pound of swordfish between three gear types in California. Data source: California Department of Fish and Wildlife, Marine Region 2014.

California Gear Type	Average price per pound ($2013 dollars)
DGN	$4.34
HPN	$8.93
LL	$3.03

B. Timeline of Regulatory History of West Coast Swordfish Fisheries

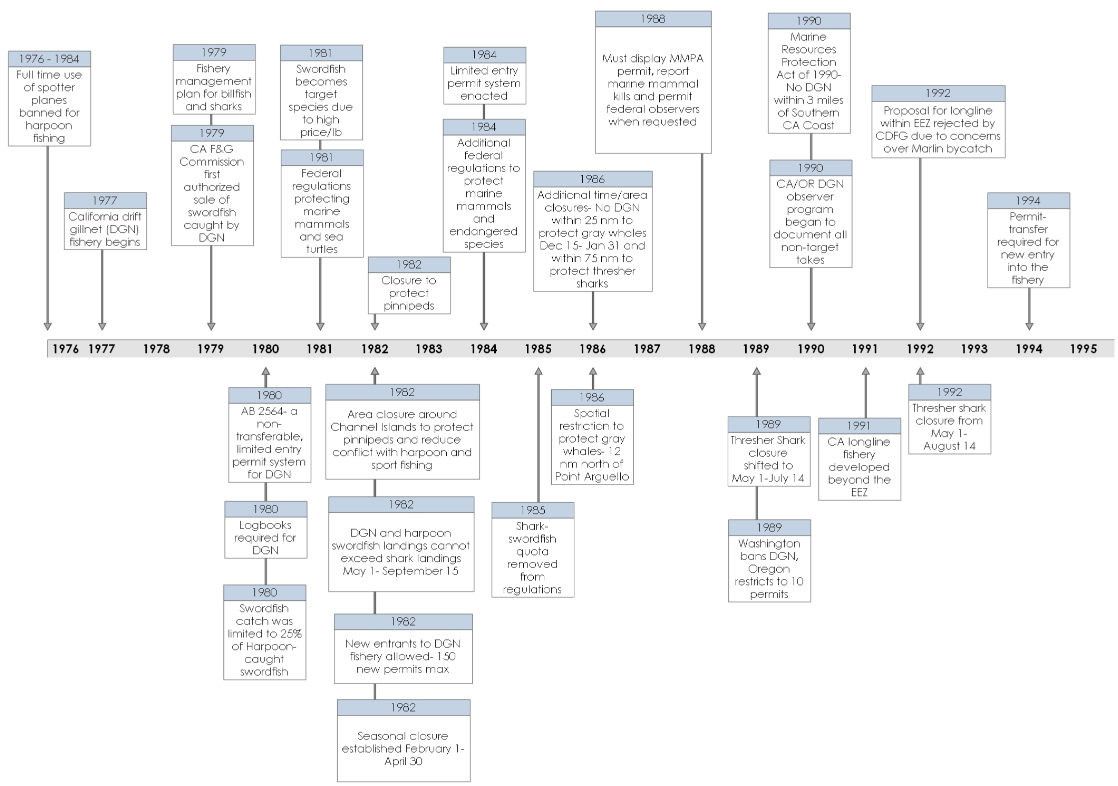


Figure 1. Timeline of Regulatory History of West Coast swordfish fisheries from 1976 – 1995.

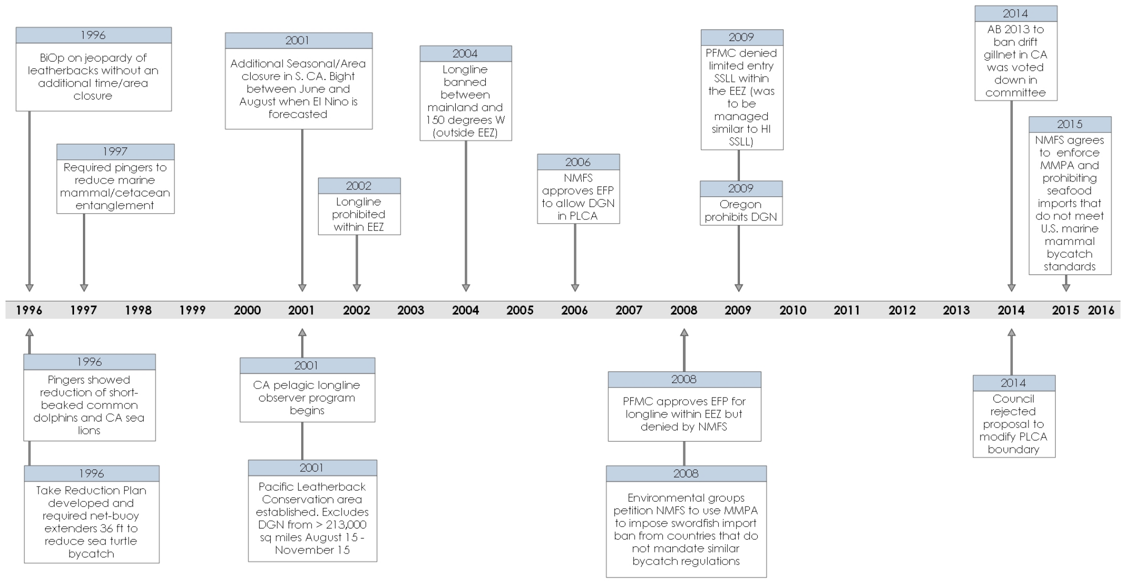


Figure 2. Timeline of Regulatory History of West Coast swordfish fisheries from 1996 – 2016.

C. Comparison of Domestic Swordfish Fisheries

Table 4. Comparison of fishery characteristics for the domestic swordfish fisheries.

FISHERY	California Swordfish Fishery (1)	California Swordfish Fishery (2)	California Swordfish Fishery (3)	Hawaii Swordfish Fishery	Atlantic Swordfish Fishery
Management Structure	Pacific Fishery Management Council	Pacific Fishery Management Council	Pacific Fishery Management Council	Western Pacific Fishery Management Council	NMFS
Gear type	Drift gillnet	Harpoon	Historical Shallow-set Longline	Shallow-set Longline	Pelagic longline
General gear description	900-1,000 fathoms netting panel with a 14 in. minimum mesh size; suspended vertically (maximum depth of 90 ft) in the water by floats along the top and weights along the bottom. Required net extenders of 36 ft and acoustic warning devices (i.e., pingers).	Metal handle 3-5 m long, attached to a metal shank and tipped with a dart.	Shallow-set longline at a max depth of 100 m and a max length of 100 km; 300m main line with two floats on either end connected to main line with 4 to 5 hooks between floats and the smaller lines 800 to 1,300 hooks in the total set.	Shallow-set longline is buoyed near the surface, have few hooks between floats, are relatively shallow, and have many lightsticks.	A main line that is suspended horizontally in the water column that is not anchored and has hooks that are attached from the mainline. 1 hook every 300ft (20-40 mi long).

Average number of vessels/year	80 (2001–2012)	30 (1995–2011)	31 (2001-2004)	27 (2005-2012)	114 (2005-2012)
Crew size	1 - 6 plus Captain	NA	4-6 crew plus Captain	4-5 plus Captain	2-6 plus Captain
Vessel length	35- 65 feet	20-87 ft	42 – 87 ft	65-70 feet	55 ft (boats that fish within EEZ); 100 ft (boats that fish outside EEZ)
Length of fishing trip	1-30 days	3-10 days	Unknown	32 days	Several days – 6 weeks
Fishing Regulations	Potential future hard caps for protected species; limited entry fishery; seasonal, temporal closures; pingers; mesh of >14 inches; net extenders to depth of 36ft	NA	Historical fishery	Hard caps for leatherbacks (26) and loggerheads (34) interactions; circle hooks and mackerel bait	Swordfish TAC; minimum swordfish size limits; circle hooks and mackerel bait
Fishing set	Single net set at dusk drifts during the night; soak duration ~9-14 hours	One harpoon; fishing during day	Set during night for 7-10 hours	Line set during night	Line set during night
Main fishing grounds	Offshore, 37 to 370 k, from Point Conception to the Mexican border	Most in Southern California Bight, but as north as Oregon	Outside of the EEZ of the West Coast	Inside and outside of the EEZ of Hawaii	Atlantic coast ranging close to home ports from Texas to Maine
Season duration within EEZ	May 1-Aug 14: >75 nmi from shore; Aug 15-Jan 31: >12 nmi; most effort from Oct – Dec; PLCA closure: Aug 15-Nov 15 (or Sep 1-Nov 15 for El Niño years)	Typically May - December	Data dot available	October 1st to January 31st	2 SWO fishing seasons: Jan 1 – June 30 and July 1 – Dec 31
How much is exported	US exports small amount	US exports small amount	US exports small amount	US exports small amount	US exports small amount
Avg. mt of swordfish landed	318 mt (2001-2008 & 2011-2012)	1,627 mt (2001-2004)	4 mt (1995-2011)	1,184 mt (2005-2012)	2,489 mt (2005-2012)
Avg. Annual Swordfish Revenue	$1.48 million (2001-2012)	$1.02 million (1995-2012)	$5.45 million (1999-2004)	$5.97 million (2005-2012)	$3.96 million (2005-2012)
Stock Health (include MSY?)	Healthy	Healthy	Healthy	Healthy	Rebuilt
Avg. Annual Observer Coverage	18.4%	NA	9.4% (2001-2004)	100%	11% (2005-2012)

Protected Bycatch Species of Concern	**Turtles:** loggerhead, leatherback, green, olive ridley **Whales:** humpback**,** sperm**,** fin**,** minke	NA	**Turtles:** loggerhead, leatherback, olive ridley **Seabirds:** black-footed & laysan albatross	**Sharks:** blue, whitetip, thresher **Seabirds:** black-footed & laysan albatross **Turtles:** loggerhead, leatherback, olive ridley, green	**Turtles:** loggerhead**,** leatherback
Targeted species / market species caught	Swordfish; sharks: common thresher, shortfin mako & blue; tuna: albacore, yellowfin, bigeye, & bluefin; groundfish	Swordfish	Swordfish; sharks: common thresher, shortfin mako & blue; tuna: albacore, yellowfin, bigeye, & bluefin; groundfish	Swordfish; tuna: albacore, bigeye, & yellowfin; mahi	Swordfish; tuna: yellowfin, skipjack, bigeye, Bluefin, albacore

D. California Swordfish Fishing: Management and Regulatory History

The California swordfish fishery has a long and complex management history in terms of the gears used within the fishery, regulations and restrictions introduced and implemented over time, and agencies responsible for management. The diverse gears utilized to catch swordfish off of California vary significantly with regards to vessel and crew size, effort, price received per pound of swordfish landed, length of trip at sea, locations fished, and non-target species caught. As a result, the three gear types used in California (drift gillnet, longline, and harpoon) incurred very different restrictions over time based on the differences in impact to populations of sensitive non-target species and competition with recreational fishermen.

As of 2015, drift gillnet and harpoon are the only allowable gears for the commercial swordfish fishery off of California. The fishery has a limited entry permit system and is managed under the Highly Migratory Species Fisheries Management Plan (HMS FMP) and is regulated under the Pacific Offshore Cetacean Take Reduction Plan (POCTRP). The HMS FMP includes various seasonal and area closures originally implemented by the California Department of Fish and Game (now California Department of Fish and Wildlife). The POCTRP includes the following requirement: pingers on drift gillnets to deter cetaceans, 36 foot deep extenders on drift gillnet lines, and skipper education workshops for the captains through the National Marine Fisheries Service Southwest Regional Office (NMFS 2014a). Fishermen from Oregon and Washington previously fished swordfish off their respective coasts, however, Oregon no longer issues state permits for the drift gillnet gear and Washington state prohibited drift gillnet due to political pressure for the non-selectivity of the gear (NMFS 2014a).

Regulations, such as seasonal and area closures, and limits on permits were established to reduce sea turtle and marine mammal bycatch interactions. To help increase swordfish catch and fleetwide profit that have since declined due to political pressure and regulations, California fishermen innovated to alter the existing gears and to create new, experimental gears in order to reduce the number of bycatch interactions.

The Early Years: A Harpoon Dominated Fishery
California's modern harpoon fishery targeting swordfish developed in the early 1900s and was modeled after the East Coast harpoon fishery, which began almost 70 years earlier (Coan et al. 1998). In 1973, the California harpoon fishery became limited entry with the requirement of a permit to fish swordfish commercially (Coan et al. 1998). The same year, California State Legislature gave regulatory authority of the swordfish fishery to the State Fish and Game Commission (F&GC) (Coan et al. 1998). The following year, the CDFW implemented a mandatory logbook system and specific permit qualification for the take of commercial swordfish, which were adopted by the F&GC (Coan et al. 1998).

The swordfish harpoon fishery peaked in 1978, when an estimated 2.6 million pounds of swordfish were landed by over three hundred harpoon fishing vessels from San Diego to Point Conception, CA (Coan et al. 1998). At that time, harpoon gear accounted for the majority of swordfish landings in California ports. Harpoon fishing continued as the only commercial fishery harvesting swordfish within the California EEZ until 1980, when drift gillnet fishing began (Coan et al. 1998).

Harpooners began using spotter planes in the early 1970's to assist in the sighting of swordfish (Coan et al. 1998). Due to conflicts between commercial fishermen who used airplanes and recreational fisherman and other commercial fishermen who did not use airplanes, a series of regulations were established in the following decades to limit the use of spotter planes in the harpoon fishery (Coan et al. 1998). In 1974, a notification was released by the F&GC stating that the use of airplanes to assist a vessel in capturing swordfish would be banned starting June 28, 1976 (Coan et al. 1998). In 1976, the F&GC allowed the use of airplanes to locate swordfish, but limitations were implemented in 1977 that increased the distance allowed between a spotter airplane and a vessel operated by a swordfish permittee (Coan et al. 1998). In 1984, the F&GC reduced the restriction to allow unlimited airplane use to directly assist the taking of any species of fish by a swordfish harpoon permittee (Coan et al. 1998).

The Entry of Drift Gillnet into the Fishery
Drift gillnet developed off of Southern California in 1977 as a thresher shark fishery, and in 1979, the F&GC authorized the sale of incidentally caught swordfish in this developing shark fishery. In 1980, California State Legislature passed a bill creating a non-transferable, limited entry permit system for the drift gillnet thresher shark fishery and also mandated the use of logbooks for drift gillnet fishers (Coan et al. 1998). Swordfish became the primary target species over thresher shark within the drift gillnet fishery in 1981 because of the higher price received per pound of fish (4 times the dockside value of shark) (NOAA 2014b).

The competition created by the more efficient drift gillnets resulted in many harpoon fishers transitioning to drift gillnet gear or obtaining permits to use both gear types (Coan et al. 1998). Drift gillnet quickly replaced harpoon as the primary method for catching swordfish due to the capacity to harvest a greater number with less effort, and today, only a few vessels continue to participate in the swordfish harpoon fishery (Coan et al. 1998, Hanan et al. 1993).

Drift Gillnet Develops
A permitting system was established in 1982 limiting the drift gillnet fishery to a maximum of 150 new permits, and each permit required that the fisher demonstrated prior grift gillnet experience ((NOAA 1988). Two years later an experimental limited entry drift gillnet program was instated for 35 new permits for fishers who had any of the following: a commercial fishing license for past 10 years, a valid general gill net permit, or had a gillnet with mesh size greater than14 inches with a reel for retrieval (Hanan et al. 1993). These provisions were removed in 1994 with the adoption of a regulation that only allowed new entrants into the fishery via a permit transfer (Drift Gill Net Shark and Swordfish Fishery 1994). In 2002, the minimum annual landings requirement for renewal of a drift gillnet permit was eliminated in California, however, fishermen were then required to purchase a permit each year to remain active in the fishery (PFMC 2015a). The regulations limiting entry into the fishery in the past were a result of a concern that swordfish were overfished based on observations in other U.S. swordfish fisheries (Martin 2012).

Protecting Bycatch and Sensitive Species
Despite the efficiency and profitability of drift gillnet, one significant problem quickly became obvious for this new California swordfish fishery. While harpoon specifically targeted and caught only swordfish, drift gillnet indiscriminately landed fish, marine mammals, and vertebrates, not all of which are target species (Hanan et al. 1993). Regulations were soon instated to reduce the overall impact of the fishery on sensitive species, starting in1982 when the CDFW adopted closures to protect pinnipeds (Hanan et al. 1993). This first closed season was established from February 1 to April 30 and an additional time and area closure was developed around the Channel Islands in order to safeguard these marine mammals and mitigate conflicts with harpoon and sport fishers (Hanan et al. 1993).

In 1984, new federal requirements were implemented to protect marine mammals and endangered species, and in 1985, time and area closures were established for the drift gillnet fishery to reduce marine mammal bycatch (PFMC 2015a). Beginning in 1986, drift gillnet vessels were not permitted to fish within 25 nautical miles (nm) of the coast from December 15 – January 31 and within 12 nm north of Point Arguello year round specifically to protect migrating gray whales and could not fish within 75 nm of the coast from June 1 to August 14 to conserve thresher sharks (PFMC 2015a). The thresher shark closure was changed in 1989 to May 1- July 15 and was extended in 1992 to August 14 (Coan et al. 1998). Additional closures included the 1989 ban on drift gillnet off of Washington State, a restriction of a maximum of 10 permits in Oregon, and the probation of drift gillnet vessels from fishing within 3 miles of the southern California coast as stated in the 1990 Marine Resources Protection Act (Coan et al. 1998).

Drift gillnet fishing was further restricted in 1988 when swordfish fishermen were required to: 1) obtain a Marine Mammal Protection Act permit; 2) report marine mammal mortalities; and 3) permit Federal scientific observers on board, if requested (Hanan et al. 1993). These new requirements were implemented because of the continued significant take of marine mammals and other marine species (Hanan et al. 1993).

In 1990, California and Oregon established an official drift gillnet observer program to document target fish species takes and the marine mammal, sea turtle, and seabird incidental takes (Hanan et al. 1993).

The observed takes of sensitive species induced the innovation of gear modifications and further regulations to reduce the interactions with marine mammals and sea turtles. In 1996, pingers, or electronic acoustic devices that broadcast sonic pings to deter cetaceans, were tested within the fishery to determine if they could reduce bycatch (Pacific Offshore 1997). Tests determined that pingers were successful at decreasing interactions with short-beaked common dolphins and California sea lions (Pacific Offshore 1997). This discovery was followed by the development of the 1996 Pacific Offshore Cetacean Take Reduction Team (POCTRT). The POCTRT established a Take Reduction Plan (TRP) in that outlined three mandatory strategies (to be implemented in 1997) in order to decrease incidental interactions with sea turtles and marine mammals (Pacific Offshore 1997). These included the mandatory inclusion of pingers both above and below the net and required the use of extenders to lower the net 6 fathoms, or 36 feet deep to reduce interactions with marine mammals and sharks that commonly surface during the night when the net is drifting. Workshops also became mandatory, as requested by NMFS, to educate fishermen on the proper installation of pingers (Pacific Offshore 1997).

The TRP also proposed a strategy for the mandatory conversion of entire drift gillnet fleet to other gear types due to the indiscriminate catch of non-target species. It was determined, however, that converting drift gillnet to longline would be too expensive and time consuming, and that the conversion from drift gillnet to harpoon would be less costly, but it would be ineffective at catching the same amount of swordfish, therefore the overall recommendation at the time was to avoid any gear conversion (Pacific Offshore 1997).

The Introduction of Longline

In 1991, the California longline was developed and the California State Legislature permitted targeting swordfish using longline outside of the California EEZ (Holt 2001). In 1992, a proposal to allow longline inside of the California EEZ to target tuna, swordfish, and shark, was rejected by the CDFW over concern for longline not being as size selective as drift gillnet and the uncertainty of the swordfish population that has since been determined that the swordfish stock is healthy (Hinton and Maunder 2011).

In the early years of its introduction, the longline swordfish fishery did not comprise a significant percentage of the total catch of the California, Washington, and Oregon longline fisheries (PFMC 2007). However, swordfish landings increased in the late 1990s and peaked in 2000, when 2,084 metric tons were caught, comprising 90% of the pelagic longline catch (PFMC 2005). When the Hawaii longline fishery closed due to sea turtle bycatch concerns in 2000, twenty Hawaiian longline fishing vessels relocated to southern California to join the fishing fleet (Holt 2001; PFMC 2005).

Conservation Concerns Continue

In October, NMFS considered whether converting drift gillnet to longline would reduce the number of turtle takes, and determined not to pursue this option further and stated that their reasoning was because: (1) California and Oregon law prohibit longline fishing within the EEZ, (2) only large vessels are capable of fishing that far offshore, therefore these vessels would likely have a significant impact on the fishery, and (3) the potential for an increase in turtle take.

In 2001, the California swordfish longline observer program was developed to document incidental take. The same year, the Council began developing the Highly Migratory

Species (HMS) FMP as the regulatory guidelines for the management of the fishery (PFMC 2011a).

As concerns over the take of sensitive species by longline vessels increased, the drift gillnet fishery experienced a significant area and temporal restriction. Due recorded interactions with endangered species, the Pacific Leatherback Conservation Area was developed in 2001. This closure, in effect annually from August 15 – November 15 (the prime foraging period off the California and Oregon Coasts) and covering an area greater than 213,000 square miles, was applied to the drift gillnet fishery under the FMP. The area closed spanned from Monterey, California to the mid-Oregon coast and westward beyond the EEZ to 129° W longitude with additional area closures in the Southern California Bight put into place when an El Niño event is forecast between June through August (Drift gillnet fishery 2007; PFMC 2011b). Members of the fishing industry believed that the implementation of the PLCA put many fishermen out of business, and this had a negative impact on the amount of swordfish supplied from the fishery (NMFS 2008). This closure has been estimated to have had economic impacts to the fishery in the form of significant declines in effort, revenue, and landings (NOAA 2011b).

Despite the decline in participation and profit with the drift gillnet swordfish fishery, the Council voted in March, 2002 against the inside EEZ longline management proposal brought forward in 2000 and voted for an indefinite moratorium on pelagic longline within the EEZ with potential re-evaluation after the completion of the bycatch reduction program (PFMC 2002a). In November, the Council voted for a general prohibition against longline within the EEZ to avoid potential bycatch and fishery competition problems, but opened up the potential for Exempted Fishing Permit (EFP) proposals for research to be evaluated (PFMC 2002b).

Due to gear improvements such as transitioning from J hooks to circle hooks and new legislation in Hawaii, the Hawaiian longline fishery reopened in 2004. However, the California longline fishery closed in 2004 (PFMC 2005; OPC 2008) under the newly established PFMC. The prohibition of shallow-set longline in California resulted in a transfer in fishing effort for this gear type to Hawaii, where longline had been recently re-implemented (PFMC 2005).

In 2004, the HMS FMP was approved for the West Coast fisheries (PFMC 2014b).

Failed Attempts at Changing the Fishery

In 2005, the PFMC discussed incorporating a modification of the PLCA time and area closure due to the impact it had on the profitability of the fishery (PFMC 2014c). The meeting resulted in the conclusion that the estimates of turtle CPUE within certain geographic regions cannot be determined because the sea turtle takes are so rare (PFMC 2014c). Consequently, the PFMC turned its focus to a proposed EFP to allow drift gillnet fishing in the current August 15 – November 15 closed area for all permittees subject to 20% observer coverage, to be implemented by August 15, 2007 (PFMC 2006a). Within their March 2006 meeting, the PFMC analyzed the impacts of the alternatives within the EFP proposal and preliminarily approved the proposal, pending the preparation of an environmental assessment (PFMC 2006a). The EFP, which received approval from NMFS in 2006, was not implemented because the environmental assessment that was prepared by the HMS Management Team for final approval by the PFMC was not signed in Washington D.C. (PFMC 2006b).

After 2004, EFPs were proposed to lift the California longline ban after new innovations proved successful in reducing sea turtle bycatch in the Hawaii longline fishery; however, longline remained a banned gear type (OPC 2008). An EFP was proposed in 2006 for one longline vessel within the West Coast EEZ. This EFP included the following criteria after the 2007 PFMC meeting: fishing was not permitted off of Washington State, circle hooks and mackerel bait were required, gear was to be set after sunset, a hard cap of 2 leatherback turtles would close the fishery immediately, observers onboard are mandatory, limit total fishing effort to 300 sets, a hard cap of 12 striped marlin, and a hard cap of 1 for short-finned pilot whale, sperm whale, fin whale, gray whale, humpback whale and minke whale (PFMC 2006a). The June Council meeting concluded the EFP needed further consideration and NMFS would need to demonstrate to the California Coastal Commission that the proposed EFP remained consistent with the enforceable policies of the California Coastal Management Plan (PFMC 2006a).

In 2008 PFMC submitted another request to have an EFP for one California fishing vessel to fish primarily swordfish, Bluefin tuna, Yellowfin tuna, and Bigeye using longline with circle hooks and mackerel bait within the EEZ along the Pacific coast (OPC 2008; PFMC 2007). The National Marine Fisheries Service (NMFS) denied this request due to sea turtle bycatch concerns, particularly regarding loggerhead and leatherback sea turtles, and heavy litigation from environmental groups and lobbyists (OPC 2008; PFMC 2007).

Due to concerns regarding the impact of foreign fisheries on sensitive species populations, in March 2008, two environmental groups, Center for Biological Diversity and The Turtle Island Restoration Network, petitioned the US government to use the MMPA (Marine Mammal Protection Act) to ban swordfish imports from nations whose bycatch of marine mammals exceeds US standards (HMSMT Report 2012). NMFS drafted a rule to define US standards for bycatch which had requirements to estimate the marine mammal interactions with swordfish fisheries (HMSMT Report 2012).

In 2009, the PFMC considered another option for a shallow-set longline fishery outside of the West Coast EEZ under the following provisions: limited entry program, gear modifications similar to the Hawaii fishery, and sea turtle hard caps (PFMC 2008). Once again, the Council voted not to consider this management change. The same year, Oregon discontinued the sale of drift gillnet fishing permits (NMFS 2014a)

These attempts to incorporate longline into the California swordfish fishery were all efforts to revitalize the fishery as the drift gillnet participation and catch declined as a result of the implemented PLCA. As these attempts all failed, in 2012 NMFS issued a questionnaire to fishermen to determine how they would prefer the fishery be revitalized (PFMC 2012b). The conclusions from this survey were as follows (PFMC 2012):

- Harpoon fishers believed that: the harpoon fishery is viable as it is, drift gillnet should be banned, and spotter planes should not be banned
- Drift gillnet fishers do not want to transition to harpoon because: high fuel expense using spotter planes, low swordfish catch rates with harpoon, unstable weather conditions
- Most drift gillnet fishers don't fish drift gillnet full time, instead, the majority of them fish other species like albacore, salmon, and crab
- Most drift gillnet vessels are too small to fish outside of the EEZ, so they are hesitant to transition to longline gear unless they were permitted to fish within EEZ
- Drift gillnet fishers that are in favor of a permit buyout would want:

- 50-100% of the value of their boat, gear, and amount made for fishing, which was estimated at $100,000 – 200,000 a year
- Some fishers wanted an exchange of their permit for another fishery with permit that is difficult to obtain (for example: groundfish, squid, or crab)

Because fishermen were highly successful in catching swordfish within the PLCA, in March 2014, fishermen proposed modifying the PLCA boundary such that fishing would be permitted in the southern area (PFMC 2014b). This proposal was rejected by the PFMC due to bycatch concerns (PFMC 2014b). After this March meeting, two developments changed the political landscape for this fishery: (1) AB 2019, a bill to ban the use of drift gillnets in California, was voted down in Committee (Committee on Water, Parks, and Wildlife) on April 29, 2014 and (2) A new stock assessment of affected sperm whale was under review (PFMC 2014b).

Further transitions for the drift gillnet fishery were considered in the April PFMC meeting. In order to provide more control over the number of participants and management specifically to NMFS and the PFMC, a Federal Limited entry permit system was created under the Magnuson Stevens Act for drift gillnet vessels (PFMC 2014b). Discussions also included a possible transition of the current fishermen to other gear types or a different drift gillnet management approach, and developed a plan for the phase out and eventual prohibition of the drift gillnet gear (PFMC 2014b). In June 2014, the Council began considering hard caps for high priority protected species including: fin, humpback and sperm whales; leatherback, loggerhead, olive ridley, and green turtles (June 2014 Council Meeting Summary). The PFMC also discussed 100% monitoring through observers and/or electronic monitoring systems for the drift gillnet fleet by 2016 or 2017 (PFMC 2014a). The PFMC also agreed to re-evaluate future access to PLCA and the potential for a longline fishery inside the EEZ in light of full accountability and acceptable bycatch cap levels (PFMC 2014a)

E. California Fishery Characteristics

Harpoon

A state permit and logbook are required for participation in the harpoon fishery in addition to a general resident or non-resident commercial fishing license and a current CDFW vessel registration (OPC 2014). Harpoon fishing effort typically occurs in the Southern California Bight from May to December, peaking in August, depending on weather conditions and the availability of fish in coastal waters (PFMC 2015a). Some vessel operators work in combination with a spotter airplane to increase the search area and to better locate swordfish. This practice will usually increase the catch-per-unit-effort compared to vessels that do not use a spotter plane, but this incurs higher operating costs due to fuel usage (NMFS 2014a). In 2013, only six harpoon vessels landed swordfish, catching 6 mt (NMFS 2014a).

Drift Gillnet Management

The drift gillnet fishery has a limited entry permit system and is managed under the Highly Migratory Species Fisheries Management Plan (FMP) and by regulations under the Pacific Offshore Cetacean Take Reduction Plan (POCTRP).

The HMS FMP requires a federal Pacific Highly Migratory Species permit with a drift gillnet gear endorsement for all U.S. vessels that fish for swordfish within the West Coast EEZ and the High Seas permit for U.S. vessels that fish outside of the EEZ and land their catch in California, Oregon, or Washington (NOAA 2014a). The permit is linked to an individual fisherman, not a vessel, and is only transferable under very restrictive conditions so that the value of the vessel does not become artificially inflated. In order to keep a permit active, permittees need to purchase a permit each year, but they are not required to make landings using drift gillnet gear in a given year. In addition, a general resident or non-resident commercial fishing license and a current vessel registration are required to catch and land fish caught in drift gillnet gear. Initially, when the limited entry program was established in 1980, about 150 permits were issued. The number of permits issued peaked at 251 in 1986 (NMFS 2014a). In 2011, there were 19 active drift gillnet fishermen and 57 latent permits and in 2013, the active permits decreased to 17 (CA AB2019).

Drift gillnet fishers are also required to document their landings in a logbook, display a Marine Mammal Protection Act permit, and must report marine mammal kills (Hanan et al. 1993; PFMC 2014c). The FMP includes various seasonal and area closures originally implemented by the CDFW. The POCTRP from 1996 includes the requirement for pingers on drift gillnets to deter cetaceans, 36 foot deep extenders on drift gillnet lines, and a requirement for vessel captains to participate in skipper education workshops though the National Marine Fisheries Service Southwest Regional Office (NMFS 2014a).

The drift gillnet fishing gear consists of a 1,000 fathom (1,829 m) gillnet with stretched mesh size from 18-22 in (45.7-56 cm), with a 14 in (35.6 cm) minimum. The net is set at dusk and allowed to drift during the night, with the fishing vessel typically attached at one end of the net. The soak duration is typically 12-14 hours depending on length of the night. Net extender lengths of a minimum 36 ft (11 m) became mandatory for the 1997-1998 fishing season, and the use of acoustic warning devices (i.e., pingers) became mandatory October 28, 1997, significantly decreasing cetacean entanglement (NMFS 2014a).

Fishing activity is highly dependent on seasonal oceanographic conditions that create temperature fronts which concentrate feed for swordfish. Off of the West coast, the outer waters of the California EEZ are cooler and less saline than more inshore waters and high seas waters beyond the EEZ (DGN – Longline EFP Background). The California Current brings cold, fresher water towards the equator long the coast, and is broadest in the northern part of the EEZ, narrower in the south, and extends to the outer EEZ boundary south of the 40°N latitude. This current is a cold water barrier between the warmer tropical waters off of the Southern California Bight inshore and warmer oceanic waters west of the EEZ boundary. Because of the seasonal migratory pattern of swordfish and seasonal fishing restrictions, over 90% of the fishing effort in recent years has occurred from August 15 – January 3 (NMFS 2014a).

This West coast fishery once included participating fishers in Oregon and Washington state fishing off of the coast of their respective states, and historically, the California drift gillnet fleet operated within EEZ waters adjacent to the state and as far north as the Columbia River, Oregon, during El Niño years. In Oregon, the drift gillnet fishery for swordfish had been managed under the Developmental Fisheries Program, which authorized up to ten annual permits to fish for swordfish with drift gillnet gear. In recent years, the fishery was inactive and no one applied for permits. This was followed in 2009 by the Oregon Fish and Wildlife Commission removing swordfish from the program, state permits to fish with drift gillnet gear off Oregon are no longer allowed, and the gear has been prohibited off of the Washington coast (NMFS 2014a).

Currently, California fishermen use drift gillnet to fish swordfish out of San Diego, Ventura/Oxnard, Santa Barbara/Goleta, and Morro Bay (Stohs 2014). San Diego has the greatest number of active fishermen (nine fishermen), while the other locations have about 2-3 fishermen (Stohs 2014). Most of the local swordfish landings are transported to Los Angeles, San Diego, and San Luis Obispo (Stohs 2014).

Drift Gillnet in CA prohibited in the following areas/times (Center for Biological Diversity 2008)

- EEZ off CA from Feb 1 – April 30
- Within 75 nm off CA coastline from May 1 – Aug 14
- Within 25 nm off CA coastline from Dec 15 – Jan 31
- Within EEZ bounded by Dana Point, Catalina Island, Point La Jolla from Aug 15 – Sept 30
- Within 12 nm from Oregon border to Point Arguello within the EEZ
- Specified areas around the Channel Islands

Longline

The Council's HMS FMP prohibits California pelagic longline fishing east of 150^{o} West longitude and the retention of striped marlin, however longline vessels fishing beyond 150^{o} West longitude can land swordfish and tuna in West Coast ports if the operator has the necessary state and Federal permits and complies with the High Seas Fishing Compliance Act (NMFS 2014a). The HMS FMP also requires a federal permit with a pelagic longline gear endorsement for all U.S. vessels fishing for swordfish outside of the EEZ and land their catch in California, Oregon, or Washington (NMFS 2014a).

The implementation of the HMS FMP in 2004 included the prohibition of a West Coast-based shallow-set longline fishery targeting swordfish, however deep-set longline gear targeting tunas is allowed outside of the EEZ. Currently only one vessel on the west coast participates in the tuna longline fishery (NMFS 2014a). Additionally, vessels with permits under the Western Pacific Fishery Management Council's Pelagics FMP are allowed to use shallow-set longline gear to target swordfish and land on the West Coast (NMFS 2014a). Swordfish landings to California ports by Hawaii-based vessels have been increasing since the Hawaiian longline fishery reopened in 2004. In 2013, seven Hawaii-permitted vessels landed swordfish in West Coast ports. For confidentiality reasons, the amount landed cannot be reported, because fewer than three dealers purchased these landings (NMFS 2014a).

F. Hawaii Swordfish Fishery

Management/Regulatory History

Both the California fishery and the Hawaii fishery originated in the early 1900s, however, they utilized different gear types. While the California fishery used harpoons to catch billfish, Hawaii used longline fishing that was introduced by Japanese Migrants in 1917 (WPRFMC 2010). Initially, Hawaiian longline fisheries targeted Yellowfin and Bigeye tuna (WPRFMC 2010). Historically the size of the Hawaii longline fishery has been much smaller than the California fishery. The Hawaiian fishery had a maximum size of about 50 longline vessels in the 1950s and 1980s, compared to the Californian fishery that had over 300 harpoon vessels in 1978 (WPRFMC 2010). However, as participation in the California fishery declined, participation in the Hawaiian longline fishery increased, consisting of 115 vessels in 2001 (Ito & Machado 2001). The expansion of the Hawaiian fishery was due to the entry of fishermen from the Atlantic Ocean and Gulf of Mexico which all fished swordfish and tuna using longline.

The increase in the Hawaiian fishery translates to 600,000 pounds of swordfish caught in 1989, increasing to about 13.1 million in 1993 (WPRFMC 2010). Now, the Hawaii fishery harvests 15 to 26.5 million pounds per year (WPRFMC 2010). The increases in catch were facilitated by not only the increase in boats but also the advancement in technology using larger longline vessels and monofilament mainline longline reels (WPRFMC 2010).

Even though the Hawaii fishery is now considered a stable and profitable fishery, it too went through extreme regulation events. When the Hawaii fishery reached a historical peak of 141 vessels in 1991, an emergency moratorium of fishing was instated in the region due to the fear of causing overfishing (WPRFMC 2010). The fishery reopened in 1994 with new restrictions including the maximum number of longline fishing permits, the size of the vessels and the addition of an observer program (WPRFMC 2010). The fishery was regulated to a maximum of 164 vessel permits and vessels were required to be less than 101 feet long (WPRFMC 2010). Another moratorium on the Hawaiian longline fishery occurred again in 2001 due to significant amount of endangered sea turtles and seabirds bycatch (WPRFMC 2010). In response, some the Hawaiian longline fishermen joined the California swordfish fishery, while others stayed in Hawaii and modified their longline gear to target tuna (WPRFMC 2010).

The reopening of the Hawaii longline fishery in April 2004 was again accompanied by new regulations and required the use of new technology. Hawaiian vessels were required to carry a satellite-based vessel monitoring system (VMS) to track the location of the vessels (WPRFMC 2010). The VMS records longitude and latitude of the vessels at all times and is monitored by NMFS to ensure the vessels are not fishing in unregulated territories (WPRFMC 2010). Other regulation changes included a time/area closure around the islands, an observer coverage level of 100% for shallow-set fishing (which targets swordfish) and hard cap on the number of turtle interactions that can occur (WPRFMC 2010). After this cap is reached, the fishing permits will be revoked and the fishery will be closed until the following season (WPRFMC 2010). Upon observer verification of observer requirements, NMFS will reimburse vessel owners a reasonable amount for observer subsistence as determined by the Regional Administrator (WPRFMC 2010).

Hawaii also requires a total of 6 different permits to operate a longline vessel within the Hawaiian Pelagic longline fishery, while the California fishery only requires 2 permits (NMFS 2010b). Both fisheries require the High Seas Fishing Compliance Act Permit. These permits required by the Hawaii fishery include: Hawaii Longline Limited Access Permit, State of Hawaii Commercial Marine License, High Seas Fishing Compliance Act Permit, Western and Central Pacific Fisheries Commission Area Endorsement, Marine Mammal Authorization Program Certificate, and the Western Pacific Receiving Vessel Permit (NMFS 2010b).

G. North Atlantic Swordfish Fishery

Similar to the California swordfish fishery, the US Atlantic swordfish fishery initially operated as a harpoon and handgear fishery and later transitioned to a more efficient gear type (NOAA 2013). While California initially transferred most fishing effort to drift gillnet followed by some transfer of effort to longline due to the low catch per unit effort associated with harpoon, the Atlantic replaced harpoon with pelagic longline gear to specifically target swordfish and tuna during the 1960’s (Stohs 2010).

The Atlantic fishery was initially managed under the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the first Atlantic Fishery Management Plan (FMP) was implemented in 1985 by the five Atlantic Regional Fishery Management Councils (New England, Mid-Atlantic, South Atlantic, Gulf of Mexico, and Caribbean) (NOAA 2014a, Stohs 2010). This management structure only lasted until 1990, after which the Blue Water Fishermen's Association (BWFA) formed and management of all highly migratory species was transferred from the regional Councils to the Secretary of Commerce and subsequently to NMFS to more effectively help with swordfish management (BWFA 2014a).

Because the North Atlantic swordfish stock became overfished in 1990 after peaking in 1987 with 20,236 mt, management changed and BWFA and NMFS established more stringent regulations with further fishing restrictions (NOAA 2014a, ICCAT 2011). By the mid-1990's, a domestic rebuilding plan was established and the ICCAT created a 10-year international rebuilding plan for the Atlantic swordfish stock (ICCAT 2011). These rebuilding plans included: reducing the total allowable catch (TAC) to 10,400 mt, setting minimum size limits, creating a limited access swordfish fishery, reducing commercial quotas, restricting swordfish dealer permits, observer and logbook reporting requirements, vessel monitoring systems for longline vessels, and closing certain fishing grounds (BWFA 2014c, NOAA 2014a, ICCAT 2011, NOAA 2013b, Stohs 2010). Due to these domestic and foreign regulatory changes, some fleets shifted distributions to the South Atlantic or out of the Atlantic altogether, while some fleets changed operating procedures to opportunistically target tuna and/or sharks due to more favorable market conditions at this time (ICCAT 2011).

The Atlantic longline fishery not only had problems with depleting the swordfish stock, but also turtle bycatch. In 2000, loggerhead and leatherback turtle "takes" exceeded acceptable levels, resulting in a large turtle closure area south of Newfoundland (NOAA 2013). Instead of closing down the longline fishery, which is what the Hawaii fishery did from 2001-2004 and California from 2004-present, the Atlantic fishery innovated to reduce turtle interactions while keeping the fishery opened. BWFA worked with NOAA to teach fishermen how to de-hook and release turtles and develop circle hooks and mackerel bait type, resulting in 88% and 86% reductions in turtle takes for loggerhead and leatherback turtles, respectively (BWFA 2014b, Stohs 2010). Because the new gear design proved successful, the turtle closure area south of Newfoundland was reopened as long as fishermen use the new gear design, possess turtle release hooks, and know how to release turtles (NOAA 2013).

Fishermen and researchers also innovated to create a new gear type that would increase swordfish catch but also minimize bycatch of protected species. This gear type, buoy gear, was introduced in the Atlantic in 2006 (NOAA 2013). Researchers in California are currently developing a buoy gear with a slightly different design to also reduce turtle bycatch.

In 2009, a stock assessment found that the North Atlantic swordfish stock was fully recovered (NOAA 2014a). The catch in 2009 was 12,655 mt, a 37% decrease from the 1987 peak of 20,236 mt (ICCAT 2011). In 2013, another stock assessment for the North Atlantic swordfish again found this stock to be healthy, or at a sustainable population level (NOAA 2014a). Through strict management and regulations including TAC, size limits, and data reporting regulations, the North Atlantic swordfish population was rebuilt. This recovery exemplifies a stock's positive response to effective management strategies.

Management was so successful that regulations actually changed from rebuilding the once overfished stock to increasing the harvest rate by reducing the minimum size limits from 29 to 25 inches (NOAA 2013). More importantly, however, was the Marine Stewardship Council certification that the Southeast North Atlantic SWO LL and buoy gear received in 2013 (MSC 2015).

H. Comparison of Bycatch Mitigation Strategies for Domestic Swordfish Fisheries

Table 5. Comparison of bycatch mitigation strategies for the domestic swordfish fisheries.

Bycatch Mitigation Requirements	California Drift Gillnet	Hawaii Shallow-set Longline	Atlantic Pelagic Longline
Observer coverage level	12-20%	100%	7-10%
Hard caps on Sea Turtle Interactions		X	
Time Area Closures	X	X	X
Protected Species Workshop		X	
Sea Turtle Handling Measures		X	X
Seabird Handling Measures		X	
Marine Mammal Handling and Release Measures		X	X
Modifications to fishing gear	X	X	X
Acoustic warning device	X	X	X
Modifications to fishing techniques	X	X	X
Ban on Shark Finning	X	X	X
Subsurface setting	X	X	X

I. Data Sources

1. California Department of Fish and Wildlife (CDFW)

a. CDFW gillnet logbook data (John Childers)

- Range of years (drift gillnet): 2001-2012
  - Years used in analysis: 2006-2011
  - Reason: Only had the average weight of drift gillnet from 2006-2011 to use with the total catch (in individuals) to calculate CPUE
- Range of years (harpoon): 1980-2013
  - Years in analysis: 2006-2013
  - Reason: Only had the average weight of drift gillnet from 2006-2011 to use with the total catch (in individuals) to calculate CPUE
- Drift gillnet logbook data includes: effort data (in number of vessel days and total number of sets), month, year, fishing block number, swordfish count (in number of individuals)

- Harpoon logbook data includes: effort data (in number of vessel days), month, year, fishing block number, swordfish count (in number of individuals), and whether aircrafts/spotter planes were used for fishing

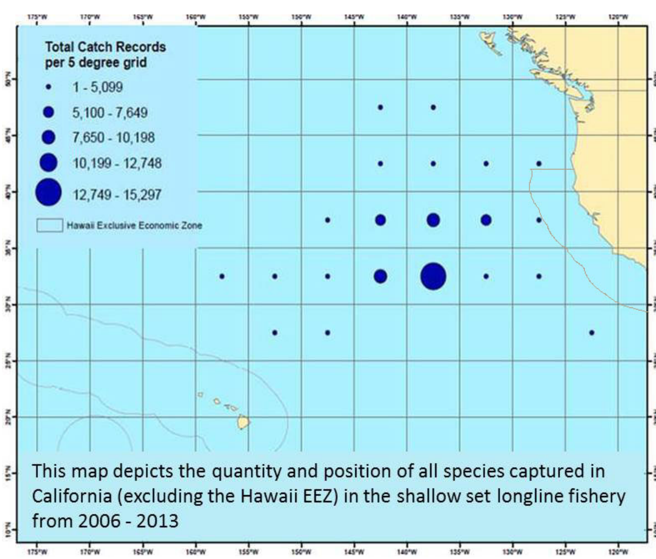
b. *Average swordfish weights* (from Liz Hellmers)

- Gear types: drift gillnet
- Datasets for drift gillnet include: day, month, year, species IDs, number of individual fish by species caught, total weight (pounds), pounds per fish

2. Pacific Islands Fisheries Science Center (PIFSC)

a. *Observer data* (from Lesley Jantz and Eric Forney)

- Includes all species on the catch form including fish, sharks, turtles, seabirds, and marine mammals (only swordfish, turtles, and marine mammals caught were actually included in this analysis)
- The observers took measurements of every third fish, per protocol
- Dataset also includes: trip number, fishing blocks in 5x5 degree blocks, haul begin and haul end dates, effort (in number of hooks), species, caught and kept/returned condition of each species, length measurements of fish (usually fishermen measured every third fish)
- PIFSC data includes: landings, logbook, observer, and size composition data (NMFS does this fishery monitoring) https://www.iattc.org/PDFFiles2/DC-1-02c.pdf
    - Mandatory logbooks (100% coverage) for both California and Hawaii are mandated by state and federal law.
    - When boats depart Hawaii and land in California, the CDFW collects federal logbooks and sends them to PIFSC in Hawaii.



3. **Southwest Fisheries Science Center/NMFS**

   a. *Observer record* (from Steve Stohs)
      - For drift gillnet only
      - Dataset includes: trip ID, month, year, latitude/longitude, species code, species caught condition, and common name of species from 1990-2013 for drift gillnet

   b. *Drift gillnet and harpoon cost and earning survey report* (from Steve Stohs)
      - From 2008-2010 for drift gillnet and harpoon

   c. *Price per pound of swordfish landed* (from Steve Stohs)
      - Initial price per pound of swordfish estimates for drift gillnet and harpoon
      - Calculations based on HMS SAFE data summaries
      - The HMS SAFE reports landings in round weights (lbs), so these weights were converted to landed weights (lbs) by using a factor of 1.45 to account for onboard processing of swordfish before it is landed

   d. *Revenue for Hawaii shallow-set longline landings to California* (from Minling Pan)
      - Aggregated West Coast PacFIN landings data by month for HI SSLL trips with landings to the West Coast over the 2006-2013 calendar years
      - Only includes revenue data for months where there were 3 or more vessels to keep with the "Rule of 3" for release of confidential data
      - Adjusted to 2013 dollars using the Implicit Price Deflator for GDP

   e. *Cost data for HI SSLL landings to California* (Minling Pan)
      - Includes trip days, days fished, month, # of trips (with cost data), fuel cost per trip, fuel cost per trip adjusted for inflation (2013$), total trip costs, total trip costs per trip adjusted for inflation, and trip costs adjusted per trip day.
      - Trip costs, labor costs, and fixed costs were provided.

J. Management Scenarios Incorporated within Model

Table 6. Management scenarios used in the model.

#	Scenario Type	Total Vessel Days	Total Drift Gillnet Vessel Days	Total Longline Vessel days	Longline Vessel Days Inside EEZ	Longline Vessel Days Outside EEZ	Description - Gear and Area (*Outside* refers to outside the EEZ, *Inside* refers to inside the EEZ; Harpoon effort was kept constant with 469 Vessel Days (maximum effort since 1980))
1	*Status Quo*	**1229**	760	0	0	0	100% Drift Gillnet
2	*Full Effort of Drift Gillnet and Longline*	1476	760	247	0	247	100% Drift Gillnet, 100% Longline Outside
3		1476	760	247	124	124	100% Drift Gillnet, 50% Longline Inside, 50% Longline Outside
4		1476	760	247	62	185	100% Drift Gillnet, 25% Longline Inside, 75% Longline Outside
5		1476	760	247	185	62	100% Drift Gillnet, 75% Longline Inside, 25% Longline Outside
6		1476	760	247	247	0	100% Drift Gillnet, 100% Longline Inside

7	***Longline Effort Transferred To Drift Gillnet***	1476	822	185	0	185	100% Drift Gillnet (Plus 25% Longline Transferred), 75% Longline Outside
8		1476	822	185	93	93	100% Drift Gillnet (Plus 25% Longline Transferred), 37.5% Longline Outside, 37.5% Inside
9		1476	822	185	185	0	100% Drift Gillnet (Plus 25% Longline Transferred), 75% Longline Inside
10		1476	884	124	0	124	100% Drift Gillnet (Plus 50% Longline Transferred), 50% Longline Outside
11		1476	884	124	62	62	100% Drift Gillnet (Plus 50% Longline Transferred), 25% Longline Outside, 25% Inside
12		1476	884	124	124	0	100% Drift Gillnet (Plus 50% Longline Transferred), 50% Longline Inside
13		1476	945	62	0	62	100% Drift Gillnet (Plus 75% Longline Transferred), 25% Longline Outside
14		1476	945	62	31	31	100% Drift Gillnet (Plus 75% Longline Transferred), 12.5% Longline Outside, 12.5% Inside
15		1476	945	62	62	0	100% Drift Gillnet (Plus 75% Longline Transferred), 25% Longline Inside
16		1476	1007	0	0	0	100% Drift Gillnet (Plus 100% Longline Transferred)
17	***Drift Gillnet Effort Transferred To Longline***	1476	190	817	0	817	25% Drift Gillnet, 100% Longline (Plus 75% Drift Gillnet Transferred) Outside
18		1476	190	817	409	409	25% Drift Gillnet; 50% Longline Inside (Plus 37.5% Drift Gillnet Transferred), 50% Longline Outside (Plus 37.5% Drift Gillnet Transferred)
19		1476	190	817	347	470	25% Drift Gillnet; 25% Longline Inside (Plus 37.5% Drift Gillnet Transferred), 75% Longline Outside (Plus 37.5% Drift Gillnet Transferred)
20		1476	190	817	470	347	25% Drift Gillnet; 75% Longline Inside (Plus 37.5% Drift Gillnet Transferred), 25% Longline Outside(Plus 37.5% Drift Gillnet Transferred)
21		1476	190	817	817	0	25% Drift Gillnet; 100% Longline (Plus 75% Drift Gillnet Transferred) Inside
22		1476	380	627	0	627	50% Drift Gillnet, 100% Longline Outside (Plus 50% Drift Gillnet Transferred)
23		1476	380	627	314	314	50% Drift Gillnet, 50% Longline Inside (Plus 25% Drift Gillnet Transferred), 50% Longline Outside (Plus 25% Drift Gillnet Transferred)
24		1476	380	627	252	375	50% Drift Gillnet, 25% Longline Inside (Plus 25% Drift Gillnet Transferred), 75% Longline Outside (Plus 25% Drift Gillnet Transferred)
25		1476	380	627	375	252	50% Drift Gillnet, 75% Longline Inside (Plus 25% Drift Gillnet Transferred), 25% Longline Outside (Plus 25% Drift Gillnet Transferred)
26		1476	380	627	627	0	50% Drift Gillnet, 100% Longline Inside (Plus 50% Drift Gillnet Transferred)
27		1476	570	437	0	437	75% Drift Gillnet, 100% Longline (Plus 25%Drift Gillnet Transferred) Outside
28		1476	570	437	219	219	75% Drift Gillnet; 50% Longline Inside (Plus 12.5% Drift Gillnet Transferred), 50% Longline Outside (Plus 12.5% Drift Gillnet Transferred)
29		1476	570	437	157	280	75% Drift Gillnet; 25% Longline Inside (Plus 12.5% Drift Gillnet Transferred), 75% Longline Outside (Plus 12.5% Drift Gillnet Transferred)
30		1476	570	437	280	157	75% Drift Gillnet; 75% Longline Inside (Plus 12.5% Drift Gillnet Transferred), 25% Longline Outside (Plus 12.5% Drift Gillnet Transferred)
31		1476	570	437	437	0	75% Drift Gillnet, 100% Longline (Plus 25%Drift Gillnet Transferred) Inside
32		1476	0	1007	0	1007	100% Longline Outside (With All Drift Gillnet Transferred)
33		1476	0	1007	504	504	50% Longline Inside (50% Drift Gillnet Transferred), 50% Longline Outside (50% Drift Gillnet Transferred)
34		1476	0	1007	442	565	25% Longline Inside (50% Drift Gillnet Transferred), 75% Longline Outside (50% Drift Gillnet Transferred)
35		1476	0	1007	565	442	75% Longline Inside (50% Drift Gillnet Transferred), 25% Longline Outside (50% Drift Gillnet Transferred)
36		1476	0	1007	1007	0	100% Longline Inside (With All Drift Gillnet Transferred)

K. Future Management Options

Gear-type Innovation: Buoy- Gear

Another gear type that could potentially increase the productivity of California swordfish fishery while minimizing impacts to bycatch species is deep-set buoy gear. Deep-set buoy gear is being developed and tested in California by the Pfleger Institute of Environmental Research (PIER) and NOAA. The gear consists of one or more floatation devices from which numerous mainlines are attached to support one to several numbers of hooks, depending on the configuration (Sepulveda et al. 2014). Trials were performed by PIER and NOAA during the 2013-2014 swordfish season off the southern California coast to develop and test modified deep-set buoy gear configurations for use by cooperative fishers in 2014-2015 (Sepulveda et al. 2014). Although these experiments were not conducted on a large enough scale to calculate the CPUE, these trials did show that swordfish could be selectively targeted at a certain depth; that non-target catch rates, for species such as sharks, were relatively low; and there were no interactions with any species of concern (Sepulveda et al. 2014). The results of the trials included the capture of 11 swordfish, 6 blue sharks, 1 salmon shark, and 1 mako shark, over the course of 12 fishing days, or 2,590 hook hours (Sepulveda et al. 2014). All of these species in the study are non-target species encountered in the California drift gillnet fishery, and some are even market species such as the mako shark, that therefore provide revenue for the fishers (Sepulveda et al. 2014).

Deep-set buoy gear appears to be more a selective gear type that catches less bycatch compared with drift gillnet and longline. Deep-set buoy gear is deployed during the daylight hours when swordfish are found in relatively deep water (i.e. 250-350 m) and species of concern, such as leatherback sea turtles, are found near the surface of the water (Collaborative Fisheries Research West). A gear type that is utilized during the day also poses less risk to species of concern in that fishers can see when a species is caught on the mainline and retrieve the set immediately; therefore, reducing the amount of time spent on a longline hook or in a drift gillnet reduces the risk of mortality.

After the additional testing of deep-set buoy gear by cooperative fishers in the 2014-2015 swordfish season, more inferences may be made regarding the economic and ecological costs of the gear type, which includes its efficiency and its effects on non-target species (Sepulveda et al. 2014). The major foreseeable cost associated with this gear type is the time required to set and retrieve each set or unit (Beverly and Robinson 2004). Also, more information regarding post-release survivorship of non-target species, such as sharks, will be critical in assessing the ecological costs associated with deep-set buoy gear (Sepulveda et al. 2014). Managers are optimistic that this may be a viable option for the California fishery because it appears to be economically viable (total cost for 10 sets of gear is around $4,000), can be utilized by small boats and is highly selective in catching swordfish (Sepulveda et al. 2013). However, it has not yet been determined whether deep-set buoy gear can supply swordfish on a commercial scale. In the March 2015 PFMC Meeting, the Council approved 2 EFPs to test buoy-gear with 100% observer coverage and only in Federal Waters (PFMC 2015c).

Electronic Monitoring

Electronic monitoring is the use of video technology to record catches, discards, and protected species bycatch (PFMC 2014f). One of the PFMC's goals as outlined in the March 2015 Highly Migratory Species Management Team (HMSMT) Report is to "reduce specified protected species takes" within the California drift gillnet fishery (PFMC 2015b). To achieve this goal, one objective of the PFMC is "to increase monitoring coverage rates above 2013 levels to facilitate implementation of bycatch reduction measures such as hard caps" (PFMC 2015b). This objective states a target for implementing 100% observer coverage through human observers and/or electronic monitoring by 2018. Further, the objective states that the costs associated with this increase in observer coverage will be non-government funded as the NMFS budget, which allocates funds for 30% coverage, is unlikely to be increased (PFMC 2014e; PFMC 2015b).

Worldwide, fisheries managers have considered the feasibility of electronic monitoring as implemented for specific gear types and fleets. The International Council for Exploration of the Sea (ICES) produced a report on bycatch of protected species that explored recent developments of electronic monitoring in Sweden and Denmark. Two pilot projects involving three drift gillnet vessels, four trawl vessels, and one seine vessel, were conducted using monitoring systems by Archipelago Marine Research. These projects concluded that electronic monitoring could be a viable, cost-effective way to monitor protected species bycatch. Furthermore, the study notes that the cost of implementing electronic monitoring would be about one third of the cost of human observers (ICES 2010). In the United States, electronic monitoring system studies have been conducted by the Northeast Fisheries Science Center (NEFSC 2014), in which cameras began recording at the start of fishing activity as triggered by a drum rotation sensor or a hydraulic pressure transducer (NEFSC 2014). An electronic monitoring pilot study was also completed for the shallow-set and deep-set longline fisheries in Hawaii. This study notes the strengths of electronic monitoring in that electronic monitoring reviewers were able to identify hooks deployed and catch retained. In regards to protected species bycatch, electronic monitoring and human observer data were similar in detecting all sea turtle interactions; however each method of observer coverage missed one of three sea turtles caught (WPFMC 2014). In the West Coast groundfish fishery, the PFMC selected final preferred alternatives for an electronic monitoring program for all groundfish fisheries in the trawl catch shares program (PFMC 2014g).

A drift gillnet electronic monitoring pilot project was completed in the 2006/2007 fishing season, the results of which demonstrated electronic monitoring as a feasible alternative or supplement for protected species bycatch monitoring (PFMC 2014b). There are both advantages and disadvantages to implementing electronic monitoring in the drift gillnet fishery. On-board observer coverage is an expensive compliance cost as vessels are billed on a per-day basis for observers for both at-sea and standby time. Therefore, this may induce higher costs for the days that a vessel does not fish when an observer is on-board. However, electronic monitoring systems can be implemented such that recording occurs when the net is set and ends when the net is hauled back on-board in order to monitor solely the time when fishing is occurring, thereby resulting in cost savings (PFMC 2014f). However, the annual costs and additional funding needed to develop and implement electronic monitoring in the drift gillnet fleet as outlined in the West Coast Regional Electronic Monitoring Plan for the 2015-2017 Phase are a cost of $850,000 in 2015, and require $852,000 in additional funding in 2015 alone (PFMC 2015d).

100% observer coverage to ensure full accountability of the fishing fleet is also closely tied to the potential establishment of bycatch hard caps (PFMC 2014d), as bycatch hard caps cannot be effectively implemented without 100% observer coverage. Disadvantages to electronic monitoring include difficulty in a camera or video recording determining mortality or serious injury of protected species, as well as lack of ability to take measurements and gather scientific information as completed by human observers (PFMC 2015c). However, if bycatch interactions are based on "entanglement," rather than mortality or serious injury, then this determination in regards to the bycatch hard caps is irrelevant. If electronic monitoring can be effectively implemented at a lower cost than human observers, it may prove to be a viable supplement to on-board human observers in the drift gillnet fishery.

Bycatch Individual Transferable Quotas

Individual transferable quotas (ITQs) are used as a management tool to limit the harvest of target species and avoid over-exploitation of fish stock (Costello et al 2008). If ITQs are well implemented, they may prevent collapse across diverse taxa and ecosystems (Costello et al. 2008). ITQs are gaining popularity because they provide fishers in limited-entry fisheries with a right to harvest a share of the total quota, which leads to reduced competition and cost (Costello et al. 2008). The transferability of these quotas promotes economic efficiency because less efficient fishers can trade their share of the quota to more efficient fishers. This provides an incentive for inefficient fishermen to exit the fishery, while the fishery as a whole still maintains the same total catch amount.

However, when ITQs are only applied to target species, the incentive to avoid bycatch may not exist (Squires et al. 1998). To incentivize bycatch avoidance, ITQs for multiple-species including marketable bycatch have been implemented (Costello et al. 2008). When used in an appropriate setting, a multi-species ITQ creates a market for bycatch species between more and less efficient fishermen to avoid bycatch and creates an incentive to reduce negative impacts to potentially sensitive species (Costello et al. 2008). Therefore, with sufficient observer coverage, ITQs for bycatch may be a potential solution to manage fisheries with bycatch concerns.

It is important to note that ITQs for bycatch are not appropriate when 1) an individual bycatch event accounts for a large percentage of the entire quota of the bycatch species and 2) when bycatch events are rare and unpredictable (Holland 2010). These events cause the allocation of individual quotas to be infeasible and the marketability of the quotas may be difficult due to high price variability (Holland 2010). This was seen in the West Coast groundfish trawl fishery, where there are very low bycatch quotas compared to target species with large quotas (Holland 2010).

The implementation of an ITQ system for cetaceans or sea turtles in the California swordfish fishery would not be feasible due to the rarity and randomness of the interactions (Stohs 2014). It would be impossible for fishers to assess the value of a bycatch quota due to the highly unpredictable capture of bycatch species, which would result in fishers having to face a substantial financial risk. Risk reduction mechanisms such as pooling quotas, self-insurance, and market insurance could be implemented by stakeholders to reduce risk; however further research needs to be conducted in this area (Holland 2010).

The Pacific Leatherback Conservation Area and Exempted Fishing Permits

The Pacific Leatherback Conservation Area (PLCA) is an annual closure area extending from Monterey, California, to mid-Oregon, and encompassing over 213,000 square miles, that excludes the drift gillnet swordfish fishers from fishing in the area from August 15 to November 15 (Figure 4) (PFMC 2014c). The PLCA was established in 2001 by the PFMC in an effort to reduce sea turtle interactions with the drift gillnet fishery, particularly leatherback turtles (PFMC 2014c). During years when an El Niño is forecasted between June through August, additional closure areas are put into place because the waters are warmer during this time period, resulting in sea turtle migrations further south outside of the PLCA, and a resultant increased vulnerability for sea turtle interactions within the drift gillnet fishery (PFMC 2006b).

One major socioeconomic consequence of the establishment of the PLCA is the significant decline in drift gillnet fishery participation; and therefore, a significant decrease in the economic viability of the fishery. For example, in 2000, just one year prior to the sea turtle closure area, 81 active fishermen targeted swordfish using1,766 sets; and, in 2004, participation in this fishery decreased to 36 drift gillnet fishermen using just over 1,000 sets (PFMC 2006b). However, in alignment with the main purpose of establishing this closure area, the number of sea turtle interactions is assumed to have significantly decreased, especially the leatherback turtles (PFMC 2006b).

The PLCA was closed off to drift gillnet and to the historical longline fishing gear type that used squid bait and J-hooks in in 2001. Although longline was banned as an allowable gear type in 2004, our project incorporates the reintroduction of the longline gear type with the new gear innovations of mackerel bait type and circle hooks – using data from Hawaii to model a potential longline fleet in California – which has shown to reduce turtle interactions by up to 86% (Finkbeiner 2011).

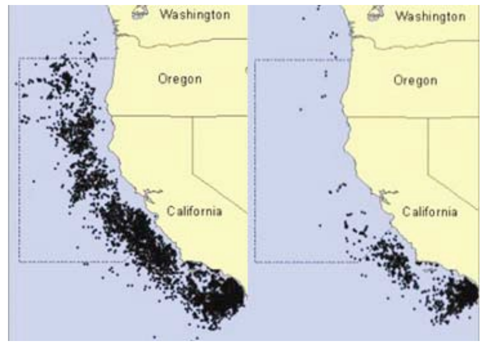


Figure 3. Drift gillnet sets from July 1990 to May 2001 before the PLCA (left) and drift gillnet sets from August 2001 to January 2010, after the closures were established (right). (NOAA 2014a).

This large, closed-off area is a highly productive region, where fishermen claimed to have had high swordfish catch per unit effort prior to the closure (Burke 2014). This is due to the warm sea surface temperatures off of the coast of California during the beginning of November, which only lasts until the middle to end of November when the temperature drops just enough that it is not suitable habitat for swordfish (Burke 2014). However, this area was closed off during certain times of the year because of the previously high sea turtle interactions, especially leatherback takes with the drift gillnet gear type (PFMC 2014c).

To help increase the economic viability of the swordfish fishery off of the West Coast, fishermen propose opening the PLCA either through (1) the use of Exempted Fishing Permits (EFPs), or (2) opening the PLCA to fishing one week earlier in the fishing season. These management changes will most likely only be considered acceptable if observer coverage is significantly increased and hard caps on certain protected species are implemented in order to control the number of bycatch interactions. These hard caps are being proposed for the status quo fishery which only includes the use of drift gillnet and harpoon gear types, not longline. Our project is conducted under the assumption that the hard caps will not change with the reintroduction of the longline gear type as conservation concerns are assumed to remain the same. Because the PLCA has not yet been reopened to fishing and data does not exist, a quantitative analysis cannot be conducted to determine how bycatch rates would change with the new longline gear innovations, and how the fishery would operate under the use of hard caps for bycatch species. Thus, the following is a qualitative assessment of how economic viability of the fishery would increase if the PLCA were opened based on prior knowledge regarding when the PLCA was open to fishing.

The Use of Exempted Fishing Permits (EFPs) Inside the PLCA

During the March 2014 PFMC meeting, the Council rejected an EFP proposal to modify the southern boundary of the PLCA that would have allowed drift gillnet fishermen to potentially access more of the swordfish stock. The area was designated based on fishers' knowledge that currents and sea surface temperature are important factors that determine swordfish abundance, particularly in the PLCA area north of Cape Mendocino (Burke 2014). However, the California State Assembly and other environmental groups were concerned with allowing fishing in this area due to catching 2 sperm whales on one observed set in 2010 (Assembly California Legislature 2013). During the June 2014 PFMC meeting, the Council members listed evaluating changes in the PLCA closure as an objective and a potential way forward to transition the drift gillnet fishery in the future under bycatch hard caps and potentially increased observer coverage (PFMC 2014a). If there were 100% observer coverage and bycatch hard caps on species of concern whereby the entire swordfish fishery would shut down for the remainder of the fishing season if these hard caps were reached, then it may be viable to consider opening the PLCA.

Opening the PLCA earlier in the Fishing Season

Shortly after the PLCA was established in 2001, fishers proposed that the PLCA open on November 1 instead of November 15. Fishers are confident that swordfish are most abundant at the beginning of November, with a hypothesized increase in swordfish abundance upward of 25-30% and associated increased economic profits for fishers were the closure opened earlier in November (Burke 2014). Prior to the PLCA closure, drift gillnet fishermen landed 11.6% of swordfish caught during the entire fishing season in the PLCA from November 1 to 15, when averaged over the period from 1991 to 2000 (Dahl 2013).

Setting Standards for Imported Swordfish

Some stakeholders do recognize the need to hold foreign swordfish fleets accountable to the same bycatch standards held in the U.S. Most of the landings and bycatch data from exporting countries do not have data available to the public for the U.S. to review and determine if the countries are in compliance with MMPA Section 1010 (a)(2) (CBD & TIRN 2008). One example of this is Singapore, which is known as a transshipment country, with the majority of the fish Singapore exports being from Taiwan (CBD & TIRN 2008). NMFS is one of the agencies in charge of implementing the ban on swordfish from countries that do not show reasonable proof of meeting U.S. standards and the Secretary of Commerce and Secretary of Treasury help to decide on whether certain imported swordfish meet the U.S.'s bycatch standards (CBD & TIRN 2008).

For this reason, Center for Biological Diversity and Turtle Island Restoration Network petitioned to the United States Government to ban swordfish imports from countries that cannot demonstrate compliance with Marine Mammal Protection Act (MMPA) regulations (CBD & TIRN 2008). A settlement was reached on January 6, 2015 in the U.S. Court of International Trade in New York between NMFS and the plaintiffs (Center for Biological Diversity, Turtle Island Restoration Network and Natural Resources Defense Council) agreeing that NMFS will enforce provisions in the MMPA prohibiting seafood imports that do not meet U.S. marine mammal bycatch standards (CBD 2015). Through this settlement, NMFS must decipher a method to implement this provision by August 2016 (CBD 2015).

The E.U. has shown that import bans on countries that refuse to comply with bycatch mitigation regulation measures is an effective way to improve the swordfish fishing practices of foreign countries (Fish2Fork.com 2014). The E.U. has placed swordfish embargos on Belize, Fiji, Panama, Togo and Vanuatu. After the embargos were instated, these countries quickly adopted the bycatch regulations demanded in order to release the ban and continue profiting from the exportation of highly demanded seafood (Fish2Fork 2014). This attests to the effectiveness of import bans to protect bycatch species on the global level. Incorporating an import ban for swordfish has the potential to decrease America's impact on bycatch species and even the playing field between domestic and foreign fishermen.

L. Cost-benefit Analysis: Methods and Results

A cost-benefit analysis was conducted as a preliminary analysis to motivate the options for the potential changes within the California swordfish fishery to present to the Pacific Fishery Management Council. This analysis explored the costs and benefits associated with a drift gillnet fleet, a longline fleet, and a fleet with a mix of these gear types under hard caps, based on each fleet's overall catch, costs, and when the bycatch hard caps would likely be reached.

The hard caps proposed for the drift gillnet fishery consider the following bycatch species of concern: loggerhead and leatherback sea turtles; and humpback and sperm whales. If hard caps for any of the species are met in a given season, the fishery would shut down at the start of the following fishing month for the remainder of the fishing season. This cost-benefit analysis considered different fleet compositions because a diverse fleet may result in different swordfish catch rates and different bycatch rates; thus affecting the amount of time that the fishery may remain open and obtain revenue before reaching the hard cap. As aforementioned, our project focuses on California landings; therefore, this analysis will incorporate California drift gillnet landings and Hawaii shallow set longline landings to California. Harpoon is not considered in this analysis due to its low participation and because it cannot reasonably supply swordfish to meet a significant portion of the U.S. demand for swordfish.

Cost-Benefit Research Question: What are the costs and benefits associated with 3 different gear type scenarios under a bycatch cap implementation, and which scenario results in the greatest profitability as represented by a larger benefit-cost ratio and/or net present value? The 3 scenarios are:

1. A fleet comprised 100% of drift gillnet vessels
2. A fleet comprised 100% of longline vessels
3. A 50/50 fleet combination of drift gillnet and longline vessels

This analysis explored the tradeoffs between the 3 scenarios of fleet compositions to determine which will generate the greatest total annual revenue, indicative of the fleet with the most catch and/or least amount of foregone revenue[11].

The following data were utilized in this cost-benefit analysis:

1. California landings data: These data include the ex-vessel revenue price for California drift gillnet from 2006-2013 (average price per pound of swordfish). These data will be utilized to calculate:
    a. The revenue per month of the California drift gillnet fishery from 2006-2013
    b. The swordfish catch in metric tons per month by the California drift gillnet fishery from 2006-2013

[11] Foregone revenue is revenue not obtained due to a fishery closure after hitting the cap.

2. California summarized landings record data: These data include the summarized annual bycatch rate per metric ton of swordfish caught in the California drift gillnet fishery for each of the bycatch species of concern from 2006-2013. These data will be utilized to determine:
    a. At what point in the fishing season the bycatch hard cap would be reached based on the amount of swordfish caught per month from 2006-2013.

    *Note: These data have already been extrapolated to assume a bycatch rate with 100% observer coverage.
3. Hawaii observer record data: These data include the landings records for swordfish caught from 2006-2013. These data will be utilized to determine:
    a. The swordfish catch in metric tons per month for shallow-set longline from 2006-2013.
4. Hawaii summarized landings record data: These data include the summarized annual bycatch rate per metric ton of swordfish caught in the Hawaii shallow-set longline fishery for each of the bycatch species of concern from 2006-2013. These data will be used to determine:
    a. At what point in the fishing season the bycatch hard cap would be reached based on the amount of swordfish caught per month from 2006-2013.

Assumptions

Drift gillnet and longline fisheries

- The timeline used in this analysis assumes that the 6-year Experimental Fishing Permits were passed in 2013, however active fishing did not start until 2014, continuing until 2019. This assumes that no revenue was produced and no costs were incurred in 2013 except for the purchase of the longline vessels as fixed upfront costs.
- The Hawaiian LL landings to California are assumed to be representative of allowing LL as a commercial gear type in California because the Hawaiian LL fishermen fish just outside the California EEZ, in the same waters in which California LL fishermen would fish if LL were an allowed gear type in California.
- The proposed California longline fleet would be the same size and engage in the same level of effort as the Hawaii fleet that lands in California HI fleet.
- The average number of HI longline vessels that landed to CA ports from 2006-2013 was 6.
- For the 100% LL fleet, assume that with the reintroduction of the CA LL fishery, there is entry or transition of DGN fishers to fill the assumed maximum amount of LL vessels being 6. This also assumes that all DGN fishers will stop actively participation in the fishery. This is a potentially likely scenario as part of the reason the Council is considering the reintroduction of LL is because there is pressure to close or phase-out the DGN fishery. The introduction of this policy could indicate to the DGN fishers that their fishery will likely be closed, leading them to choose to transition to LL or find other forms of employment.
- For the 50/50 scenario, assume that exactly half of the amount of fishing effort occurs, and therefore half of the projected revenue for both gear types.
- The total number of trips taken by HI LL vessels that landed to CA from 2006-2013 was 67; therefore we assume the average number of trips that will be taken for the CA LL fishery from 2014-2019 will be equivalent at 11.16.

- The number of average annual trips for the DGN swordfish fishery from 2014-2019 will be equivalent to the average number taken from 2006-2013, which was 11.2.
- The only LL gear that will be allowed for CA permits is shallow set (<100 m deep), not deep set.
- The fishing season is based on the number of fishing months within a calendar year (starting on January 1) for both fisheries
    - The LL fishery has 7 fishing months: January, February, March, April, October, November, and December
    - The DGN fishery has 6 fishing months: August, September, October, November, and December
- Assume the swordfish stock is stable and will not reach MSY with an increase in effort, therefore a cap on swordfish catch was not considered for this analysis.
- Assume oceanographic and fishing conditions remain the same from 2014-2019 as they were from 2006-2013, resulting in similar swordfish and bycatch numbers.

Bycatch

- The amount of bycatch caught in the drift gillnet fishery was extrapolated due to the 20% observer rate. This combined with the reality that bycatch events are rare may result in bycatch projections that are overestimated.
- Assume that, from 2014-2019, each of the gear types will catch the same exact number of bycatch in the same month as those gear types historically caught from 2006-2013. This assumption needed to be made in order to realistically illustrate the potential for bycatch interactions as the events are random and rare and cannot be accurately simulated.
- Bycatch caps are reset at the beginning of a calendar year during this time period.
- When bycatch caps are hit the closure of the fishery does not go into effect until the following month. Therefore, there is no foregone profit when a bycatch cap is hit in December.
- 30% of Observer coverage will be paid by the National Marine Fisheries Service, leaving 70% of the costs to the fishers.
- Assume that all DGN vessels have the capability to incorporate added observers.
- The average total cost of hosting an observer aboard a fishing vessel in the swordfish fishery is assumed to be $800 per trip for each gear type (Source: correspondence from NOAA scientist.)
- Assume no improvements in bycatch reduction technology occur from 2014-2019

Calculations

- The average annual variable costs used in this analysis for all scenarios were based on the historical average annual costs. This assumes that the average annual variable costs for swordfish fishing for a given gear remain the same from 2014-2019 and therefore do not need to be projected into the future for this analysis.
- The 2013 base revenue for the longline fishery used to project the annual revenue from 2014-2019 was based on the average annual revenue from 2006-2013 due to the specificity of the data available. This assumes that the average annual revenue for the HI LL fishery would be equivalent to a CA LL fishery of the same size from 2006-2013.

- Data from 2007 weren't included because the data for the 2007 HI LL fishery were not available.
- The cost of a used swordfish shallow set longline boat equipped to fish, along with a permit is $145,000 (based on the research conducted).
- Projected average annual revenue growth for the DGN fishery from 2014-2019 is assumed to be equivalent to the average annual trend in growth (which in this case was a decline) in the DGN swordfish fishery revenue from 2006-2013.
- Calculated projected average annual revenue growth for the LL fishery was based on the growth in revenue of the HI LL fishery landing to CA from 1993-2011, assuming that the growth in revenue for the CA LL fishery would be the same. With the same number of vessels constant throughout this period, this growth in revenue would likely be due to improvements in knowledge and skill at catching swordfish and effectively utilizing the gear within the fishery.
- The revenues for the 50/50 fleet were calculated by dividing each of the projected revenues in half and adding the two together. This assumes that the mixed gear fishery from 2014-2019 would produce exactly half of the effort and therefore exactly half of the revenue produced by each fishery from 2006-2013.

Costs and Benefits

Costs: To equate the same types of costs for drift gillnet and longline, the costs associated with each gear type are summarized by a variable cost per trip metric.

Variable Costs	Fixed Costs
• Fuel, food, crew, gear, maintenance, ice, bait, observer coverage costs	• The 100% DGN scenario has zero fixed costs. • The 100% LL scenario incorporates the purchase of 6 LL vessels to participate in the proposed LL fleet under the EFP trial period[12,13]. • The 50% DGN/50% LL scenario incorporates the purchase of 3 LL vessels.

Benefits: The benefit evaluated in this analysis is the revenue incurred by each swordfish fleet scenario. This benefit is quantified as the amount of revenue that the fishery obtains prior to hitting a bycatch hard cap. Further details on cost and benefit calculations may be found in the Analysis Methodology section.

Methodology

Each scenario analyzes the projected revenue due to swordfish catch per month for the fleet(s) starting in year 2014 and continuing through 2019 for a total of 6 active fishing years. The projections were estimated from historical revenue data from both the active California DGN fleet and active Hawaii LL fleet landing to California during 2006-2013. The number and month of actual historical bycatch recorded by observers are incorporated to determine at what month in a given year throughout this future 6 year period would result in the fishery's closure due to a hard cap being reached, if at all.

[12] Although not all LL fishers may have to purchase a new vessel (a fisher could have a vessel because s/he participated in the historical longline fishery, or a fisher from the Hawaii fleet could join the CA fleet), it is assumed that all fishers would have to purchase a vessel, such that this analysis doesn't underestimate costs.

[13] 6 LL vessels are purchased as this is about the average number of LL vessels in the Hawaiian LL fleet that have landed to California during the time period from 2006-2013. Therefore, it is most probable that 6 LL vessels would be the number of permits participating in the EFP trial period.

Bycatch Caps
The annual hard cap levels for each of the four species (Leatherback and Loggerhead turtles and Sperm and Humpback whales) were predetermined by the Pacific Fishery Management Council. These hard cap levels are compared to the number of "takes[14]" of each of these species for every year from 2006-2013 to determine if the hard caps are reached. If the number of "takes" for any of the four bycatch species equal or are greater than the PFMC's hard cap levels, then the fishery shuts down for the remaining of the calendar year – meaning no more fishing is allowed through the end of December. If the number of "takes" for all of the bycatch species is less than the hard cap levels, then the fishery remains open for the entire calendar year. To simplify the analysis, we are assuming that the fishery shuts down at the end of the calendar year instead of the end of the fishing season. The hard cap levels reset every year, meaning if the cap is reached in November of 2008, then fishermen can resume fishing DGN in January 2009. The PFMC bycatch hard cap proposals are as follows: Leatherback turtles: 2 individuals, Loggerhead turtles: 2 individuals, Sperm whales: 2 individuals, Humpback whales: 1 individual.

Cost and Benefit Calculations

Fishing Months: Based on the historical data from 2006-2013, the total number of active fishing months per year for both gear types is determined. The total fishing months for DGN and LL were the same every year for both gear types throughout this time period: DGN fished 6 months and LL fished 7 months.

Time Frame: Year 2013 is used as the base year 0 in which no fishing activity occurs and the only costs for the fishery are those associated with the LL fleet purchasing the vessels (any other potential costs for the fishermen associated with not fishing during this year is not considered). For this analysis, fishing begins in 2014, or year 1, and the analysis ends after 2019, or year 6 (the end of the EFP trial period).

Costs: Total "annual average variable costs" were calculated for each gear type by taking the sum of the variable costs averaged from 2006-2013. All historic costs for each gear type were calculated into present value (2014 dollars) for the analysis. Observer coverage costs to the fishermen were calculated by taking 70% of the average observer cost per trip in a swordfish fishery multiplied by the number of average annual trips taken by a specific gear type. These are added to the "annual average variable cost" of a specific fishery to obtain the "annual cost." The annual cost is divided by the number of fishing months for a gear type to obtain a value for monthly cost, which was then multiplied by the number of months remaining in the calendar year after the month the cap is hit to obtain the "forgone costs" each year. The foregone costs are subtracted from the annual costs to calculate the "total average annual costs," which was then calculated into present value (2014$) and summed to obtain a total present value of costs for each scenario (see Excel for calculations).

Benefits: The benefit measure used in this analysis is the sum of the projected total annual revenue obtained before each of the three fleets hits the hard bycatch cap during the time period from 2014-2019. The projected annual revenue for each fleet from 2014-

[14] The term "take" means to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal (NOAA 2014a).

2019 is projected from the historic revenues of a given gear type[15] starting from 2013 and using the projected annual revenue growth rate, which we calculated based off of past trends for each gear type (see Excel spreadsheet for calculations)[16,17]. The calculated projected annual revenue is then divided by the number of each gear type's respective fishing months to obtain the projected monthly revenue. The "forgone revenue," which is the revenue not obtained in a given year for a fleet after the hard cap is hit, was calculated by multiplying the monthly projected revenue by the number of months left in the calendar year after the month the cap is hit. The annual "forgone revenue" for a given scenario is then subtracted from the "projected annual revenue," resulting in the annual "total revenue". These total revenues were then calculated into present value (2014 dollars) and summed to obtain a total present value of revenues for each scenario (see Excel spreadsheet for calculations).

Net Present Value and Benefit-Cost Ratio: For each scenario, the total present value (TPV) of costs is subtracted from the TPV of benefits to obtain the net present value (NPV) for the scenario. The benefit-cost ratio (B/C Ratio) was calculated by dividing the TPV of revenues by the TPV of costs.

Sensitivity Analysis: A sensitivity analysis was conducted for the three different management scenarios to determine if and how much the B/C ratio and the NPV would change with different discount rates. Discount rates of 4%, 5%, 6%, and 8% were used because fishermen acquire loans from the California Fisheries Fund at an interest rate between 4 and 8%.

Results

The 100% DGN scenario has the highest B/C ratio at 13.02, the 100% LL scenario has the highest NPV value at $10,275,650. The DGN scenario has the lowest NPV value at $1,678,498 and the LL scenario has the lowest B/C ratio at 6.35, while 50% DGN and 50% LL ranked in the middle for both NPV and B/C ratio at $6,270,545 and 7.00, respectively.

A sensitivity analysis was conducted for the 3 different management scenarios in order to determine how sensitive the NPV and the B/C ratio results were to the discount rate. The sensitivity analysis shows that NPV and the B/C ratios are not significantly sensitive to different discount rates because DGN has the highest B/C ratio and LL has the highest NPV value across all discount rates.

[15] The mixed gear type fleet's projected revenues summed 50% of the drift gillnet projected revenue and 50% of the projected LL revenue.
[16] Note: for the LL projections, the 2013 base revenue for the longline fishery used to project the annual revenue from 2014-2019 was the average annual revenue from 2006-2013 for the HI LL fishery landing to CA ports.
[17] The historic revenues were calculated into 2014 dollars for the analysis.