Spillover Effects of Environmental Regulation for Sea Turtle Protection in the Hawaii Longline Swordfish Fishery

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ABSTRACT

This study examines spillover effects resulting from US fishing regulations instituted to protect sea turtles. Sea turtles, along with US and foreign fisheries for swordfish co-occur on the high seas in the North and Central Pacific and that allows for "spillover effects." When one fishery is required to curtail fishing activity to reduce incidental fishing mortality on sea turtle populations, the activity of other, unregulated fleets may change in ways that adversely affect the very species intended for protection. This study provides an empirical model that estimates these "spillover effects" on sea turtle bycatch resulting from production displacement between regulated US and less-regulated non-US fleets in the North and Central Pacific Ocean. The study demonstrates strong spillover effects, resulting in more sea turtle interaction due to increased foreign fleet activity when Hawaii swordfish production declines.

Key words: Hawaii swordfish longline fishery, spillover effect, turtle bycatch.
JEL Codes: Q51, Q58, Q5.

INTRODUCTION

Highly migratory pelagic fish stocks, such as tuna and swordfish, are targeted by longline fishing fleets from the US and other nations. Longline fishing may result in incidental mortality of turtles (Wallace et al. 2010). Shallow-set fishing that targets swordfish usually catches more turtles per unit of fishing effort than regular longline because the fishing occurs in certain ocean environments, such as specific water depths and sea surface temperatures that are favored by the turtles (Howell et al. 2008). Longlining to target swordfish represents a small fraction of worldwide longline fishing.

Although the US is not a major swordfish producer worldwide and is a net importer of swordfish, the Hawaii longline swordfish fishery was the major domestic producer of sword-

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fish for the US market in the 1990s until it was restricted in 2001 by Federal government sea turtle bycatch regulations that included an area closure, gear restrictions, annual fishing effort limits, and increased observer coverage (NMFS 2001). As a result, the Hawaii-based longline fishery for swordfish was prohibited from fishing from April 2001 until March 2004. Although the fishery reopened in April, there was little swordfish fishing activity in 2004, since it took time to resume swordfish fishing and the best part of the swordfish season had passed. These regulatory changes not only restricted fishing in the Hawaii fishery, but also prompted changes in US imports from foreign countries (Sarmiento 2006; Rausser et al. 2009). Hypothetically, an increase in US imports would lead to an increase in foreign production, as foreign fisheries were not restricted by the US fishing regulations. We hypothesize that they seized the market opportunity that resulted from the reduction in US swordfish production in the Pacific Ocean, which declined from 5,632 metric tons (mt) in 2000 to 2,504 mt in 2001 (FAO 2014). US fresh imports increased from 8,789 mt in 2000 to 9,054 mt in 2001 and 9,921 mt in 2002 (NMFS 2014). Foreign fleets were not required to use modified gear or implement procedures to minimize sea turtle interactions until 2010.[1] During the period of our study, foreign fishery activity had a higher sea turtle bycatch per unit effort (Molony 2005; Robins, Bache, and Kalish 2002) relative to US fishing activity (Gilman et al. 2007) (*sea turtle bycatch* is also termed *sea turtle interactions* in some studies); thus, an increase in foreign swordfish production could lead to more sea turtle bycatch overall. Previous studies tried to demonstrate and measure the spillover effect based on an observed increase in US swordfish imports. However, an increase of US imports may not necessarily indicate an increase sea turtle bycatch if there is no increase in corresponding swordfish production by foreign vessels having a higher sea turtle bycatch rate. Therefore, the objective of this study is to assess the spillover effect of sea turtle bycatch due to the possible production displacement between US and foreign fleets.

Fisheries bycatch has been a pervasive problem for many commercial fisheries due to the spatial coexistence nature of the target and non-target species and non-selective gear usage. Bycatch of charismatic, endangered species, like turtles and marine mammals, is subject to pressure from the public, environmental groups, and government legal requirements. However, without government intervention vessels owners have little incentive to adopt costly bycatch reduction activities. As pointed out in Abbott and Wilen (2009), the bycatch problem essentially was a behavioral problem; incentive-based approaches could potentially change fishing behavior and lower bycatch. Alverson et al. (1994) discussed different regulatory-based solutions to the bycatch problem like effort reduction, incentive/disincentive programs, individual transferable quotas, and time/area control. Some studies theoretically analyzed the effectiveness of different bycatch reduction policy options that affected fishing outcomes, including an individual trans-

1. Prior to 2010, shallow-set longline fisheries for swordfish participating in the Western and Central Pacific Fisheries Commission Convention Area did not have any gear restrictions for turtle conservation. Starting January 1, 2010, Commission Members, Cooperating non-Members and participating Territories (CCMs) with longline vessels fishing for swordfish in a shallow-set manner shall ensure that the operators of such vessels, while in the Convention Area, are required to employ or implement at least one of the following three methods to mitigate the capture of sea turtles: (1) use only circle hooks, (2) use only whole finfish for bait, (3) use any other measure, mitigation plan, or activity that has been reviewed and approved by the Commission to be capable of reducing the interaction rate of turtles in swordfish shallow-set longline fisheries (Conservation and Management Measure 2008-03). The Inter-American Tropical Tuna Commission (IATTC) also adopted a *Resolution to Mitigate the Impact of Tuna Fishing Vessels on Sea Turtles* that includes provisions for longline vessels, but there are no definite restrictions on gear usage (IATTC Resolution C-07-93).

ferable quota system for target species and bycatch species (Boyce 1996), a common-pool quota system with seasonal closure of the fishery when any of the quotas for target or bycatch species was reached (Abbott and Wilen 2009), and a turtle bycatch quota system with a proportional monetary penalty and reward structure (Segerson 2009). Moore et al. (2008) provided a comprehensive empirical summary of the current status of marine mammal, sea turtle, and seabird bycatch and the policies to reduce bycatch in the US fisheries. They concluded that the current bycatch management policies were not the most efficient, as they did not have a holistic approach to reduce bycatch from a multi-species, multi-gear perspective. At the global level, Kelleher (2005) summarized international guidance and instruments to reduce bycatch and pointed out that most of the bycatch reduction policies were at the country level, with some OECD countries demonstrating the best practice. It was the lack of an international bycatch reduction policy that was a contributing factor to the spillover effect.

Spillover effect (ref: general use) is an unintended effect, such as an effect resulting from action in a target market or entity having consequences over a broader market or entity, and is an externality; i.e., an economic effect on entities other than those participating in or directly targeted by a given activity (Pigou 1920). Spillover effects resulting from regulations or policy changes have long been studied in many areas. One of the areas is related to policies that reduce emissions. International spillovers occur when carbon abatement policies induce lower global demand for fossil fuels and cause international prices to fall. Lower prices provide positive spillover effects to countries that are net importers of fossil fuels and vice versa for countries that are net exporters (Bohringer and Rutherford 2002). On the other hand, negative spillovers occur when greenhouse gas emission regulations in one region induce the carbon-intensive industries to relocate to an unregulated region and cause higher emissions in the unregulated region (Babiker 2005; Goulder and Parry 2008; Wiener 2007). In fisheries, research related to spillover includes the migration of adult fish stock from marine protected areas to adjacent fishing zones (Abesamis and Russ 2005; Ashworth and Ormond 2005; Francini-Filho and Moura 2008; Roberts et al. 2001); fishery spillover with the transfer of fishing effort from regulated to unregulated species due to changes in individual vessel quotas (Asche, Gordon, and Jensen 2007; Ekerhovd 2007; Hutniczak 2014) or transfer of fishing effort across regional fisheries boundaries due to catch share programs in one region (Cunningham, Bennear, and Smith 2016); and bycatch spillover with Sarmiento's (2006) and Rausser's (2009) attention to the Hawaii longline fishery.

Several fishery studies have investigated the possible spillover effects on sea turtle bycatch from the 2001–2004 closure of the Hawaii longline swordfish fishery. Bartram and Kaneko (2004) compared the sea turtle bycatch rate in the Hawaii longline swordfish fishery to other fisheries operating in the same area (Western and Central Pacific). They identified the Hawaii longline swordfish fishery, which was subjected to significant regulation and monitoring, as a "model" fishery with low fish and sea turtle bycatch rates. The study raised a concern that restrictions on the Hawaii longline swordfish fishery may indirectly stimulate the expansion of high-bycatch foreign longline fisheries through production leakage (decline in local production) and trade leakage (increase in imports). In a subsequent study, Bartram, Kaneko, and Kucey-Nakamura (2010) quantified the turtle bycatch-to-fish-catch ratios in different fisheries and concluded that Hawaii longline tuna and swordfish fisheries under management measures instituted in 2004 showed the lowest bycatch-to-fish-catch ratios among other major Pacific longline fisheries.

In the fisheries economics literature, Sarmiento (2006) examined the degree of trade leakage during the Hawaii longline swordfish fishery closure, finding that during the first year of the closure, US fresh swordfish imports from Ecuador and Panama increased significantly. Therefore, he suggested that the Hawaii longline swordfish fishery closure had led to the transfer of longline fishing activity to some foreign fleets, and it was unlikely to result in an overall reduction in sea turtle bycatch because turtle mortality would likely increase in the stocks affected by the foreign fleets. However, Sarmiento did not estimate the increase in the number of sea turtle interactions associated with increased imports.

Rausser et al. (2009) were the first to estimate the possible increase in the amount of sea turtle bycatch associated with increased US swordfish imports during the 2001–2004 closure of the Hawaii swordfish fishery. Opposite to the increasing trend of world consumption, US swordfish consumption was in a downward trend from about 1998 through 2009 (so was declining during 2001–2004) possibly influenced by a swordfish conservation campaign begun in January 1998 and an advisory issued by the US Food and Drug Administration in 2001 warn-

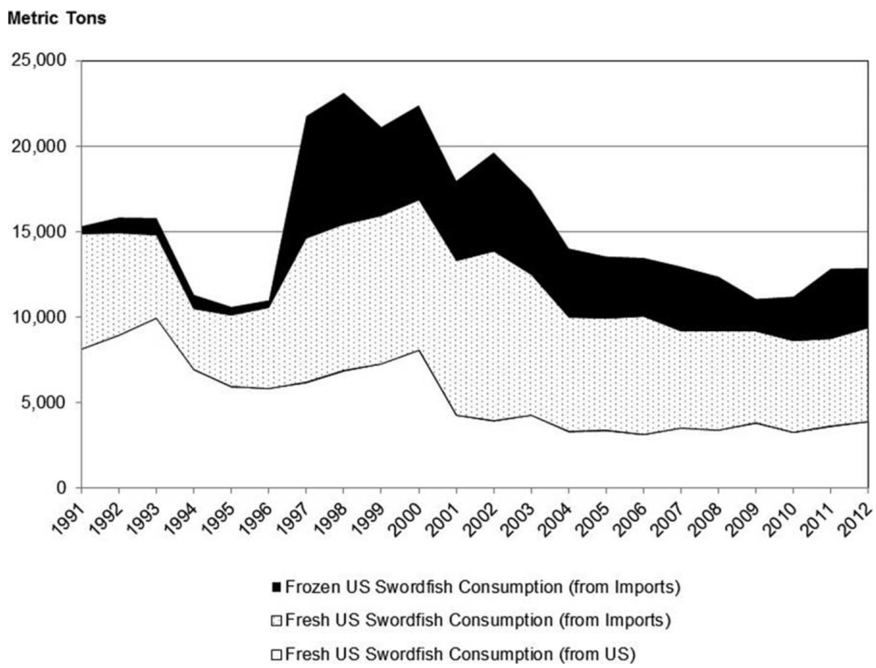

Figure 1. US Swordfish Consumption, 1991–2012

Note: US swordfish production data are available from FAO and NOAA, but the estimates from these two sources are slightly different. Because the data for other countries and production by ocean are from FAO, to be consistent we use FAO data for both the US and other countries. Import data are from NOAA foreign trade data, originating from the US Census Bureau. A change occurred in the product definition in 1997. Prior to 1997, swordfish imports were recorded as either fresh or frozen swordfish products. Starting in 1997, three new swordfish categories were added: frozen fillets, fresh steaks and frozen steaks. Prior to the introduction of these codes, cut swordfish products were recorded as "unclassified fish fillets" (pers. comm., Steve Koplin, NOAA Fisheries, Silver Spring, MD). The new codes led to a tripling in the amount of swordfish imports recorded by US Customs from 5,140 mt in 1996 to 15,598 mt in 1997, which, in turn, caused a doubling of US consumption from 10,982 mt in 1996 to 21,761 mt in 1997.

Source: Fresh and frozen US swordfish consumption from imports: NMFS (2014); fresh US swordfish consumption (= US production – exports): US production from FAO (2014) and exports from NMFS (2014).

ing consumers of high levels of mercury in swordfish (Rausser et al. 2009). US fresh imports started to decline in 2003 (figure 1). Rausser et al. (2009) measured the impacts of the Hawaii swordfish fishery closure on US imports and projected that US swordfish imports would have been 1,602 mt lower if there had been no closure of the Hawaii shallow-set longline swordfish fishery, and that the market transfer brought about by the closure resulted in an additional 2,882 sea turtle interactions. With a longer period of data available, Chan and Pan (2012) compared US imports in three periods: before, during, and after the closure. Import statistics show that during the reopened period in 2005–2008, annual average US fresh imports indeed fell by 2,256 mt, confirming the Rausser et al. (2009) projection of a decline.

These prior studies, however, did not demonstrate whether the changes in US imports due to the regulations of the Hawaii longline fishery caused foreign production to increase. Thus, market replacement (through import changes) may not lead to more sea turtle interactions if the increase in imports does not result in an increase in foreign production with higher bycatch rates. In other words, market replacement may not yield any impacts in sea turtle bycatch. However, if changes in Hawaii production result in foreign production changes, the spillover effect in sea turtle bycatch can be estimated. This study evaluates the broader market impact of regulatory changes in the Hawaii longline swordfish fishery, particularly reduced Hawaii swordfish production and the possible associated spillover effect of an increase in the number of sea turtle interactions due to higher turtle interaction rates in foreign fisheries that increased production to meet the market opportunity. The next section discusses the conceptual models of this study. The third section defines the fishery data used for the model and provides historical data on US and Hawaii swordfish production and consumption. The fourth section discusses the method to estimate the spillover effect. The fifth section presents the results of production displacement estimation and the spillover effects under different policy alternatives. The final section provides some discussion and conclusions.

CONCEPTUAL MODELS

A spillover effect would not occur if foreign production did not increase as domestic production declined or if the foreign fisheries did not have higher levels of turtle interaction than the Hawaii fishery. We employ the following conceptual model for our analysis. If Hawaii production of swordfish decreased by ΔQ_H and demand remained the same, then overall market price would tend to rise. That would have provided the market opening for foreign swordfish production to increase by ΔQ_F (figure 2). Since the Hawaii longline swordfish fishery's bycatch curve (B_H) is shallower (i.e., fewer interactions per marginal unit effort) than the foreign fisheries' bycatch curve (B_F), this translates into higher bycatch overall with the increase in foreign production.

Such production displacement could result in more turtles being caught than would otherwise have been caught if the US fishery had remained open. A sufficient condition for a spillover effect of higher turtle bycatch due to production displacement is:

$$-b_H \Delta Q_H < b_F \Delta Q_F. \tag{1}$$

Equation (1) states that the absolute value of the decrease in turtle bycatch from the Hawaii swordfish fishery is less than the increase in turtle bycatch from the foreign swordfish fisheries under the conditions depicted in this model. This is illustrated as the Hawaii bycatch rate (b_H)

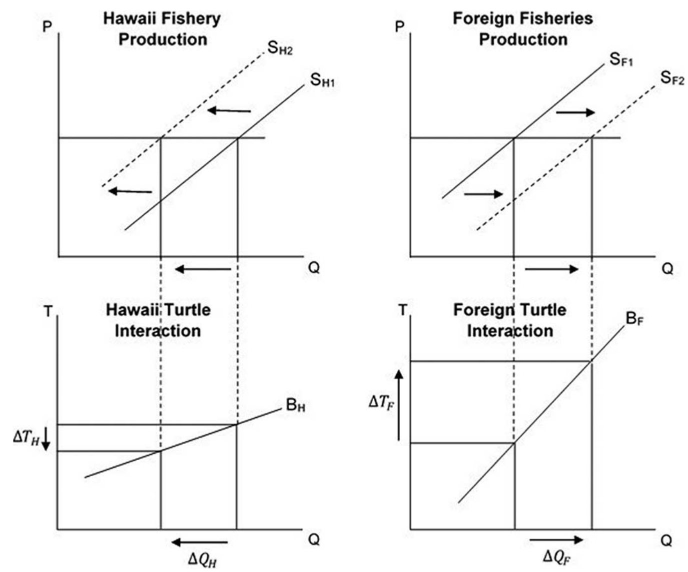

Figure 2. Conceptual Diagram of Spillover Effects between Fisheries

Note: Q = Swordfish caught, P = Swordfish price, T = Sea turtle bycatch, H = Hawaii fishery, F = Foreign fisheries, S_H = Swordfish supply curve for Hawaii fishery, S_F = Swordfish supply curve for foreign fisheries, B_H = Bycatch curve for Hawaii, B_F = Bycatch curve for foreign fisheries.

times the decrease in Hawaii production ΔQ_H (left side) being outweighed by the foreign bycatch rate (b_F) times the increase in foreign production ΔQ_F (right side). By adding and subtracting the same element ($b_H \Delta Q_F$) on the right side, equation (1) becomes:

$$-b_H \Delta Q_H < (b_F - b_H)\Delta Q_F + b_H \Delta Q_F. \tag{2}$$

Equation (2) shows that an increase in foreign bycatch can be comprised of two elements. The first element ($(b_F - b_H)\Delta Q_F$) shows an increase in foreign bycatch due to the differential in the bycatch rates (the foreign bycatch rate being higher), and the second element ($b_H \Delta Q_F$) shows an increase in foreign bycatch due to production displacement (higher foreign production). In the inverse case, if US fishing regulations allow more US swordfish production, this could displace foreign production and result in fewer turtle interactions. Unlike previous studies that examined the spillover effect through changes in US imports, this study examines the spillover effect through changes in domestic and foreign swordfish production.

FISHERY DATA FOR MODELING AND HISTORICAL DATA

FISHERY DATA FOR MODELING

The study first seeks to detect the existence of production displacement by analyzing the relationship between Hawaii longline swordfish production and foreign swordfish production in the North and Central Pacific Ocean. FAO swordfish catch statistics (FAO 2014) are used in this study, and the fishing area included in the analysis is North and Central Pacific Ocean, which consists of four FAO-designated subareas including Eastern Central Pacific (FAO Area 77), Western Central Pacific (FAO Area 71), Northeast Pacific (FAO Area 67), and Northwest Pacific (FAO Area 61).[2] Although the Hawaii longline swordfish fishery operates in a limited area of the North and Central Pacific Ocean (i.e., Eastern Central Pacific),[3] all countries that operate in the North and Central Pacific are included in the analysis because turtles and swordfish could be caught by vessels that operate elsewhere in the North and Central Pacific. The FAO statistics represent swordfish catch by all fisheries combined and do not distinguish between shallow-set or deep-set longline fishing, or any of the other fisheries that catch swordfish. However, longline fishing (shallow- and deep-set combined) catches the great majority of swordfish in Hawaii and throughout the Pacific (WCPFC 2011). Countries that catch swordfish in the North and Central Pacific include the US, Japan, Taiwan, China, Korea, Mexico, the Philippines, Indonesia, and Australia. Baseline turtle bycatch is calculated based on these countries' production levels and their respective bycatch rates (see Web Appendix A).

US AND HAWAII SWORDFISH PRODUCTION TRENDS

US swordfish production has declined in recent decades. In 1991, US swordfish catch (in the Pacific and Atlantic Oceans) was 8,148 mt, representing 12% of global swordfish landings; US Pacific Ocean catch (only occurs in North and Central Pacific) (4,597 mt), representing 32% of all North and Central Pacific landings. Hawaii represented the majority (74% from 1991 to 2000 combined) of all US Pacific Ocean swordfish landings, and the US West Coast represented the rest, predominantly from drift gillnet fisheries and Hawaii-based longline landed in California in the fall and winter seasons. In April 2001, the Hawaii shallow-set longline fishery for swordfish was closed by the US National Marine Fisheries Service as the result of a US Federal Court order to reduce incidental sea turtle bycatch.[4] We classify 2001–2004 as the closure period even though the fishery reopened in April 2004 (the reopening had little effect in 2004 because the swordfish season was almost over when the fishery formally opened and only minimal fishing activity occurred in the rest of 2004). As a result of the closure, some Hawaii-based swordfish vessels converted to tuna fishing, and about 20 of them relocated to California and fished and unloaded from there year round. However, this relocation did not result in an increase of total swordfish production in California due to the declining fishing efforts by other vessels in the same period. Before the closure, 40 Hawaii-based vessels fished from and landed in Hawaii in spring and summer but moved their operations to California in fall and winter (NMFS 2004). After the closure, only half of the 40 vessels continued swordfish fishing and landings in California. In addition, the Pacific Leatherback Conservation Area Closure was enacted in 2001 for the US West Coast drift gillnet fishery. This also lowered the number of active drift gillnet vessels from 78 in 2000 to 40 in 2004 (Pacific Fishery Management Council 2015). On the other hand,

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2. US swordfish production data are available from FAO and other sources like NOAA and Regional Fisheries Management Organizations (RFMOs), and the figures from these sources are slightly different. Because FAO data cover all ocean areas and all other countries, to be consistent we use FAO data for both the US and other countries.

3. The Hawaii shallow-set longline fishery operates in different zoning systems. FAO statistical area 77 (Eastern Central Pacific) includes most of the Hawaii fishery in most years, although some fishing has taken place in waters farther to the west in some years. Hawaii fishery operations straddle the boundary at 150 west longitude (bisecting FAO area 77) between the statistical areas of the Inter-American Tropical Tuna Commission (IATTC) and the Western and Central Pacific Fisheries Commission (WCPFC).

4. The Hawaii longline fishery operates in two modes: a shallow-set (< 100 m) longline fishery that targets swordfish and a deep-set (> 100 m) longline fishery that targets bigeye tuna. The shallow-set longline fishery has a much higher turtle interaction rate than the deep-set longline fishery because sea turtles, especially loggerheads, usually forage in shallower water (Polovina et al. 2004).

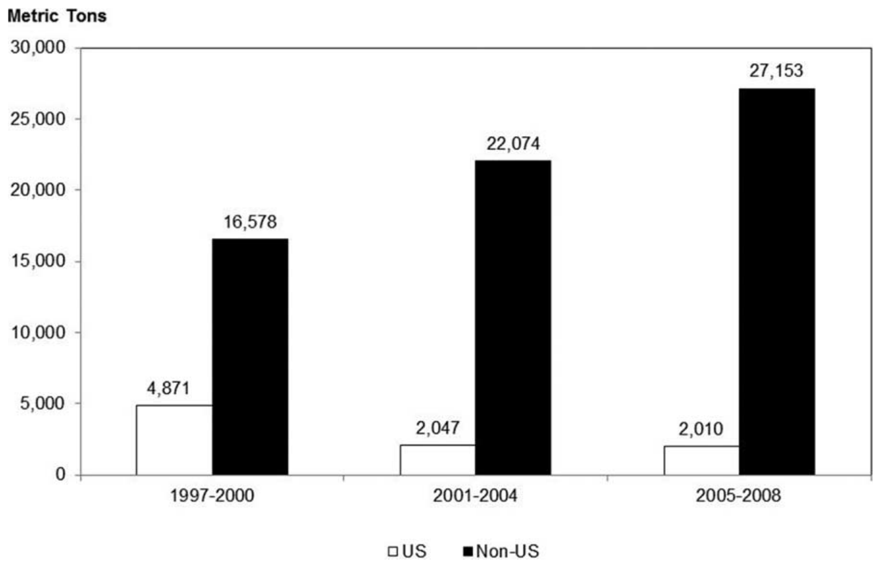

Figure 3. Annual Average US and non-US Swordfish Production in the North and Central Pacific Ocean Before, during (2001–2004), and After Hawaii Closure
Source: FAO (2014).

higher production was observed in non-US fleets in the North and Central Pacific Ocean. Non-US production of swordfish in the North and Central Pacific Ocean by all fishing gears, combined, increased by 5,500 mt, on average, during the 2001–2004 period, while US production fell by 2,800 mt annually averaged over 2001–2004 (figure 3).

The Hawaii shallow-set longline swordfish fishery reopened on April 2, 2004 after incorporating measures to reduce sea turtle bycatch, including (among others): (1) the use of circle hooks to replace J hooks; (2) the use of fish as bait instead of squid; (3) the imposition of an annual sea turtle hard cap and annual fishing effort cap; and (4) 100% observer coverage.[5] Subsequently, sea turtle bycatch rates in the Hawaii shallow-set longline fishery declined by 90% for loggerheads and 83% for leatherbacks (comparing the May 2004–March 2006 period with the March 1994–February 2002 period) (Gilman et al. 2007). A month after the Hawaii swordfish fishery reopened, a new regulation that prohibited West Coast-based shallow-set longline fishing targeting swordfish in the high seas off the US West Coast caused most of the vessels that had relocated to California to move back to Hawaii. Only one longline vessel remained in California and was allowed to fish tuna under the "grandfather" rule (Ito and Childers 2014). Nevertheless, after the fishery reopened (2005–2008), Hawaii's total swordfish production from all fisheries (including deep-set and shallow-set longline and others) remained 50% below the pre-closure period (1997–2000). Currently, US production is still less than 9% of total North and Central Pacific production. However, non-US swordfish production in the North and Cen-

5. Effort in the Hawaii shallow-set longline fishery was limited to 2,120 sets annually (after the fishery reopened in 2004; the effort cap ended January 11, 2010), which is about half of the historical peak level: http://www.st.nmfs.noaa.gov/observer-home/regions/pacificislands/swordfish.

tral Pacific continued to increase. It increased 12% annually from 1997 to 2000, 10% from 2001 to 2004, and slowed down to 1% from 2005 to 2008.

US SWORDFISH CONSUMPTION TRENDS

Swordfish production in the US has never been fully able to meet US demand. Almost all US landings are consumed domestically (as fresh product), and US swordfish consumption is typically three to four times its domestic landings. The difference is supplied by imports. Table 1 shows US swordfish production, trade, and consumption before, during, and after the Hawaii closure in four-year increments. During the closure period, total US consumption fell by 22%, but fresh imports remained almost unchanged. During the reopened period, US consumption continued to fall (down 24% or 4,180 mt compared to 2001–2004) and total US production also fell by 10%, but fresh imports fell dramatically by 27%.

As mentioned earlier, these trade data showing the decline of fresh imports during the re-opened period support the kind of market transfer effects predicted by Rausser et al. (2009). The re-opening of the Hawaii longline swordfish fishery reduced US consumption of foreign swordfish (i.e., imports) while increasing US consumption of domestic product. However, such a market transfer effect might not reduce stock-wide sea turtle bycatch in the North and Central Pacific if there were no re-distribution of production (fishing) among countries with different sea turtle bycatch rates.

METHOD FOR ESTIMATING THE SPILLOVER EFFECT

CONDITIONS FOR SPILLOVER EFFECT

In the case of the Hawaii longline swordfish fishery, some conditions must be met for spillover to occur: (1) both turtles and swordfish co-occur in many locations on the high seas and are caught by both Hawaii and foreign longline fisheries (both shallow- and deep-set); (2) sea turtle bycatch rates of the foreign longline fleets are higher than the sea turtle bycatch rate of the now regulated Hawaii shallow-set longline fishery targeting swordfish; and (3) the fishing activities of foreign longline fleets respond to the changes of Hawaii swordfish production by increasing production (swordfish production displacement occurs between the Hawaii fleet and foreign fleets).

Most of the Hawaii longline fleet's swordfish catch is obtained from the high seas of the Western and Central Pacific Ocean (WCPO) under the jurisdiction of the Western and Central Pacific Fisheries Commission (WCPFC), and the rest is obtained from the Eastern Pacific Inter-American Tropical Tuna Commission (IATTC) area. Figure 4 shows the spatial distribution (5 × 5 degree) of swordfish caught by the Hawaii fleet vs. foreign fleets in the WCPO in 2000 vs. 2004. In 2000, before the closure of the Hawaii swordfish fishery, Hawaii's production was a small portion of the entire WCPO production, and it concentrated in the area from longitude 180W to 150W and latitude 20N to 40N. In fact, swordfish production in this area (longitude 180W to 150W and latitude 20N to 40N) was dominated by the Hawaii longline fishery. However, after four years of the swordfish closure, the Hawaii fishery disappeared and was replaced by swordfish production by foreign fleets. We show only the maps for 2000 and 2004 because the shift of foreign production in 2001 to 2003 was relatively gradual.

Leatherback and loggerhead turtles also occur on the high seas, migrating east-west across the North Pacific Ocean (Benson et al. 2007; Polovina et al. 2004; and Kobayashi et al. 2008). In many cases, the migration routes of leatherback and loggerhead turtles intersect prime

Table 1. Annual Average US Swordfish Production, Trade, and Consumption Before, During, and After the Closure of the Hawaii Longline Swordfish Fishery

			US Production Pacific Ocean			Total Imports		Total Exports		
Annual Average (mt)	Total US Production	US Production Pacific Ocean	Hawaii	Rest of Pacific	US Production Atlantic Ocean	Fresh Imports	Frozen Imports	Fresh Exports	Frozen Exports	Total US Consumption
Pre-closure period: 1997–2000	7,091	4,871	3,054	1,817	2,220	8,633	6,376	0	0	22,100
Closure period: 2001–2004	3,940	2,047	253	1,794	1,893	8,482	4,839	0	0	17,261
Reopened period: 2005–2008	3,545	2,010	1,534	476	1,535	6,226	3,500	80	111	13,081
Amount of change between periods (mt)										
Pre-closure vs. closure	−3,151	−2,824	−2,801	−23	−327	−151	−1,537	0	0	−4,839
Closure vs. reopened	−395	−37	1,281	−1,317	−358	−2,256	−1,339	80	111	−4,180
Percent of change between periods (%)										
Pre-closure vs. closure	−44	−58	−92	−1	−15	−2	−24	–	–	−22
Closure vs. reopened	−10	−2	506	−73	−19	−27	−28	–	–	−24

Source: US imports, exports, and Hawaii production: NMFS (2014); US production by ocean: FAO (2014).

swordfish fishing grounds on the high seas. So even if the Hawaii longline swordfish fishery were completely closed, swordfish production in the North and Central Pacific by other countries would affect the same species and stocks of turtles.[6]

Another condition for spillover is higher foreign bycatch rates relative to those in the Hawaii shallow-set longline fishery. Most studies of sea turtle bycatch by countries longlining for swordfish in the North and Central Pacific indicate higher sea turtle bycatch rates (turtles caught per 1,000 hooks) than the Hawaii longline fishery. Details of the bycatch rates used in this study to estimate the spillover effects and the data sources are shown in Web Appendix A.

Production displacement may occur because when multiple fleets operate in the same ocean area, they may respond to changes in US production. Foreign fleets could increase swordfish production when a swordfish shortage emerges in response to reduced US production (for example as caused by US fishing regulations). As shown in figure 4, foreign fleets changed their fishing locations and replaced Hawaii production during the closure period. Figure 5 shows US and non-US swordfish production in the North and Central Pacific is moving in the opposite direction; while US production is showing a downward trend during the 1991–2012 period, non-US production is showing an upward trend.[7] The next section will test whether production displacement occurred between US and non-US fleets that fish for swordfish in the North and Central Pacific Ocean.

ESTIMATION OF PRODUCTION DISPLACEMENT

To test whether production displacement exists between US and non-US production as shown in figures 3 and 4, we statistically test the relationship between US production and non-US production attributable to the Hawaii closure. The intuition for our testing is that if nothing changes except the Hawaii longline swordfish fishery closure from 2001 to 2004, foreign fleets harvesting swordfish from the same common pool resource in the North and Central Pacific would be catching more swordfish with the closure than without it. Since the foreign fleets' production was, in general, an upward trend since the late 90s, a regression model was applied to distinguish its "normal" growth pattern with and without the attribution of the closure. We consider the Hawaii longline swordfish fishery closure as a policy treatment that may or may not affect foreign swordfish production in the North and Central Pacific by comparing the observed foreign production with a counterfactual. This is similar to Smith, Zhang, and Coleman (2006) who considered a marine reserve as a policy treatment and used a treatment effect model to quantify the effects of marine reserves on fisheries. Their model took into account the exogenous effects on catch and selection bias and considered an area far away and unaffected by the reserve as the counterfactual. In our case, the counterfactual is the estimated

6. It is important to note that spillover effects may affect different species/stocks of turtles in the North and Central Pacific Ocean in different ways. For example, spillover effects caused by lower Hawaii swordfish production could increase mortality of the critically endangered eastern Pacific leatherback if foreign fleets that operate in the Eastern Central Pacific (FAO Area 77) increase their production. This is because leatherbacks that nest in the Eastern Pacific have declined to extremely low levels of abundance. On the other hand, spillover effects may have a lesser effect on the Eastern Pacific olive ridley population, which is relatively healthy. This study does not consider turtle interactions at the species/stock level because species-specific and stock-specific bycatch rates are not available.

7. We use data from 1991 in the graph and for the statistical analysis below because it was the first year of the Federal logbook program in the Hawaii longline fishery. It is believed that the reported Hawaii (US Pacific) catch data have become more reliable since then.

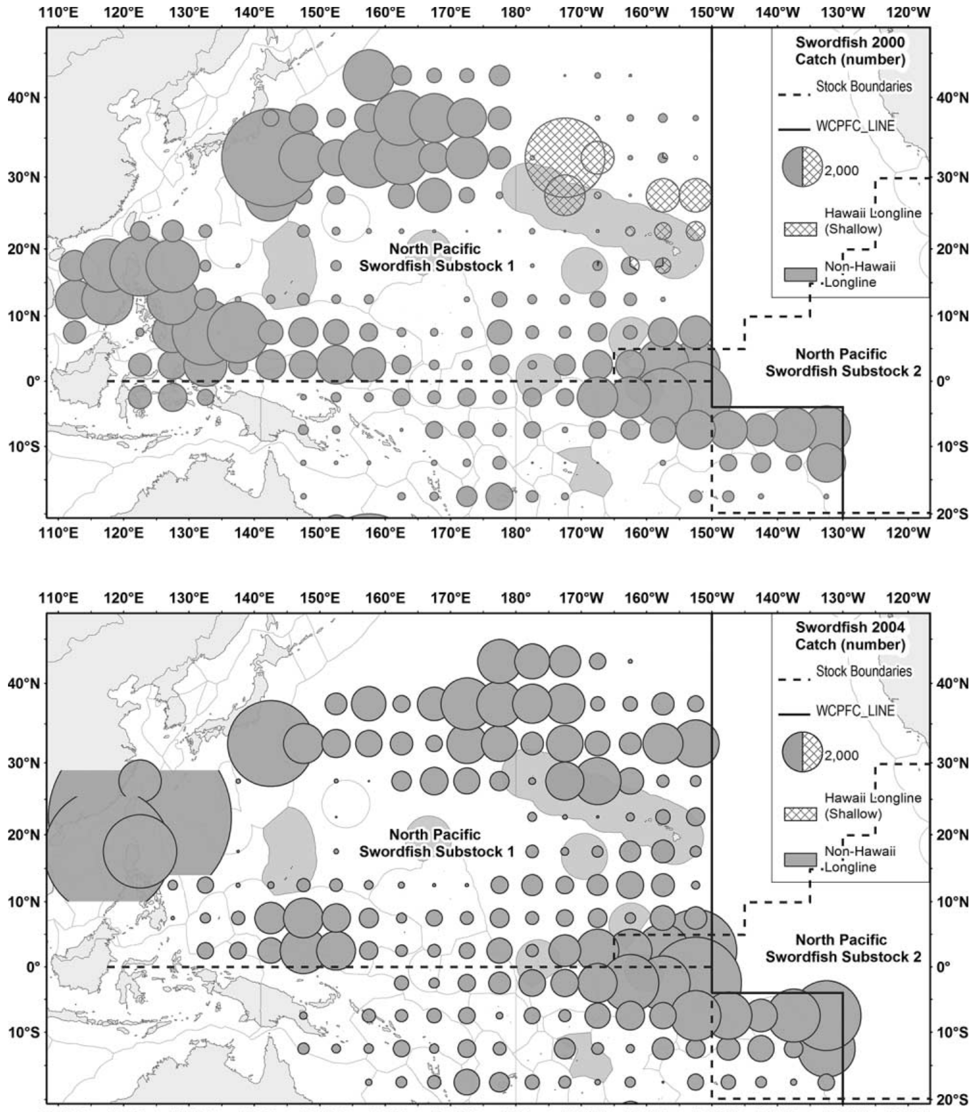

Figure 4. Swordfish Catch Distribution in WCPO by Hawaii vs. Foreign Fleets, 2000 and 2004
Swordfish Catch Distribution in WCPO, 2000 (before the closure)

Swordfish Catch Distribution in WCPO, 2004 (three years after the closure)

Source: The spatial distribution of swordfish catch was from WCPFC and the swordfish stock boundary was based on the swordfish stock assessment report (Brodziak and Ishimura 2010). We thank Dr. Haiying Wang, PIFSC spatial data analyst and developer, for the mapping assistance.

non-US production time trend using the time period before the closure (1991–2000). The differences between the non-US production and the counterfactual represent the non-US production attributable to the closure. We verified this approach in two ways. First, a structural break was found in 2001 when examining the time trend between 1991 and 2012 that was stationary and without serial correlation. This was essentially finding two parallel time trends before

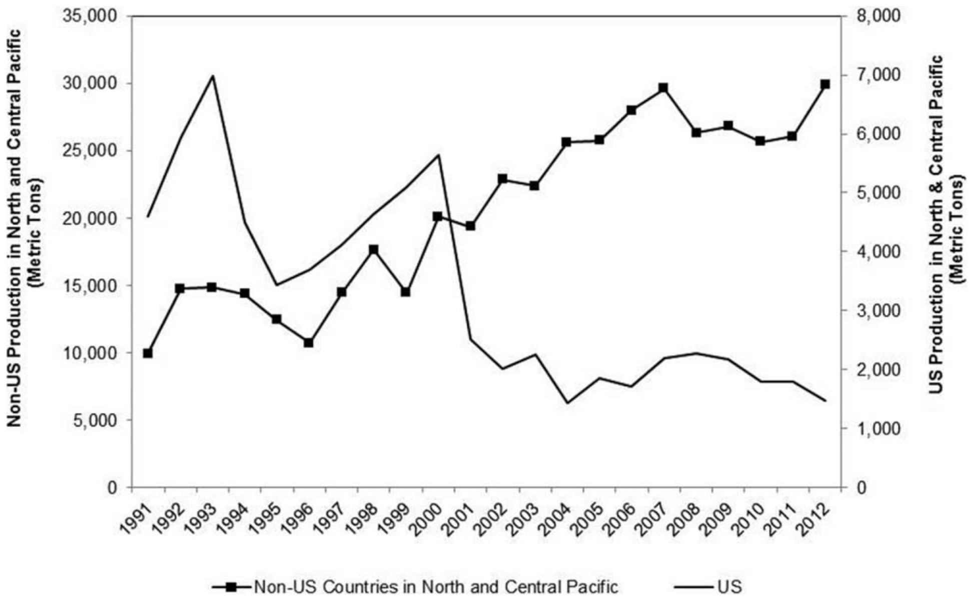

Figure 5. US and non-US Swordfish Production in the North and Central Pacific Ocean, 1991–2012
Source: FAO (2014).

and after the closure with a structural break occurring in 2001. It is similar to a difference-in-differences approach with the time trend before the closure estimated as the counterfactual with a significant treatment effect occurring during closure. This supports the estimated time trend before the closure as non-US production without the impact of closure (see Web Appendix B). The second verification was that no correlation was found between US and non-US swordfish production during the period of 1991–2000, but a negative correlation (–0.527, p = 0.078) was found during the period of 2001–2012 (see Web Appendix C). These two verifications suggest the estimated time trend for non-US production for the period of 1991–2000 represents the intrinsic production by non-US countries in North and Central Pacific before the US fishing regulations took effect. The deviations from the estimated time trend (de-trended changes or residuals) could be a random walk, but if they demonstrate systematic patterns that are related to US production, this suggests foreign production was linked to US production.

The time trend for non-US production is specified as follows:

$$Y_t = a + bt + \varepsilon_{t,} \tag{3}$$

where Y_t is non-US production in period t, where t = 1991 to 2000 (N = 10), and t stands for year (Web Appendix D lists the time series data used in the model). The residuals from equation (3) ($\varepsilon_t = Y_t - \hat{Y}_t$) represent the differences between actual non-US production, Y_t, and the estimated non-US production from the time trend, $\hat{Y}_t$.

Equation (4) is formed to test the hypothesis that the change in US production results in displacement of non-US production:

$$Y_t - \hat{Y}_t \ = \ c + d\, X_t + u_t, \tag{4}$$

where X_t stands for US production in period t, and u_t is an error term, where t = 1991 to 2012 (N = 22).

ESTIMATION OF SPILLOVER EFFECTS

Using the estimated production displacement result, spillover effects associated with different policies can be estimated. Fishing activities in the post-closure Hawaii longline swordfish fishery were limited by a series of regulatory regimes, such as sea turtle caps and effort limits. The fishery was also closed in much of 2006 and briefly in 2011 as a result of reaching the annual interaction limits that were part of the regulations. However, if certain regulations were removed, Hawaii longline swordfish fishery production might increase and produce positive spillover effects in terms of less turtle bycatch. We consider a scenario where the Hawaii longline swordfish fishery effort returns to its historical peak level (5,500 sets annually) from its current level of around 1,400 sets annually. The estimation steps are as follows:

(1) Estimate the number of sea turtle interactions for all the fleets/countries that fish in the North and Central Pacific based on the current (2012) production level and bycatch ratio of each country;
(2) Estimate Hawaii shallow-set longline swordfish fishery production at the effort level of 5,500 sets;
(3) Based on the estimated production displacement rate, calculate how much foreign production is displaced by the increased Hawaii swordfish production and proportionally deduct from each foreign country;
(4) Estimate the number of sea turtle interactions for all the fleets/countries based on their production levels when the Hawaii shallow-set longline swordfish fishery is at the 5,500 sets effort level; and
(5) Estimate the net change by comparing sea turtle bycatch in these two scenarios.

Another potential policy alternative to illustrate the effect on sea turtle bycatch is to consider changes in bycatch rates in non-US fleets. Currently, the Hawaii longline swordfish fishery has the most restrictive regulations to minimize sea turtle bycatch of any fleets fishing in the North and Central Pacific, and, as such, has one of the lowest bycatch rates. The 2005–2012 annual average sea turtle bycatch in the Hawaii longline swordfish fishery is 17 turtles, about 1% of total sea turtle bycatch in the North and Central Pacific. Although the WCPFC implemented some longline gear restrictions for turtle conservation in 2010 (see footnote 1), the restrictions are not as strict as those of the US. This scenario considers the effects if all fisheries in the North and Central Pacific adopted US fishing regulations and had the same bycatch rate as the Hawaii fleet.

RESULTS

PRODUCTION DISPLACEMENT

Table 2 shows the regression result of equation (3). The coefficient b = 617 is significant at the 5% level (p = 0.054) and indicates a significant upward trend in foreign production before the "shock" of the Hawaii longline swordfish fishery closure. We also tested for potential serial correlation. The critical values for the Durbin-Watson test at the 5% significance level for N =

Table 2. Regression Results for Time Trend, Non-US Production

Independent Variable	
a	−1,217,438.52*
	(−2.23)
b	617.28**
	(−2.25)
R^2	0.39

Note: Numbers in parentheses are t-ratios; * significant at the 10% level; ** significant at the 5% level.

10 and two regressors are $d_L = 0.88$ and $d_U = 1.32$. $d = 1.77$ is greater than $d_U = 1.32$; therefore, there is no serial correlation in the residuals of the estimated time trend.

With the estimated non-US production time trend ($\hat{Y}_t$) removed from the foreign production both before and after the "shock" in 2001, figure 6 shows the residuals from the time period (1991–2000) used to estimate the initial foreign trend. It also shows residuals from the predicted trend in the subsequent period during and after the Hawaii longline swordfish fishery closure (2001–2012).

Table 3 shows the regression result of equation (4). The coefficient $d = -1.01$ is significant at the 1% level. This result suggests that the displacement between US and non-US swordfish production in the North and Central Pacific is nearly one for one. To test for heteroskedasticity, we conducted a Koenker test with H_0 hypothesis of homoskedasticity. The Koenker chi-square statistic for the regression is 1.063 and the p-value is 0.3024. Because the p-value is greater than 0.05, we accept the H_0 hypothesis of homoscedasticity and conclude that there is no heteroskedasticity.

Based on the results from equation (4), it is reasonable to assume that a one-unit increase in Hawaii longline swordfish fleet production will prompt a one-unit decrease in foreign fleet production (i.e., one-for-one displacement) in the North and Central Pacific Ocean. This is

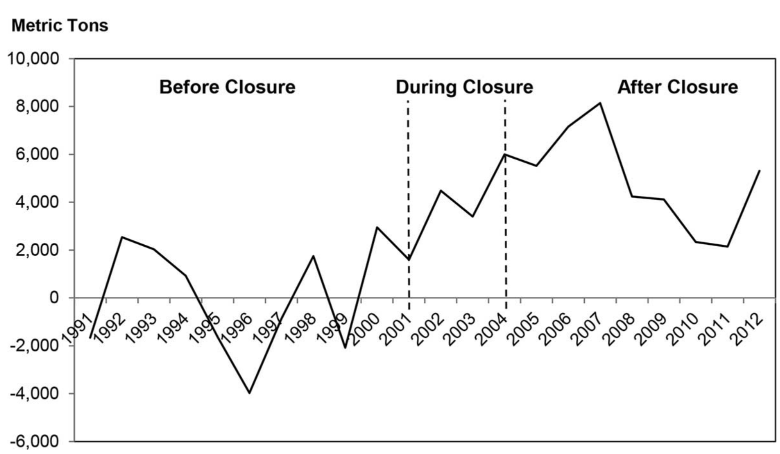

Figure 6. Residual from Actual Non-US Production and Estimated "Intrinsic" Time Trend, 1991–2012

Table 3. Regression Results for US Production Affecting Non-US Production

Independent Variable	
c	5,770.09***
	(4.42)
d	−1.01***
	(−2.82)
R^2	0.28

Note: Numbers in parentheses are t-ratios; *** significant at the 1% level.

represented in figure 2, where the decrease in Hawaii swordfish production equals the increase in foreign swordfish production.

SPILLOVER EFFECT UNDER DIFFERENT POLICY ALTERNATIVES

After confirming the existence of swordfish production displacement between the US and foreign fleets, we can quantify the spillover effects in terms of changes in the amount of sea turtle bycatch under different policies.

First, we estimate sea turtle bycatch associated with swordfish longline fisheries in the North and Central Pacific in 2012. In that year, total swordfish production in that area was 31,330 mt. The US, Taiwan, Japan, Indonesia, the Philippines, China, Korea, Australia, and Mexico represent 94% of production in the region. Based on each country's swordfish production level and the country-specific bycatch rates, we estimate that 2,270 turtle interactions resulted from swordfish production in the North and Central Pacific in 2012. The details of this estimation appear in Web Appendix E.

Next, we estimate sea turtle bycatch if US effort consisted of 5,500 sets in 2012. In that case, Hawaii longline swordfish fishery production is estimated at 4,985 mt, or 3,905 mt more than actual 2012 production.[8] From the results of the above regressions, we apply one-for-one displacement and proportionally deduct the amount of the increased US production from each non-US country based on its 2012 production level. In this scenario, the Hawaii longline swordfish fishery would contribute 16% of the total production in the North and Central Pacific. This is similar to the ratio of Hawaii longline swordfish fishery production to total production in the North and Central Pacific as actually occurred during the 1991–2000 period (19%).

With the increase in US effort and assumed associated decrease in non-US effort, estimated sea turtle bycatch in this scenario would total 2,010 interactions. This reflects an 11% decrease in turtle bycatch (or 260 fewer interactions) when compared with 2012 bycatch (i.e., 2,270 turtles). The detailed results for this scenario, including the re-distribution of swordfish production and sea turtle bycatch among the relevant countries, can be found in Web Appendix F.

8. Based on Hawaii longline swordfish fishery logbook statistics, the average number of hooks per set for US longline vessels landing in Hawaii and targeting swordfish was 946 between 2005 and 2012. For 5,500 sets, this yields an estimate of 5,203,000 hooks. In addition, actual Hawaii longline swordfish fishery capture data from NMFS and 100% observer coverage in that fishery indicate that from 2005 to 2012, the average swordfish CPUE was 0.958 mt/1,000 hooks, and the turtle bycatch rate was 0.012 turtles/1,000 hooks. This would produce an annual average 4,985 mt of swordfish.

If we were to assume that all fisheries in the North and Central Pacific had the same bycatch rate as the Hawaii fleet, turtle bycatch under this scenario would decline to 392 (Web Appendix G). This scenario shows an 83% decrease in turtle bycatch (or 1,878 fewer turtles) when compared with the current level of 2,270 turtles. Table 4 summarizes the results under different scenarios.

CONCLUSIONS AND IMPLICATIONS

The study analyzed the possible spillover effects resulting from production displacement between the Hawaii longline swordfish fleet and foreign fleets operating in the North and Central Pacific Ocean. It estimated the spillover effects in terms of the change in sea turtle bycatch associated with such displacement under various fishing effort levels.

The regression modeling suggests that non-US fresh swordfish production in the North and Central Pacific moves in the opposite direction of US (mostly Hawaii) fresh swordfish production; specifically, foreign fleet production displaces Hawaii production on a one-for-one scale and vice versa.

This finding implies that reducing Hawaii longline swordfish production through regulatory changes (especially closures and both production and sea turtle interaction caps) does not cause an overall lower level of sea turtle bycatch in the North and Central Pacific. This is because the Hawaii longline swordfish fishery has one of the lowest sea turtle bycatch rates among the fleets fishing in the North and Central Pacific. The study concludes that a decrease in US fishing effort was associated with an increase in foreign fishing effort, and because the foreign fleets interact with more turtles per unit effort, the expected overall turtle bycatch increased. Furthermore, if the Hawaii longline swordfish fishery effort were to rise to its historical peak level of fishing effort (5,500 sets), the analysis indicates that 11% less turtle bycatch (or around 260 fewer turtle interactions) would occur when compared with the current level of 2,270 interactions in the North and Central Pacific area.

This study has built on, enhanced, and extended previous research on this topic in several ways. First, this study examines the spillover effects resulting from possible production displacement. While the study by Rausser et al. (2009) examined spillover effects stemming from an increase in US swordfish imports, market flows (imports and exports) alone may not be sufficient to prove the spillover effect stock-wide without consideration of production displacement. Second, this study links the actual amount of swordfish production from each country or fishery and the sea turtle bycatch rate reported for the specific fishery/country. This contrasts with the Rausser et al. (2009) methodology that used a single bycatch rate generated from the average bycatch rates across 17 studies to calculate the net effect on sea turtle bycatch resulting from the total imports. Using country and gear (longline)-specific bycatch rates rather than a multination average, this analysis may present a more accurate estimate of the amount of sea turtle bycatch. However, one aspect this study does not consider is the spillover effect on individual species of sea turtles. A potential future study could model these details so that the displacement effect can be measured at the individual sea turtle species level if bycatch rates for non-US fleets and better information on spatial distribution of different species of turtles in the North and Central Pacific Ocean become available.

The sea turtle bycatch rates for different fisheries are critical elements for determining the direction and magnitude of the spillover effects. The bycatch rates used in this study are based on a limited number of studies conducted in certain time periods or locations that may not be

Table 4. Summary of Scenario Analysis

	Annual Hawaii Swordfish Production (mt)	Annual Swordfish Production, North and Central Pacific (All Countries Combined) (mt)	Annual Turtle Bycatch North and Central Pacific (All Countries Combined)	Annual Reduction in Turtle Bycatch (Change from 2012)	Annual Reduction in Turtle Bycatch (Percent Decrease from 2012)
Estimated 2012 landings and sea turtle bycatch	1,080	31,330	2,270	—	—
Scenario 1: Hawaii longline swordfish fishery effort increases to 5,500 sets with one-for-one replacement of foreign production	4,985	31,330	2,010	260	−11
Scenario 2: Production by all countries if all had the same bycatch rate as the Hawaii longline swordfish fishery	—	31,330	392	1,878	−83

strictly applicable to the entire group of fisheries considered. Some fisheries did not have any data on sea turtle bycatch; in these cases, we assumed bycatch rates were the same as in other non-US fisheries where some information was available. In addition, for some fleets that use other countries' flags (taking advantage of fishing quotas or rights) production data may not be consistent with export data, and the fish caught may be sold or reported as the production of the 'flag' countries. In this case, the sea turtle bycatch rate could be misrepresented as being associated with a different country than that in which actually produced the bycatch. Nonetheless, the data that are available and the analysis herein suggest strong spillover effects from regulations on the Hawaii longline fishery for swordfish.

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