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Effects of Sea Surface Temperature on Tuna Catch: Evidence from Countries in the Eastern Pacific Ocean

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ABSTRACT

Tuna move towards higher latitudes or deeper waters in response to ocean warming. The spatial redistribution of tuna will affect countries in the Eastern Pacific Ocean (EPO). We apply a production function approach to establish the relationship between sea surface temperature (SST) and yellowfin and skipjack tuna catch of purse seines. We use data for 1° latitude/longitude grids within the exclusive economic zones of countries in the EPO. Catch of yellowfin and skipjack tuna increases with SST in all countries with high values recorded in the eastern coastal borders. The biggest increase in revenue from yellowfin and skipjack tuna as result on 1°C increase in SST is for Mexico while the smallest is for Kiribati. However, if we adjust these values by coastal population, highest values are for Kiribati and French Polynesia. The higher tuna catch due to ocean warming translates to higher government revenue from tuna fishing licenses and more jobs for tuna fishers and those in the tuna processing industry in the state. However, it is possible that the recorded positive effects on tuna catch will be offset by the reduction on catch of other species and may even result in negative net impact overall. We highlight the importance of conducting research on SST that must be species-, gear-, and location-specific to fully account for the impact of ocean warming.

Keywords: Eastern Pacific Ocean, Production Function, Sea Surface Temperature, Tuna
JEL CODES: Q22, Q54

1. INTRODUCTION

Ocean temperature is increasing over time, with some regions warming much faster than other regions. This trend is expected to continue into the future under climate change conditions (Bindoff et al. 2019). As ocean warms, fish populations adapt by moving to higher latitudes or deeper waters. This spatial redistribution of fishes may lead to rapid changes in marine ecosystems (Perry et al. 2011; Vergés et al. 2019) and consequently fishing operations and the effectiveness of fisheries management measures (Sumaila et al. 2011).

The impacts of ocean warming vary across areas. Fish production at high latitudes is predicted to increase with ocean temperature while production at low and mid latitudes are predicted to decrease, allowing for regional variations (Barange et al. 2014). It is predicted that lower income countries would experience relatively more reductions in fish catch with climate change because they are concentrated in tropical and sub-tropical regions of the world. Employment and export earnings of economies are affected by the spatial redistribution of fishes in response to warming waters. Government revenue is also affected through fishing licenses sold to distant fishing nations (Sumaila et al. 2011).

The relative importance of fisheries to national economies is one of the factors that determine the vulnerability of countries to impacts of climate change (Allison et al. 2009). Island nations such as Kiribati and French Polynesia have high dependence to marine ecosystems. Countries with high dependence on revenue from fisheries or foreign fishing access agreement are those with major pelagic or high value fisheries such as tuna (Selig et al. 2019).

Tuna are highly migratory and move between coastal ecosystems and the open ocean, and between domestic jurisdictions and international waters. As ocean warms, tuna move towards areas with preferred habitat temperatures as a compensatory mechanism (Dizon, Neill, and Magnuson 1977). In the Pacific Ocean, there are expected decreases in biomass of yellowfin and skipjack tuna in areas west of 170 °E and increases in EEZs east of 170°E (Bell et al. 2018). Pacific Ocean is important for tuna as seventy percent of the total global catch in 2010 came from this fishing ground (Lehodey et al. 2013). Changes in spatial distribution of tuna driven by climate change will affect catch in countries in the Pacific Ocean.

We determine the relationship between SST and tuna catch in areas within the exclusive economic zones (EEZ) of countries in the Eastern Pacific Ocean (EPO) following the production function approach used in Mediodia et al. (2020) using gridded data. Focus is on yellowfin and skipjack tuna as these are the dominant species caught by purse seine in EPO. The different types of purse seine sets are considered in the analysis. We compute for the marginal product and marginal revenue product for 1°C increase in SST for the countries included in this study.

We contribute to the literature by providing evidence for the impacts of ocean warming in the EPO. The whole of Pacific Ocean is affected by ocean warming but most of the studies on its impacts focus on the western and central pacific as most of the small island developing states are in this area. A study that focuses on the countries in the Eastern Pacific Ocean is warranted.

In terms of measures of effects of SST on catch, we extend the method used in Mediodia et al. (2020) by expressing the marginal product of SST in international dollar terms. This is relevant to capture differences in purchasing power across countries. We also express the values in relation to coastal population to capture differences in dependence of countries to tuna.

Our results show that the volume of catch of skipjack and yellowfin tuna in the EEZ of countries in the Eastern Pacific Ocean increases as ocean warms. This supports the conclusion in fisheries science studies that showed that the dispersion of tuna towards the eastern part of Pacific Ocean as ocean warms. We find that Mexico will have the highest increase in tuna catch dues to ocean warming due to the size of their EEZ. If we adjust for coastal population, however, then the marginal revenue product for island nations such as Kiribati and French Polynesia are greater compared other countries in EPO.

In the next section, we discuss economic impacts of climate change in fisheries focusing on countries in the Eastern Pacific Ocean. This is followed by a presentation of the model we estimate, the data, and the estimation procedure used in the study. We then discuss the results of the analysis, and finish with some concluding remarks.

2. REVIEW OF RELATED LITERATURE

2.1. Climate change and Fisheries

The average ocean temperature is increasing over time due to anthropogenic influences and this trend is expected to continue in the next century (Collins et al. 2013; Rhein et al. 2013; Bindoff et al. 2019). The vulnerability of most organisms to warming is determined by their physiology, which defines their limited temperature ranges and thermal sensitivity (Pörtner et al. 2014), and biological functions such as metabolism, growth, and reproduction (Bindoff et al. 2019). The change in ocean temperature results in the redistribution of marine organisms, from phytoplankton to marine mammals. Recent evidence records observed shifts in the distribution of marine species across regions (Poloczanska et al. 2016).

Projections show that the ocean warming will continue to cause the redistribution of species from the tropics towards the poles. The poleward shift are projected to result in reduction of species richness in the tropics and increase in the mid to high-latitude areas (Ben Rais Lasram et al. 2010; Jones and Cheung, 2015; Cheung and Pauly, 2016; Molinos et al. 2016). This then has effects on the timing of activities, abundance, and migration patterns of species (Pörtner et al. 2014). Warming is also projected to impact on the physiological growth of fishes (Pauly and Cheung 2017).

2.2. Economic Impacts of Climate Change in Fisheries

Fisheries provide food, nutrition, income and livelihoods for millions of people (FAO 2018). Generally, there is an expected loss of fisheries productivity due to warming ocean. Productivity may expand in higher latitudes as ocean warms but this is offset by reduction in productivity in low- and mid-latitudes (Hoegh-Guldberg et al. 2018). This means that ocean warming will affect income and employment from fisheries.

Global marine fisheries landings are valued at 150 billion in 2010 USD, which is 5 times more than the estimate for 1950 (Tai et al. 2017). Climate change will lead to a global decrease in revenue (Lam et al. 2016). However, spatial variations of climate impacts on and the flexibility and capacities of food production systems can result to regional differences in the impact (Pörtner et al. 2014; Lam et al. 2016). Lam et al. (2016) showed that there will be a projected increase in fish catch in high latitudes as ocean warms but this may not translate into increase in revenues because of the dominance of low value fish and decrease in the catch by the vessels of countries in high latitudes operating in adversely-affected distant waters . They also found that lower income countries with high fisheries dependency are negatively affected. The impact on revenues from fisheries may have implications on other sectors with linkages to the fisheries sector such as boat building and maintenance, equipment supply, and the hospitality sectors.

The changes in the dynamics of fish species will have direct impacts on communities and economies. As fishes move, fishers that target the new fishes will benefit while those in established fisheries will be adversely affected (Madin et al. 2012). Capital costs increase as fishers need to improve gears and vessels and incur higher fuel, ice, and labour costs due to longer search time are expected in areas where species move out. (Sumaila et al. 2011). On the other hand, migration of species into other areas can translate into higher revenue and lower costs.

The economic implications of climate change on fisheries vary between regions and countries. Blasiak et al. (2017) showed that countries most vulnerable to the effects of climate change on fisheries are primarily small island states in the Pacific Ocean and Caribbean, and those along the western and eastern coasts of Africa. The vulnerability of these countries is mainly driven by deficits in the ability to modify fisheries and livelihoods to cope with the adverse impacts of climate change and pursue emerging opportunities. There is no linkage between levels of national development and exposure to the impacts of climate change on fisheries. The high vulnerability of low income countries is attributable to the importance of the fisheries sector to the economy in terms of employment and revenue.

The dependence of countries on marine ecosystems matter in the assessment of impact of climate change. Selig et al. (2019) measured the nutritional, economic, and coastal protection dependence of countries to marine ecosystem. The patterns they establish vary by country and type of dependence measured. Island nations in Pacific and Indian Ocean have high overall dependence on marine resources. Countries with major pelagic fisheries and high value fisheries like tuna are also the countries that have high economic dependence on marine resources. The measures of dependence and ranks of the countries in our study are presented in Appendix Table 1.

2.3. Tuna Fisheries and Climate Change

Tuna fisheries are affected by ocean warming through changes in tuna physiology and behaviour or the abundance of their prey. Increase in temperature is projected to result in a decrease in the productivity of phytoplankton. This affects the tuna larvae and juvenile as they feed on the phytoplankton (Lehodey et al. 2013). Spatial distribution of tuna is conditioned by sea temperature. Tuna move to preferred habitat temperatures as a compensatory mechanism to ocean warming (Dizon, Neill, and Magnuson 1977; Schaefer, Fuller, and Block 2007). Monllor-Hurtado, et al. (2017) showed that tropical tuna species move towards the poles in response to ocean warming.

The two tropical tuna species – yellowfin and skipjack – are among the fish species affected by increasing sea temperature. Sea temperature affects the growth of these species. Skipjack tuna commence spawning when the SST is greater than 24 °C (Ashida and Horie 2015). The development and survival of yellowfin tuna larvae is also affected by SST. Temperatures of about 26° to 31 °C is associated with rapid growth and moderate to high survival in yellowfin tuna larvae (Wexler, Margulies, and Scholey 2011). The spatial distribution of tropical tuna is also affected by temperature. Ocean warming may increase the suitability of some habitats for skipjack tuna (Muhling et al. 2015) and yellowfin tuna (Schaefer, Fuller, and Block 2007). Increase in SST also promotes the tuna-dolphin bond for large yellowfin tuna (Scott et al. 2012).

In the Pacific Ocean, projections show that these tropical tuna species will have a redistribution from the west to the east (Lehodey et al. 2013; Monllor-Hurtado, Pennino, and Sanchez-Lizaso 2017). Bell et al. (2018) showed that there are expected decreases in biomass of yellowfin and skipjack tuna in areas west of 170 °E and increases in EEZs east of 170°E. A progressive biomass displacement towards the poles is also projected (Lehodey et al. 2013). This redistribution of tuna will translate to effects on livelihood and revenue, with countries in the east gaining while countries in the west losing.

2.4. Tuna Fisheries in Eastern Pacific Ocean

There is an extensive literature on the effects of climate change on fisheries-dependent countries in the Pacific Ocean (Bell, Ganachaud, et al. 2013; Bell, Reid, et al. 2013; Asch, Cheung, and Reygondeau 2018), but most of the studies are on the Western and Central Pacific. Bell, et al. (2013) showed that the east region of the Western and Central Pacific Ocean is expected to receive more revenue as tuna catch increase in their region. Countries in west may face a reduction in revenue as are tuna are redistributed progressively to the east. There is no work, to the best of our knowledge, which conducts an analysis on the effects of the countries extending towards the eastern coastal boundaries of the Pacific Ocean.

2.5. Purse Seine

Purse seines are fishing gears designed to catch fishes swimming together in the same direction in a coordinated manner. It is made of a long wall of netting hung on a float line and the bottom is attached to a lead line. A purse line threaded through steel ring (also called purse rings) spaced along the bottom of the net is drawn tight to stop the school of fish escaping downwards under the net. The purse seine is set from one or two boats to surround the fish (ICES 2007). In the EPO, nets have been becoming deeper for the vessels fishing on FADs, and longer for the vessels setting on dolphin (Hall and Roman 2013).

There are different ways in which tunas are detected and encircled, and this gives rise to a classification of purse seine sets in several types. The data from IATTC classify sets either as dolphin set, floating object set, or unassociated set.

Dolphin sets are made for tuna that associate with dolphins in genera *Stenella* and *Delphinus*. These sets are practically monospecific for yellowfin tuna. Other major tuna species are very rare in these sets. Fishers launch speedboats to chase the dolphin pod associated with tuna until it stops swimming. The purse seine then encircles and captures the tuna associated with the dolphins. This method is controversial due to the incidental mortality of dolphins, even though fishers employ mechanisms to allow dolphins to escape (Hall 1998; Hall and Roman 2013).

Floating object sets are made for tuna schools associated with drifting objects. The object can be plant materials (logs, tree branches), aquatic plants (kelps), wooden crates and pallets, lost fishing gears, or dead animals (sharks, whales). Use of fish aggregating devices (FAD) became frequent in the last decade. FADs are man-made floating objects outfitted with tracking devices to ensure re-encounter. The composition of catch using floating object sets is a mixture of skipjack, bigeye, and yellowfin, with a clear predominance of skipjack (Bayliff 2001; Hall and Roman 2013).

Unassociated sets or school sets (Hall and Roman 2013) target tuna associated with schools of different species or seabirds. This type of set is the least predictable of all because fish behaviour may change abruptly in response to environmental or biological factors. Small-sized yellowfin and skipjack tuna are the usual species caught through unassociated sets (Hall 1998).

2.6. Fisheries Production Function

The production function approach in fisheries is applied to establish linkages between the habitat of a fishery and its economic productivity. Barbier and Strand (1998) demonstrated how an environmental factor, specifically habitat, directly affects the carrying capacity, which is the largest possible fish stock size given food supplies, habitat, and other factors. Foley et al. (2010) showed that the environmental factor also indirectly affects the carrying capacity through the intrinsic growth rate of the fish stock.

Studies apply a static fisheries production function model based on the assumption that the fishery is in a long-run equilibrium (Barbier 2007). Application of this framework includes establishing linkages of mangrove and shrimp catch (Barbier and Strand 1998), mangrove and artisanal demersal and shellfish catch (Barbier, Strand, and Sathirathai 2002), and cold water coral and redfish catch (Foley et al. 2010). There is a growing literature that includes environmental factors in the fisheries production function (see Vondolia et al. 2019; Armstrong et al. 2017; Kahui, Armstrong, and Vondolia 2016; Armstrong, Foley, and Kahui 2016; Hassan and Crafford 2015).

2.7. Temperature and Production Function

There is extensive research that includes temperature in the production function in terrestrial systems. These studies treat temperature as a productive input that explains variations in economic outcome. Most of the studies establish a relationship between temperature and macroeconomic variables such as growth of aggregate output (Hsiang and Jina, 2013), sectoral output (Hsiang 2010), and export growth (Jones and Olken 2010). The approach is also applied to study relationship of temperature and crop yields (Schlenker and Roberts 2009; Schlenker and Lobell 2010), agricultural profits (Deschênes and Greenstone 2007), and output of specific crops (Gupta, Sen, and Srinavasan 2014). Deschenes (2014) and Heal and Park (2016) review studies on the relationship of temperature and other economic outcomes.

Mediodia et al. (2020) is first to apply the production approach to establish the relationship between SST and catch using gridded data. They extended the framework pioneered by Barbier and Strand (1998) to show the positive relationship between SST and tuna in Eastern Pacific Ocean. SST and catch were linked directly through the carrying capacity and indirectly through the growth rate of tuna fisheries. There is a nonlinear (i.e. logarithmic and quadratic) relationship between the SST and the carrying capacity of tuna fisheries.

3. MODEL, STUDY AREA, ESTIMATION PROCEDURE, AND DATA

We follow the fisheries production function approach used in Mediodia et al. (2020) to link SST and tuna catch. The standard static open access fishery model pioneered by Barbier and Strand (1998) is modified in to account for the relationship between carrying capacity and SST.

We estimate the following equation assuming a logarithmic relationship between SST and carrying capacity:[1]

$$Tuna_{it} = \beta_1 Sets_{it} * lnSST_{it} + \beta_2 Sets_{it}^2 + \varepsilon_{it} \quad (1)$$

where $Tuna_{it}$ is the amount of tuna caught and $Sets_{it}$ is the number of sets in grid *i* in year t. The two variables are expressed in per square kilometre terms to account for differences in the surface area of grids. The equation also includes $lnSST_{it}$ which is the natural log of annual mean SST in grid *i* in year t, $Sets_{it}^2$ is the square of $Sets_{it}$, and ε_{it} is the error term.

Regression through the origin (RTO) is implemented similar to Armstrong et al. (2016), Thanh Thuy and Flaaten (2013), and Foley et al. (2010). RTO handles the unrealistic possibility of positive output of tuna without fishing effort. Eisenhauer (2003) provides a brief review of the literature on RTO approach in modelling.

The measure of effort, *Sets*, is proportionally adjusted to the amount of yellowfin and skipjack tuna caught within a set. This is done to isolate species-specific effort because purse seine catch different species on each set. A similar adjustment to effort was done in Foley et al. (2010). It is assumed that fishers give equal importance to yellowfin and skipjack tuna consistent to the effort proportion allocation procedure used in Wang et al (2015).

The marginal product of SST at means, MP_{SST}, as derived from the previous equation is:

$$MP_{SST} = \frac{\partial Tuna}{\partial SST} = \beta_1 \frac{Sets}{SST}. \quad (2)$$

[1] Similar to Mediodia et al. (2020), we also test for a quadratic relationship between SST and carrying capacity. Estimation results produced lower coefficient of determination compared to logarithmic assumption. Coefficients are also not statistically significant for most countries for the four model specifications.

We extend the model to include time trend to account for technological progress. Another extension is to include dummy variables for grids to control for time-invariant, grid-specific factors affecting the tuna catch such as area, location, and bathymetry. Estimations were also done to include both time trend and dummy variables for grids.

The marginal revenue product of SST is then computed by converting the MP_{SST} to international dollar terms. We use the price of skipjack and yellowfin tuna in January 2019 as reported in the European Price Report by Food and Agriculture Organization (FAO 2019). Prices of whole tuna in Ecuador were used because the report identified EPO as the source of tuna. The value is then converted to local currency units using average annual nominal exchange rate for 2018 and then converted back to international dollars using purchasing power parity (PPP) rates.[2] The use of PPP rates is important in this case to account for purchasing power of currencies, thus capturing differences in the benefits accruing to the countries.

To account for differences in the dependence of population to fisheries, we divide the marginal revenue product by the coastal population. We use the 2019 coastal population data adjusted by the share of the area of the country's EEZ within the EPO to the total area of the EEZ. [3]

We include the countries and territories within the agreement area of the Inter-American Tropical Tuna Commission (IATTC). This is the portion of Pacific Ocean east of 150°W up to the coastline of North, Central, and South America and between 50°N and 50°S as defined in the Antigua Convention. As the data we used are in 1° latitude/longitude grids, there are grid cells that overlap the boundaries between the EEZ of countries and between an EEZ and international waters. The overlap is illustrated in a box in Figure 1.

We use countries to refer to the sovereign countries and territories in the IATTC Agreement area. Four definitions to address the discrepancy between the EEZ maritime borders and the 1° latitude/longitude grid cells were considered (Table 1). We conduct separate analyses for these groups and compare the results to check for robustness. Results presented are averages of results of analyses using for datasets four model specifications for brevity with detailed results included in the appendices.

[2] Official (nominal) exchange rates (LCU per USD) and PPP conversion factors for GDP (LCU per international dollars) are from the World Bank's World Development Indicators (World Bank 2020) except for the nominal exchange rate for Nicaragua which is from Banco Central de Nicaragua (2018).

[3] Coastal population data is from the Low Elevation Coastal Zone (LECZ) Urban-Rural Estimates of the Socioeconomic Data and Applications Center (SEDAC) operated by the(Center for International Earth Science Information Network (CIESIN) Columbia University (Center for International Earth Science Information Network (CIESIN) Columbia University 2020).

Table 1. Data groups

Group	Description
With Overlaps	Grid cells that overlap with EEZ of other countries and international waters are included
Without Country Overlaps	Grid cells that overlap with EEZ of other countries are excluded but grid cells that overlap with international waters are included
Without International Waters Overlaps	Grid cells that overlap with EEZ of other countries are included but grid cells that overlap with international waters are excluded
Without Overlaps	Both grid cells that overlap with EEZ of other countries and international waters are excluded

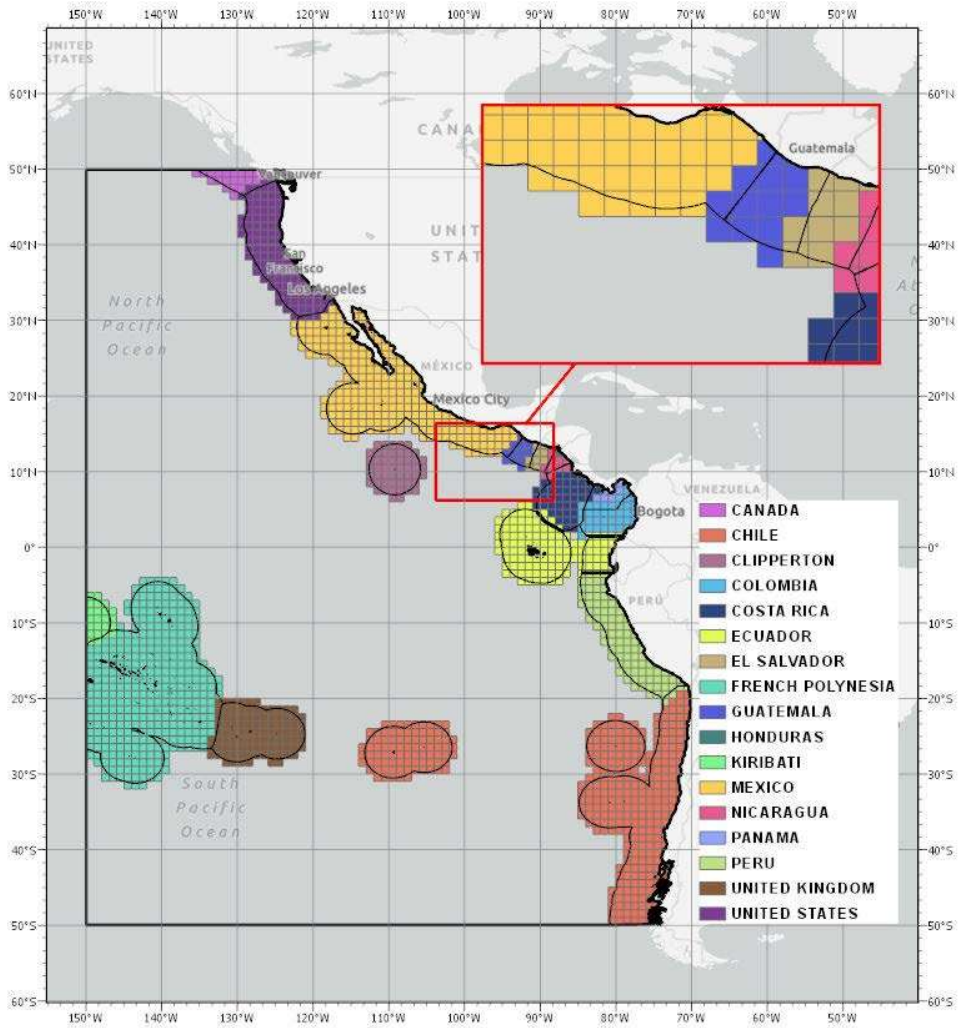

Figure 1. Exclusive Economic Zones of Countries in the Eastern Pacific Ocean

Tuna catch and effort data for purse seine we use are from the website of IATTC. Data show monthly tuna catches and number of sets by purse seine vessels in every 1°latitude/longitude grid and disaggregated by set type and by species of tuna caught (IATTC 2018). We compute for the annual totals of both catch and effort for every grid and express the data per square kilometre terms to account for the differences in the area of the grid cells.

SST data is from the Centennial In Situ Observation-Based Estimates of the Variability of SST and Marine Meteorological Variables, version 2.9.2 (COBE-SST2) by the Japan Meteorological Agency (JMA) (Hirahara, Ishii, and Fukuda 2014).[4] We compute for the annual averages of SST for each grid from 1970 to 2018 using monthly SST observations from COBE-SST2.

An unbalanced annual panel data for 1° latitude/longitude grid of containing tuna catch and effort data in the Eastern Pacific Ocean from 1970 to 2018 is included in the analysis. We perform separate estimations for observations grouped by species, types of set with standard errors clustered on the grid. [5]

4. SUMMARY STATISTICS

Figure 2 shows the total area in square kilometres with reported catch and effort data per country for the two data groups. Mexico has the largest fished area for tuna followed by Ecuador, then Peru. Even though the EEZ of the United States of America is larger, only a small portion of this area is fished for tuna. The EEZ of Honduras is covered by only one grid cell, thus it is not included in the presentation of results.

The figure is also indicative of the difference in the area covered for each country for the different data groups. There are wide gaps for Mexico and Ecuador. It is in these countries that there are number of grids that overlap with other countries or with the international waters.

Table 2 presents averages of the number of sets, total tuna catch, catch per set, and share of each species to total catch for all purse seine sets arranged in decreasing order by number of sets. Mexico

[4] COBE-SST2 data used in this study was taken from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at https://www.esrl.noaa.gov/psd/.

[5] Estimation was also done with standard errors clustered both on grid and time to handle heterogeneity due to spatial and temporal correlation we arrive at the same results.

records the highest number of effort (30%) and catch (24%) if we consider all purse seine sets from 1980 to 2018. This is followed by Ecuador that accounts for 25 percent of the total sets and 26 percent of total tuna catch. Honduras recorded only 15 sets thus this country is no longer included in the presentation of the results.

The data for each type of set is presented in Appendix Table 1. Dolphin sets account for 12 percent of the total sets and 13 percent of the catch. Most of the sets are in the Northern Hemisphere mostly recorded in Mexico (53%), Clipperton (21%), Costa Rica (12%). The dominant species is yellowfin tuna comprising 93 to 97 percent of the total catch of the different countries with dolphin sets.

Twenty one percent of the total effort and 30% of the catch from 1980 to 2018 are for floating object sets. Ecuador (33%), Colombia (24%), Costa Rica (15%), and Peru (8%) are the top for countries in terms of effort. These sets mostly catch skipjack tuna except for Guatemala, El Salvador, Nicaragua in which yellowfin tuna is the dominant species caught.

Unassociated sets account for majority of the total catch (56%) mainly in Mexico (34%), Ecuador (27%), Peru (21%). Yellowfin is dominant is Mexico (57%), Panama (69%), Costa Rica (55%), El Salvador (70), Nicaragua (76%), Clipperton (74%). Skipjack is the dominant species in Ecuador (66%), Peru (64%), Colombia (54%), Chile (93%), Line (Kiribati) (98%), French Polynesia (94%).

Catch per unit effort is highest for floating objects sets, followed by dolphin sets, then unassociated set. Looking at data per country, Kiribati has the highest value for all sets (46.7 metric tons) as majority of the effort are floating objects sets with high catch per unit effort at 52.3 metric tons per set.

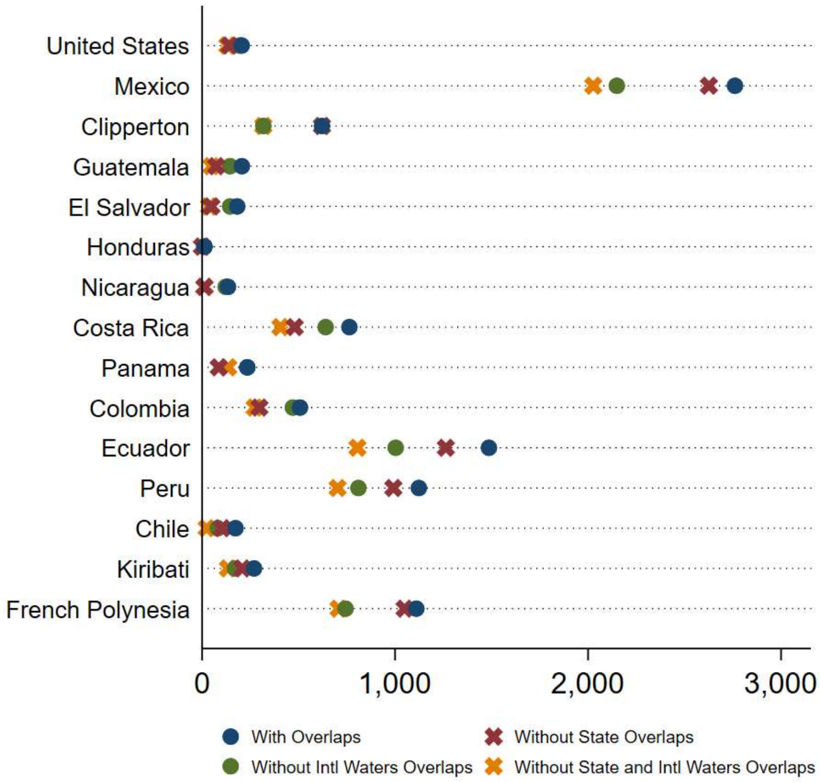

Figure 2. Total area with tuna catch and effort data by country and data group (in '000 square kilometres)

Table 2. Number of Sets, Tuna Catch, Catch per set, Percentage distribution of tuna catch by species, by country and data group for all set types

	Number of Sets	Total Tuna Catch (in metric tons)	Catch per set (in metric tons)	Percentage distribution of tuna catch by species		
				Yellowfin	Skipjack	Other species
ALL SETS						
Mexico	204,288	2,097,392	10	67	22	10
Ecuador	166,577	2,295,306	14	35	58	7
Peru	94,966	1,381,747	16	33	64	3
Colombia	66,498	832,114	13	41	56	3
Costa Rica	62,301	960,892	15	67	32	1
Panama	31,898	367,097	12	67	32	1
Clipperton	23,586	364,470	15	84	16	1
Guatemala	11,857	167,101	14	77	23	0
El Salvador	6,333	107,220	16	79	21	0
United States	3,465	28,789	9	17	20	63
Nicaragua	3,278	61,879	21	83	17	0
French Polynesia	1,397	51,114	34	9	76	16
Kiribati	989	42,357	47	7	86	7
Chile	551	16,227	38	21	70	9
Honduras	15	352	24	92	8	0

Ocean warming in the countries in EPO is captured by the COBE-SST2 dataset. The annual SST of countries increases over time is fluctuating but there is an upward trend (Figure 1). The slope of the trend line is positive and statistically significant for all countries except for Peru in which the slope is not statistically significant but still positive (see Appendix Table 3). The magnitude of the slopes across countries are comparable with values between 0.010 and 0.019.

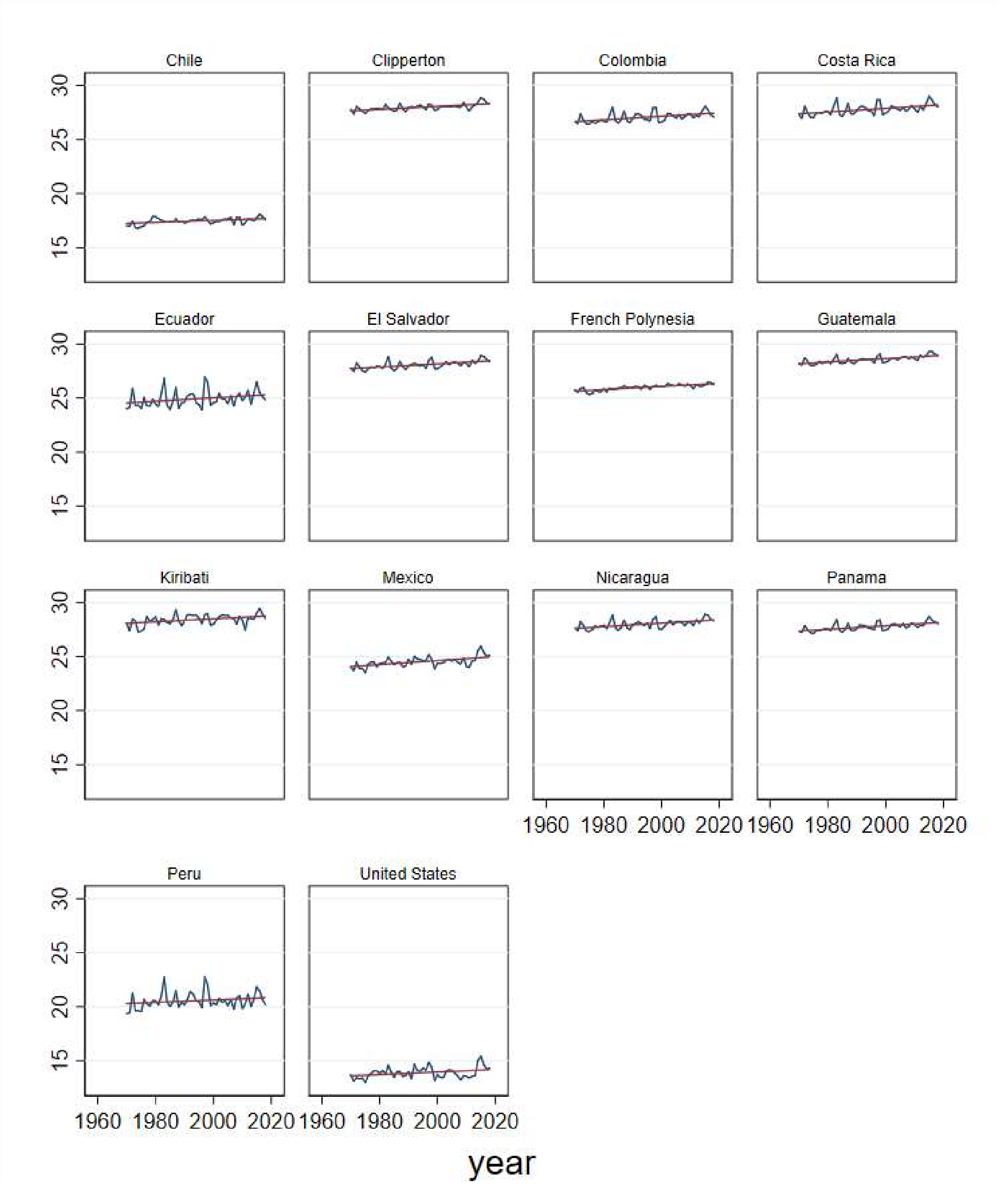

Figure 3. Annual SST by country, 1960-2018

5. RESULTS

5.1. Marginal Product of SST

Figure 4 shows the increase in tuna catch as a result of 1°C increase in SST for both yellowfin and skipjack tuna for countries arranged from North to South for each type of sets. The results presented are average values of MP_{SST} computed using the four data groups. Values of MP_{SST} for each data group are presented in Appendix Table 4. The MP_{SST} are positive except for some countries in which the value is zero for specific species.

If we consider all purse seine sets, the MP_{SST} is highest for Peru for skipjack in which 1°C increase in SST results to 8.92 x 10^{-5} MT of catch per square kilometre. The highest MP_{SST} for yellowfin tuna is in Panama at 8.48 x 10^{-5} MT of catch. The MP_{SST} for skipjack is greater than MP_{SST} for yellowfin for Colombia, Ecuador and countries in the Southern Hemisphere. The MP_{SST} for yellowfin tuna is greater than skipjack tuna for other countries in the Northern Hemisphere.

The MP_{SST} for yellowfin is greater than MP_{SST} for skipjack in all countries for dolphin sets. The highest is for Peru 7.67 x 10^{-6} MT per square kilometre of fished area. There are no dolphin set efforts in the United States, Chile, French Polynesia, and Kiribati.

The MP_{SST} for floating object sets are all positive in countries with recorded effort. In most countries, the MP_{SST} for skipjack tuna is higher compared to yellowfin tuna. This is not the case, however, for three countries in the Northern Hemisphere – Guatemala, El Salvador, and Nicaragua.

MP_{SST} for unassociated sets are greater compared to dolphin and floating object sets. The MP_{SST} for skipjack is greater than the MP_{SST} for yellowfin in Chile, Mexico, Ecuador, Peru, and Line Island in Kiribati. The difference is most pronounced in Nicaragua in which the MP_{SST} for skipjack is at 1.55 x 10^{-5} MT compared to 8.60 x 10^{-5} MT per square kilometre of fished area for yellowfin. In the US, Clipperton, Panama, Mexico, Guatemala, Costa Rica, Ecuador, the MP_{SST} for yellowfin is greater than the MP_{SST} for skipjack. These countries are all on the Northern Hemisphere.

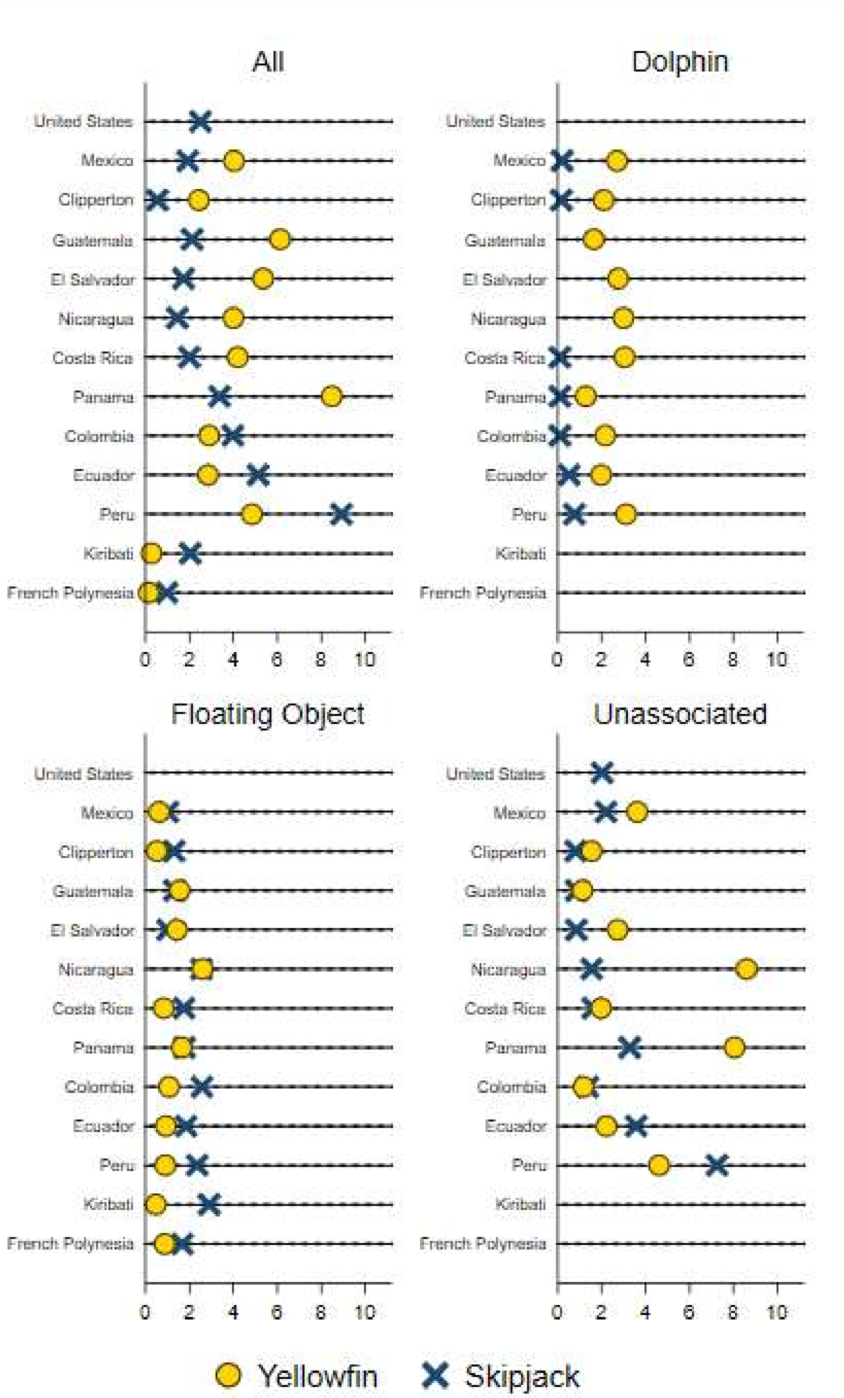

Figure 4. Marginal product of SST at means per square km (in x10^{-5} metric tons)

5.2. Marginal Revenue Product of SST

All countries considered will gain form the increase in tuna catch as a result of increase in SST as indicated by positive marginal revenue product. Figure 5 shows the average marginal revenue product by country for the yellowfin and skipjack tuna for the different set types computed using the four data groups.

For yellowfin tuna, highest value is for Mexico at Int$ 437,808 followed by Peru (Int$ 177,861) and Ecuador (Int$ 128,174) considering all types of sets. Lowest values are for Kiribati (Int$ 1,580) and French Polynesia (Int$ 2,995). The values for skipjack tuna are lower compared to yellowfin. The highest for all types of sets are is Peru (Int$ 201,837) followed by Ecuador (Int$ 142,134) and Mexico (Int$ 129,122) with low values for the US (Int$7,196) and Clipperton (Int$ 2,887).

The marginal revenue product for dolphin sets is higher for yellowfin tuna compared to skipjack tuna for all countries. Yellowfin accounts for 93 percent of the total value for all countries compared to 7 percent for skipjack tuna.

If we consider floating object sets, skipjack tuna account for 59 percent of the sum of the marginal revenue product of all countries. The marginal revenue product for skipjack is greater than marginal revenue product for yellowfin in most countries, with the greatest difference in Mexico and Ecuador. For Costa Rica, Guatemala, Nicaragua, and El Salvador, MRP for yellowfin is greater than skipjack by more than Int$ 3000.

For unassociated sets, the marginal revenue product for yellowfin in bigger compared to skipjack tuna in most countries. Highest for the sum of the marginal revenue products for yellowfin and skipjack is for Mexico at 566 thousand international dollars as a result of 1°C increase in SST. This is followed by Peru (378 thousand international dollars) then Ecuador (270 thousand international dollars).

MP_{SST} and corresponding standard errors computed using models with time trend, with grid dummy, and both time trend and grid dummy are presented in the appendices. Separate estimations were done for data with overlaps (Appendix Table 5), without country overlaps (Appendix Table 6), without water overlaps (Appendix Table 7), and without state and water overlaps (Appendix Table 8). Results show that the MP_{SST} is not sensitive to the model specification, given that MP_{SST} is similar across model specifications. The next sections, we compute for the marginal revenue product using results from the RTO model.

5.3. Marginal Revenue Product per Coastal Population

Table 3 shows the marginal revenue product of SST at means per 100 coastal population for the different countries by type of set and species. French Polynesia and Kiribati, countries in the western border of the IATTC agreement area, record the highest marginal revenue product per 100 coastal population if we consider the sum for both yellowfin and skipjack.

If adjusted for the coastal population, then the marginal revenue product is the highest for Kiribati for both species across types of set. There is a wide margin between the Kiribati (Int$ 143.5) compared to French Polynesia (Int$ 6.71) which records the second highest value if we get the sum for both species. Guatemala and United States record the lowest marginal revenue product per coastal population for both species and all types of sets.

Figure 5. Marginal Revenue Product of SST at means by country (in '000 international dollars)

Table 3. Marginal Revenue Product of SST at means per 100 coastal population[6] by country, species, and type of set (in international dollars)

Country	All	Dolphin	Floating Object	Unassociated
Skipjack				
Kiribati	117.69		167.85	82.48
French Polynesia	5.37		9.23	4.41
Panama	0.99	0.03	0.52	0.96
Ecuador	0.82	0.08	0.30	0.57
Costa Rica	0.69	0.03	0.60	0.55
Peru	0.62	0.05	0.16	0.50
Nicaragua	0.39	0.09	0.68	0.41
Colombia	0.28	0.01	0.18	0.10
Mexico	0.14	0.01	0.07	0.16
El Salvador	0.12	0.03	0.07	0.06
Guatemala	0.05	0.00	0.03	0.02
United States	0.03			0.03
Yellowfin				
Kiribati	25.81		44.58	478.67
Panama	4.04	0.61	0.79	3.84
Costa Rica	2.35	1.71	0.46	1.10
Nicaragua	1.73	1.30	1.13	3.73
French Polynesia	1.34		7.82	
Ecuador	0.74	0.51	0.24	0.58
El Salvador	0.63	0.32	0.17	0.32
Peru	0.55	0.35	0.10	0.52
Mexico	0.47	0.31	0.07	0.42
Colombia	0.33	0.25	0.12	0.13
Guatemala	0.25	0.07	0.06	0.05
United States	0.04			0.03
Sum				
Kiribati	143.5		212.43	561.15
French Polynesia	6.71		17.05	4.41
Panama	5.03	0.64	1.31	4.80
Costa Rica	3.04	1.74	1.06	1.65
Nicaragua	2.12	1.39	1.81	4.14
Ecuador	1.56	0.59	0.54	1.15
Peru	1.17	0.40	0.26	1.02
El Salvador	0.75	0.35	0.24	0.38
Colombia	0.61	0.26	0.30	0.23
Mexico	0.61	0.32	0.14	0.58
Guatemala	0.30	0.07	0.09	0.07
United States	0.07			0.06

6. DISCUSSION

We show that the volume of catch of skipjack and yellowfin tuna in the EEZ of countries in the Eastern Pacific Ocean increases as ocean warms. The results of our study support the conclusion in fisheries science studies that showed that the dispersion of tuna towards the eastern part of Pacific Ocean as ocean warms. This result is in contrast with the results of studies on Western and Central Pacific Ocean where there are expected reduction in catch as a result of ocean warming.

Although all countries have positive MP_{SST}, the MP_{SST} of countries on the eastern side of the IATTC area is greater compared to countries in western side of the IATTC. The sum of revenue for yellowfin

[6] Population adjusted by the share of the area EEZ within the IATTC Agreement area to the total area of EEZ. Clipperton is not included in this table because it is uninhabited.

and skipjack as a result of 1°C increase in SST is higher in countries in the east (e.g. Mexico, Peru) compared to French Polynesia which is the western side of the IATTC agreement area. This again supports eastward movement of tuna species within the IATTC agreement area.

The higher tuna catch due to ocean warming translates to higher government revenue from more tuna fishing licenses to be issued to purse seiners. More jobs will be created for tuna fishers and those in the fish processing industry in the country. Those offering ancillary services to tuna purse seine operators will also benefit from the increase in catch.

Upper middle-income countries benefit the most from the increase in tuna catch with the increase in SST. Mexico, Peru, and Ecuador have the highest revenue from the increase in tuna catch. These are also the countries with largest fishing areas for tuna in the IATTC. Even though the MP_{SST} per square kilometre for lower middle-income countries such as Nicaragua and Guatemala is positive with a magnitude comparable to other countries, the revenue is low compared to other countries as the fished areas of the countries are comparatively smaller.

Unassociated sets have the highest MP_{SST} in the three types of sets. Unassociated sets target both species, thus it benefits from in the increase in catch in both catch of yellowfin and skipjack tuna. The dominant species caught through unassociated sets in the countries in Northern Hemisphere is yellowfin tuna while skipjack tuna is the dominant species in the countries in Southern Hemisphere. This is consistent with studies on the habitat choice of these species

If we consider the population adjusted marginal revenue product, however, then the values for the countries on the western side of the IATTC agreement area such as Kiribati and French Polynesia are greater compared to countries in the east. The population adjusted marginal revenue product of SST is positively correlated with the measures of economic and overall dependence by Selig et al. (2019) showing that countries highly dependent on the marine resources are the same countries that records the highest revenue from the increase in tuna catch as ocean warms.[7]

Government agencies or regional fisheries management organizations should consider the results of this study to manage tuna resources. Countries in the EPO should exert effort to maintain the current levels of protection given to yellowfin and skipjack tuna as catch increases as ocean warms. This can

[7] The correlation coefficient between population adjusted marginal revenue product and overall dependence measure is 0.906 (p-value=0.000) and 0.964 (p-value=0.000) with economic dependence.

be done though management of spawning grounds and fishing effort. They may encourage the use of unassociated sets given than the marginal product is highest for this type of set. The method also spreads the pressure to both yellowfin and skipjack tuna and not just on a single species. There are countries, however, that unassociated sets does not provide the highest MP_{SST}. In Guatemala, we can expect more dolphin sets as ocean warms because of high economic returns. The increase in fishing effort targeting yellowfin tuna may affect the sustainability of the resource.

The relationship we established may not be applicable to other scenarios as it is bound by the species, fishing gear, location, and period covered in this study. As oceans continue to warm, the SST may reach the upper threshold of temperature for desired habitat of tuna resulting to decline in catch in the area. A comprehensive analysis covering all species may also result to a negative net effect on fish catch as the recorded positive effects on tuna catch may be offset by the reduction on catch of other species. Future studies should consider species, gear-, and location-specific analyses so that the impact of ocean warming can be fully accounted.

7. CONCLUSION

We established that countries within the Eastern Pacific Ocean gain from the redistribution of tuna due to ocean warming. Increases in SST result in an increase in tuna catch for all countries. This conclusion was arrived at after applying a production function approach that links SST to catch through the carrying capacity and intrinsic growth of tuna fisheries. The MP_{SST} of countries in eastern border of the IATTC agreement area is higher compared to countries in the western border highlighting the eastward redistribution of tropical tuna species in the Pacific Ocean. Countries highly dependent on the marine resources are the same countries that record the highest population adjusted marginal revenue product of 1°C increase in SST. We demonstrate that an analysis of link between SST and catch in an economic framework produces results consistent with conclusions of results models in fisheries science. Countries should consider the results of this study to manage tuna fisheries within their EEZs.

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APPENDIX TABLES

Appendix Table 1. Measures of dependence on marine ecosystems

Country	Integrated dependence	Nutritional dependence	Economic dependence	Econ (Jobs)	Econ (Revenue)	Coastal Protection
Kiribati	0.72	0.74	0.86	0.93	0.80	0.07
French Polynesia	0.36	0.46				0.07
Honduras	0.27		0.23	0.23	0.24	0.35
Peru	0.24	0.23	0.19	0.13	0.27	0.07
Nicaragua	0.19	0.1	0.22	0.17	0.30	0.30
Ecuador	0.19	0.06	0.27	0.2	0.36	0.08
Panama	0.17	0.13	0.21	0.31	0.13	0.06
El Salvador	0.15	0.09	0.17	0.16	0.21	0.15
Chile	0.15	0.06	0.20	0.18	0.23	0.05
Mexico	0.11	0.08	0.11	0.13	0.11	0.25
Costa Rica	0.11	0.04	0.16	0.19	0.15	0.05
Guatemala	0.10	0.01	0.16	0.17	0.16	0.26
Colombia	0.08	0.02	0.12	0.18	0.08	0.10
United States	0.05	0.05	0.04	0.04	0.07	0.28

Source: Selig et al. (2019)

Appendix Table 2. Number of Sets, Tuna Catch, Catch per set, Percentage distribution of tuna catch by species, by country, data group, and set type

	Number of Sets	Total Tuna Catch (in metric tons)	Catch per set (in metric tons)	Percentage distribution of tuna catch by species		
				Yellowfin	Skipjack	Other species
DOLPHIN SETS						
Colombia	1099	16543	15	94	5	0
Costa Rica	8674	132141	15	98	2	0
Ecuador	4518	119828	27	95	5	0
El Salvador	548	9181	17	96	4	0
Clipperton	15395	233975	15	94	6	0
Guatemala	2262	31610	14	97	3	0
Honduras	8	149	19	93	7	0
Mexico	39702	480615	12	94	6	0
Nicaragua	525	11804	27	94	6	0
Panama	1350	18399	14	96	3	0
Peru	895	28142	32	86	14	0
United States	2	65	24	0	100	0
UNASSOCIATED SETS						
Chile	356	8425	30	5	93	1
Colombia	29716	289444	10	44	54	2
Costa Rica	12207	171424	14	55	44	2
Ecuador	110387	1225151	11	31	66	4
El Salvador	1983	26191	13	70	30	0
Clipperton	1285	22228	17	74	26	0
French Polynesia	225	3279	13	5	94	0
Guatemala	2290	23404	10	53	47	0
Honduras	7	203	29	93	7	0
Line (Kiribati)	236	5659	26	1	98	0
Mexico	136795	1298377	9	57	27	16
Nicaragua	1393	20853	15	76	24	0
Panama	19216	208217	11	69	30	1
Peru	83498	1048572	14	33	64	4
United States	3450	28686	9	17	20	63

Appendix Table 2. ***Continuation***

	Number of Sets	Total Tuna Catch (in metric tons)	Catch per set (in metric tons)	Percentage distribution of tuna catch by species		
				Yellowfin	Skipjack	Other species
FLOATING OBJECT SETS						
Chile	179	7582	55	32	56	13
Colombia	30461	445653	15	26	69	5
Costa Rica	18956	352754	19	30	67	3
Ecuador	41521	799004	19	19	66	15
El Salvador	2013	43098	21	70	30	0
Clipperton	2835	55998	20	30	67	3
French Polynesia	1160	47684	40	9	74	17
Guatemala	3255	56270	17	52	47	1
Line (Kiribati)	744	36698	52	8	84	8
Mexico	6838	130571	19	32	68	1
Nicaragua	901	21744	22	71	28	1
Panama	8343	105098	13	46	51	2
Peru	9664	291405	31	26	72	2
United States	9	21	2	19	81	0

Appendix Table 3. Trend of SST by country ($SST_t = \hat{\beta}_0 + \hat{\beta}_1 Year + \hat{\mu}_t$)

Country	β_1	se(β_1)	Observations	R^2
Chile	0.010***	(0.003)	49	0.233
Clipperton	0.013***	(0.002)	49	0.398
Colombia	0.016***	(0.004)	49	0.263
Costa Rica	0.017***	(0.004)	49	0.248
Ecuador	0.016**	(0.007)	49	0.092
El Salvador	0.015***	(0.003)	49	0.347
French Polynesia	0.015***	(0.002)	49	0.639
Guatemala	0.016***	(0.002)	49	0.496
Kiribati	0.014***	(0.005)	49	0.168
Mexico	0.019***	(0.004)	49	0.331
Nicaragua	0.016***	(0.003)	49	0.329
Panama	0.016***	(0.003)	49	0.391
Peru	0.011	(0.008)	49	0.046
United States	0.012**	(0.005)	49	0.113

*** p<0.01, ** p<0.05, * p<0.1

Appendix Table 4. Marginal product by species and data group using RTO model

Country and Set Types	Skipjack								Yellowfin							
	With Overlaps		Without Country Overlaps		Without Water Overlaps		Without Water and Country Overlaps		With Overlaps		Without Country Overlaps		Without Water Overlaps		Without Water and Country Overlaps	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
All																
Chile	7.2	[0.8]	3.9	[0.4]	9.9	[1.3]			2.2	[0.2]	1.1	[0.3]	1.1	[0.3]		
Clipperton	0.6	[0.0]	0.6	[0.0]	0.5	[0.1]	0.5	[0.1]	2.4	[0.1]	2.4	[0.1]	2.4	[0.1]	2.5	[0.1]
Colombia	3.7	[0.2]	4.0	[0.2]	3.7	[0.2]	4.5	[0.3]	3.0	[0.1]	2.9	[0.1]	2.9	[0.1]	2.8	[0.1]
Costa Rica	2.3	[0.1]	1.8	[0.1]	2.2	[0.1]	1.7	[0.1]	3.7	[0.1]	4.4	[0.1]	4.4	[0.1]	4.3	[0.1]
Ecuador	4.5	[0.5]	4.7	[0.3]	5.5	[0.7]	5.8	[0.5]	2.7	[0.3]	2.7	[0.3]	2.7	[0.3]	3.3	[0.4]
El Salvador	1.6	[0.3]	2.3	[0.6]	1.4	[0.3]	1.6	[0.1]	5.2	[0.4]	5.9	[0.6]	5.9	[0.6]	4.4	[0.3]
French Polynesia	1.4	[0.1]	1.4	[0.2]	0.7	[0.2]	0.4	[0.1]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.0	[0.0]
Guatemala	2.2	[0.1]	2.3	[0.1]	1.9	[0.2]	2.1	[0.1]	5.4	[0.2]	6.4	[0.1]	6.4	[0.1]	6.3	[0.1]
Kiribati	2.5	[0.3]	2.6	[0.3]	1.0	[0.4]			0.3	[0.0]	0.3	[0.0]	0.3	[0.0]	0.2	[0.0]
Mexico	1.9	[0.1]	1.9	[0.1]	2.0	[0.1]	1.9	[0.1]	3.9	[0.1]	3.9	[0.1]	3.9	[0.1]	4.4	[0.1]
Nicaragua	1.5	[0.2]			1.4	[0.2]			4.0	[0.3]						
Panama	3.2	[0.1]	3.4	[0.2]	3.2	[0.1]	3.7	[0.2]	6.3	[0.4]	9.6	[0.9]	9.6	[0.9]	8.4	[0.6]
Peru	7.3	[1.4]	8.1	[0.7]	9.7	[1.9]	10.6	[1.0]	6.1	[1.0]	4.1	[0.4]	4.1	[0.4]	5.1	[0.6]
United States	2.9	[0.6]	2.1	[0.1]	2.9	[0.6]	2.1	[0.1]	2.9	[0.2]	1.5	[0.4]	1.5	[0.4]	1.6	[0.4]
Dolphin																
Clipperton	0.1	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	1.7	[0.1]	2.3	[0.1]	2.3	[0.1]	2.1	[0.1]
Colombia	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	3.4	[0.1]	1.8	[0.1]	1.8	[0.1]	1.7	[0.1]
Costa Rica	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	1.2	[0.1]	3.7	[0.1]	3.7	[0.1]	3.6	[0.1]
Ecuador	0.3	[0.1]	0.5	[0.1]	0.6	[0.1]	0.7	[0.1]	3.4	[0.1]	1.4	[0.2]	1.4	[0.2]	1.7	[0.3]
El Salvador	0.5	[0.1]			0.2	[0.1]			4.1	[0.2]	2.7	[0.0]	2.7	[0.0]	1.5	[0.3]
Guatemala	0.0	[0.0]	0.1	[0.0]	0.3	[0.0]			1.4	[0.2]	0.2	[0.0]	0.2	[0.0]	4.8	[0.2]
Mexico	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	1.5	[0.1]	3.6	[0.1]	3.6	[0.1]	2.1	[0.1]
Nicaragua	0.3	[0.1]			0.4	[0.1]			3.0	[0.3]						
Panama	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.9	[0.1]	1.1	[0.2]	1.1	[0.2]	2.0	[0.2]
Peru	0.9	[0.2]	0.9	[0.1]			0.5	[0.2]	0.6	[0.3]	4.9	[0.6]	4.9	[0.6]	2.1	[0.3]

Appendix Table 4 ***Continuation***

Country and Set Types	Skipjack								Yellowfin							
	With Overlaps		Without Country Overlaps		Without Water Overlaps		Without Water and Country Overlaps		With Overlaps		Without Country Overlaps		Without Water Overlaps		Without Water and Country Overlaps	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
Floating Objects																
Chile	2.3	[0.4]	2.6	[0.5]	4.2	[0.4]			1.4	[0.4]	0.9	[0.3]	0.9	[0.3]		
Clipperton	3.5	[0.0]	0.7	[0.0]	0.5	[0.1]	0.5	[0.1]	1.2	[0.0]	0.3	[0.0]	0.3	[0.0]	0.3	[0.0]
Colombia	1.4	[0.1]	3.1	[0.1]	2.7	[0.1]	3.1	[0.2]	0.6	[0.1]	1.2	[0.0]	1.2	[0.0]	1.3	[0.0]
Costa Rica	2.2	[0.1]	1.5	[0.1]	1.9	[0.1]	1.4	[0.1]	0.9	[0.0]	0.8	[0.0]	0.8	[0.0]	0.8	[0.0]
Ecuador	1.2	[0.2]	2.1	[0.1]	2.0	[0.2]	2.1	[0.2]	1.5	[0.0]	0.7	[0.1]	0.7	[0.1]	0.8	[0.1]
El Salvador	0.5	[0.1]	1.5	[0.3]	1.0	[0.1]	1.0	[0.2]	0.1	[0.2]	2.0	[0.4]	2.0	[0.4]	1.6	[0.1]
French Polynesia	4.5	[0.1]	1.1	[0.1]	0.4	[0.1]	0.7	[0.1]	3.2	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]
Guatemala	0.7	[0.1]	2.0	[0.2]	1.3	[0.2]	1.3	[0.1]	0.1	[0.2]	2.0	[0.2]	2.0	[0.2]	2.1	[0.2]
Kiribati	2.9	[0.3]	2.9	[0.3]					1.3	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Mexico	0.9	[0.1]	1.0	[0.1]	1.1	[0.1]	1.1	[0.1]	1.2	[0.0]	0.4	[0.0]	0.4	[0.0]	0.5	[0.0]
Nicaragua	4.1	[0.1]			1.0	[0.1]			2.6	[0.1]						
Panama	1.0	[0.1]	2.0	[0.2]	2.1	[0.1]	2.0	[0.1]	0.5	[0.1]	2.2	[0.2]	2.2	[0.2]	1.7	[0.1]
Peru	0.8	[0.2]	3.2	[0.1]	2.4	[0.2]	3.0	[0.2]	0.6	[0.1]	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]
Unassociated																
Chile	0.7	[1.8]			11.2	[2.7]			1.9	[0.1]						
Clipperton	2.4	[0.0]	0.3	[0.0]	0.3	[0.0]	0.3	[0.0]	2.6	[0.0]	1.1	[0.0]	1.1	[0.0]	1.4	[0.0]
Colombia	0.6	[0.1]	1.7	[0.1]	1.5	[0.1]	1.7	[0.1]	0.8	[0.1]	1.2	[0.1]	1.2	[0.1]	1.5	[0.1]
Costa Rica	3.8	[0.1]	0.8	[0.0]	0.9	[0.1]	0.9	[0.0]	3.9	[0.1]	1.3	[0.2]	1.3	[0.2]	1.4	[0.2]
Ecuador	1.0	[0.4]	3.7	[0.3]	4.8	[0.6]	4.8	[0.4]	1.2	[0.3]	2.4	[0.3]	2.4	[0.3]	2.9	[0.4]
El Salvador	0.7	[0.1]			1.0	[0.1]			0.5	[0.3]	3.3	[0.5]	3.3	[0.5]	3.8	[0.6]
French Polynesia	1.0	[0.2]	0.6	[0.2]												
Guatemala	0.1	[0.1]	1.2	[0.1]	1.0	[0.1]	1.1	[0.1]	0.4	[0.2]	1.3	[0.1]	1.3	[0.1]	1.5	[0.2]
Kiribati	2.8	[0.5]	1.3	[0.5]	0.8	[0.2]	0.8	[0.2]	15.1	[0.0]	0.1	[0.0]	0.1	[0.0]		
Mexico	1.2	[0.1]	2.6	[0.1]	2.5	[0.1]	2.5	[0.1]	1.3	[0.2]	4.3	[0.2]	4.3	[0.2]	4.6	[0.2]
Nicaragua	2.1	[0.1]			1.0	[0.1]			8.6	[0.2]						
Panama	5.9	[0.1]	2.3	[0.1]	2.1	[0.1]	2.8	[0.2]	7.6	[0.5]	8.4	[0.9]	8.4	[0.9]	7.8	[0.6]
Peru	2.1	[1.3]	7.3	[0.7]	9.7	[1.8]	9.9	[1.0]	2.7	[1.3]	5.0	[0.7]	5.0	[0.7]	5.8	[0.9]
United States	1.0	[0.6]	2.1	[0.1]	2.9	[0.6]	2.1	[0.1]	0.3	[0.2]	1.5	[0.4]	1.5	[0.4]	1.6	[0.4]

Appendix Table 5. Marginal Product of SST by species for four model specifications using data with overlaps

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
All																
Chile	7.2	[0.8]	6.9	[0.9]	6.6	[1.1]	6.8	[1.0]	2.2	[0.2]	2.2	[0.2]	2.3	[0.3]	2.3	[0.3]
Clipperton	0.6	[0.0]	0.5	[0.0]	0.6	[0.0]	0.5	[0.0]	2.4	[0.1]	2.6	[0.1]	2.9	[0.2]	2.9	[0.2]
Colombia	3.7	[0.2]	3.6	[0.3]	3.6	[0.3]	3.7	[0.2]	3.0	[0.1]	2.9	[0.2]	2.8	[0.2]	2.9	[0.1]
Costa Rica	2.3	[0.1]	2.3	[0.1]	2.3	[0.1]	2.3	[0.1]	3.7	[0.1]	3.8	[0.1]	3.8	[0.1]	3.8	[0.1]
Ecuador	4.5	[0.5]	4.4	[0.6]	4.8	[0.5]	4.9	[0.5]	2.7	[0.3]	2.6	[0.3]	2.8	[0.3]	2.8	[0.3]
El Salvador	1.6	[0.3]	1.5	[0.3]	1.5	[0.3]	1.4	[0.3]	5.2	[0.4]	5.3	[0.6]	5.5	[0.5]	5.5	[0.6]
French Polynesia	1.4	[0.1]	1.5	[0.2]	1.4	[0.2]	1.5	[0.2]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Guatemala	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	5.4	[0.2]	5.6	[0.3]	5.7	[0.3]	5.7	[0.3]
Kiribati	2.5	[0.3]	2.3	[0.3]	2.3	[0.4]	2.3	[0.4]	0.3	[0.0]	0.2	[0.1]	0.2	[0.1]	0.2	[0.1]
Mexico	1.9	[0.1]	1.8	[0.1]	1.8	[0.1]	1.8	[0.1]	3.9	[0.1]	3.8	[0.1]	4.0	[0.1]	3.9	[0.1]
Nicaragua	1.5	[0.2]	1.4	[0.2]	1.5	[0.2]	1.4	[0.2]	4.0	[0.3]	4.2	[0.4]	4.2	[0.4]	4.4	[0.4]
Panama	3.2	[0.1]	3.2	[0.2]	3.2	[0.2]	3.2	[0.2]	6.3	[0.4]	6.4	[0.5]	6.2	[0.4]	6.3	[0.4]
Peru	7.3	[1.4]	6.5	[1.4]	6.9	[1.7]	7.6	[1.5]	6.1	[1.0]	5.8	[1.0]	6.3	[1.1]	6.5	[1.1]
United States	2.9	[0.6]	2.9	[0.7]	2.9	[0.8]	2.9	[0.8]	2.9	[0.2]	2.8	[0.3]	2.8	[0.4]	2.8	[0.4]
Dolphin																
Clipperton	0.1	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	1.7	[0.1]	2.5	[0.1]	2.8	[0.2]	2.8	[0.2]
Colombia	0.1	[0.0]	0.1	[0.0]					3.4	[0.1]	1.9	[0.1]	2.0	[0.1]	1.9	[0.1]
Costa Rica	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	1.2	[0.1]	3.1	[0.1]	3.2	[0.1]	3.2	[0.1]
Ecuador	0.3	[0.1]	0.5	[0.1]	0.4	[0.1]	0.4	[0.1]	3.4	[0.1]	1.4	[0.2]	1.5	[0.2]	1.5	[0.2]
El Salvador	0.5	[0.1]	0.2	[0.1]	0.3	[0.1]	0.3	[0.1]	4.1	[0.2]	3.1	[0.3]	3.2	[0.3]	3.3	[0.3]
French Polynesia																
Guatemala	0.0	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	1.4	[0.2]	4.1	[0.2]	4.2	[0.2]	4.2	[0.2]
Kiribati																
Mexico	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	1.5	[0.1]	2.1	[0.1]	2.2	[0.1]	2.2	[0.1]
Nicaragua	0.3	[0.1]	0.4	[0.1]	0.4	[0.1]	0.4	[0.1]	3.0	[0.3]	2.5	[0.3]	2.4	[0.4]	2.6	[0.3]
Panama	0.1	[0.0]							0.9	[0.1]	2.5	[0.2]	2.4	[0.2]	2.4	[0.2]
Peru	0.9	[0.2]	0.7	[0.2]					0.6	[0.3]	2.0	[0.3]	1.9	[0.4]	1.9	[0.4]

Appendix Table 5. ***Continuation***

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
Unassociated																
Chile	0.7	[1.8]	9.1	[2.1]	9.1	[2.3]	9.7	[2.4]	1.9	[0.1]	2.0	[0.2]	1.8	[0.2]	1.9	[0.3]
Clipperton	2.4	[0.0]	0.3	[0.1]	0.3	[0.1]	0.3	[0.1]	2.6	[0.0]	1.1	[0.0]	1.1	[0.1]	1.1	[0.1]
Colombia	0.6	[0.1]	1.4	[0.1]	1.4	[0.1]	1.4	[0.1]	0.8	[0.1]	1.5	[0.2]	1.5	[0.1]	1.5	[0.1]
Costa Rica	3.8	[0.1]	0.8	[0.1]	0.8	[0.1]	0.8	[0.1]	3.9	[0.1]	1.2	[0.1]	1.2	[0.1]	1.2	[0.1]
Ecuador	1.0	[0.4]	3.8	[0.5]	4.2	[0.5]	4.3	[0.5]	1.2	[0.3]	2.5	[0.3]	2.6	[0.3]	2.6	[0.3]
El Salvador	0.7	[0.1]	1.1	[0.1]	1.1	[0.1]	1.1	[0.2]	0.5	[0.3]	2.4	[0.4]	2.4	[0.3]	2.4	[0.3]
French Polynesia	1.0	[0.2]														
Guatemala	0.1	[0.1]	1.2	[0.1]	1.2	[0.2]	1.2	[0.1]	0.4	[0.2]	1.6	[0.3]	1.7	[0.3]	1.6	[0.3]
Kiribati	2.8	[0.5]							15.1	[0.0]	0.1	[0.0]	0.0	[0.0]	0.0	[0.0]
Mexico	1.2	[0.1]	2.5	[0.1]	2.5	[0.1]	2.5	[0.1]	1.3	[0.2]	4.2	[0.2]	4.1	[0.2]	4.1	[0.2]
Nicaragua	2.1	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]	8.6	[0.2]	2.6	[0.4]	2.6	[0.4]	2.6	[0.4]
Panama	5.9	[0.1]	2.1	[0.2]	2.1	[0.1]	2.1	[0.1]	7.6	[0.5]	5.4	[0.5]	5.1	[0.5]	5.2	[0.5]
Peru	2.1	[1.3]	6.8	[1.4]	7.0	[1.7]	7.8	[1.5]	2.7	[1.3]	7.7	[1.4]	8.1	[1.5]	8.4	[1.5]
United States	1.0	[0.6]	2.9	[0.7]	2.8	[0.8]	2.8	[0.8]	0.3	[0.2]	2.8	[0.3]	2.8	[0.4]	2.8	[0.4]
Floating																
Chile	2.3	[0.4]	3.7	[0.4]	3.2	[0.5]	3.2	[0.6]	1.4	[0.4]	1.8	[0.6]	1.9	[0.6]	1.9	[0.6]
Clipperton	3.5	[0.0]	0.6	[0.1]	0.7	[0.1]	0.7	[0.1]	1.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Colombia	1.4	[0.1]	2.6	[0.1]	2.5	[0.1]	2.6	[0.1]	0.6	[0.1]	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]
Costa Rica	2.2	[0.1]	2.0	[0.1]	1.9	[0.1]	1.9	[0.1]	0.9	[0.0]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]
Ecuador	1.2	[0.2]	2.0	[0.2]	2.0	[0.2]	2.0	[0.2]	1.5	[0.0]	0.6	[0.1]	0.6	[0.1]	0.6	[0.1]
El Salvador	0.5	[0.1]	1.0	[0.1]	1.1	[0.2]	1.1	[0.1]	0.1	[0.2]	2.0	[0.2]	2.1	[0.3]	2.0	[0.3]
French Polynesia	4.5	[0.1]	1.1	[0.2]	1.1	[0.2]	1.1	[0.2]	3.2	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]
Guatemala	0.7	[0.1]	1.7	[0.2]	1.7	[0.2]	1.7	[0.2]	0.1	[0.2]	2.0	[0.3]	2.1	[0.2]	2.0	[0.3]
Kiribati	2.9	[0.3]	3.2	[0.4]	2.9	[0.5]	3.2	[0.5]	1.3	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.1]
Mexico	0.9	[0.1]	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]	1.2	[0.0]	0.5	[0.0]	0.5	[0.0]	0.5	[0.0]
Nicaragua	4.1	[0.1]	1.1	[0.1]	1.1	[0.1]	1.1	[0.1]	2.6	[0.1]	1.7	[0.2]	1.7	[0.2]	1.6	[0.2]
Panama	1.0	[0.1]	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	0.5	[0.1]	1.6	[0.1]	1.6	[0.1]	1.6	[0.1]
Peru	0.8	[0.2]	2.7	[0.2]	2.5	[0.2]	2.6	[0.2]	0.6	[0.1]	1.2	[0.2]	1.2	[0.1]	1.2	[0.2]

Appendix Table 6. Marginal Product of SST by species for four model specifications using data without country overlaps

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
All																
Chile	3.9	[0.4]	4.2	[0.6]	4.3	[0.4]	4.3	[1.2]	1.1	[0.3]	1.1	[0.4]				
Clipperton	0.6	[0.0]	0.5	[0.0]	0.6	[0.0]	0.5	[0.0]	2.4	[0.1]	2.6	[0.1]	2.9	[0.2]	2.9	[0.2]
Colombia	4.0	[0.2]	3.9	[0.3]	4.0	[0.3]	3.9	[0.3]	2.9	[0.1]	3.0	[0.2]	3.0	[0.2]	2.9	[0.2]
Costa Rica	1.8	[0.1]	1.8	[0.1]	1.8	[0.1]	1.8	[0.1]	4.4	[0.1]	4.5	[0.2]	4.5	[0.2]	4.5	[0.2]
Ecuador	4.7	[0.3]	4.6	[0.4]	4.8	[0.4]	4.9	[0.3]	2.7	[0.3]	2.7	[0.3]	2.8	[0.3]	2.9	[0.3]
El Salvador	2.3	[0.6]	2.4	[0.6]	2.5	[0.5]	2.4	[0.7]	5.9	[0.6]	6.3	[0.6]	6.2	[0.6]	6.3	[0.7]
French Polynesia	1.4	[0.2]	1.5	[0.2]	1.4	[0.2]	1.5	[0.2]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Guatemala	2.3	[0.1]	2.4	[0.1]	2.4	[0.1]	2.3	[0.1]	6.4	[0.1]	6.7	[0.3]	6.6	[0.2]	6.7	[0.3]
Kiribati	2.6	[0.3]	2.4	[0.4]	2.4	[0.4]	2.4	[0.4]	0.3	[0.0]	0.2	[0.1]	0.2	[0.1]	0.2	[0.1]
Mexico	1.9	[0.1]	1.8	[0.1]	1.8	[0.1]	1.8	[0.1]	3.9	[0.1]	3.8	[0.1]	3.9	[0.1]	3.9	[0.1]
Panama	3.4	[0.2]	3.3	[0.3]	3.3	[0.3]	3.3	[0.3]	9.6	[0.9]	10.0	[0.9]	9.8	[0.9]	9.8	[0.9]
Peru	8.1	[0.7]	7.8	[0.8]	7.6	[0.8]	8.0	[0.8]	4.1	[0.4]	4.0	[0.5]	4.0	[0.6]	4.2	[0.5]
United States	2.1	[0.1]	2.1	[0.2]	2.1	[0.2]	1.9	[0.4]	1.5	[0.4]						
Dolphin																
Chile																
Clipperton	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	2.3	[0.1]	2.5	[0.1]	2.8	[0.2]	2.8	[0.2]
Colombia	0.1	[0.0]	0.2	[0.0]	0.2	[0.1]	0.2	[0.1]	1.8	[0.1]	1.8	[0.1]	1.9	[0.1]	1.8	[0.1]
Costa Rica	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	3.7	[0.1]	3.9	[0.2]	4.0	[0.2]	4.0	[0.2]
Ecuador	0.5	[0.1]	0.6	[0.1]	0.5	[0.1]	0.5	[0.1]	1.4	[0.2]	1.5	[0.2]	1.6	[0.2]	1.6	[0.2]
El Salvador									2.7	[0.0]	2.8	[0.0]	2.7	[0.0]	2.8	[0.0]
Guatemala	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Mexico	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	3.6	[0.1]	3.6	[0.1]	3.8	[0.1]	3.8	[0.1]
Panama	0.1	[0.0]	0.1	[0.0]	0.2	[0.0]	0.1	[0.0]	1.1	[0.2]						
Peru	0.9	[0.1]	1.0	[0.2]	1.3	[0.3]	1.3	[0.3]	4.9	[0.6]	5.4	[0.8]	4.9	[1.0]	4.9	[1.0]
Unassociated																
Chile											0.3	[0.0]	1.1	[0.0]		
Clipperton	0.3	[0.0]	0.3	[0.1]	0.3	[0.1]	0.3	[0.1]	1.1	[0.0]	1.1	[0.0]	1.1	[0.1]	1.1	[0.1]
Colombia	1.7	[0.1]	1.7	[0.1]	1.8	[0.1]	1.8	[0.1]	1.2	[0.1]	1.1	[0.1]	1.2	[0.1]	1.2	[0.1]
Costa Rica	0.8	[0.0]	0.8	[0.0]	0.8	[0.0]	0.8	[0.0]	1.3	[0.2]	1.3	[0.2]	1.4	[0.2]	1.4	[0.2]
Ecuador	3.7	[0.3]	3.7	[0.3]	4.0	[0.4]	4.1	[0.4]	2.4	[0.3]	2.3	[0.3]	2.5	[0.3]	2.5	[0.3]
El Salvador									3.3	[0.5]	3.5	[0.7]	3.5	[0.5]	3.5	[0.7]

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
French Polynesia	0.6	[0.2]														
Guatemala	1.2	[0.1]	1.3	[0.1]	1.3	[0.2]	1.2	[0.1]	1.3	[0.1]	1.3	[0.2]	1.3	[0.1]	1.3	[0.2]
Kiribati	1.3	[0.5]							0.1	[0.0]	0.1	[0.0]	0.0	[0.0]	0.0	[0.0]
Mexico	2.6	[0.1]	2.6	[0.1]	2.5	[0.1]	2.5	[0.1]	4.3	[0.2]	4.3	[0.2]	4.2	[0.2]	4.2	[0.2]
Panama	2.3	[0.1]	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	8.4	[0.9]	8.6	[0.9]	8.3	[0.9]	8.3	[1.0]
Peru	7.3	[0.7]	7.2	[0.8]	7.1	[0.8]	7.4	[0.8]	5.0	[0.7]	5.0	[0.7]	4.9	[0.8]	5.3	[0.7]
United States	2.1	[0.1]	2.2	[0.2]	2.1	[0.2]	2.0	[0.4]	1.5	[0.4]						
Floating																
Chile	2.6	[0.5]	3.1	[0.9]	3.1	[0.3]	4.0	[1.6]	0.9	[0.3]						
Clipperton	0.7	[0.0]	0.6	[0.1]	0.7	[0.1]	0.7	[0.1]	0.3	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Colombia	3.1	[0.1]	3.0	[0.2]	3.0	[0.2]	3.0	[0.2]	1.2	[0.0]	1.2	[0.1]	1.2	[0.1]	1.2	[0.1]
Costa Rica	1.5	[0.1]	1.5	[0.1]	1.5	[0.1]	1.5	[0.1]	0.8	[0.0]	0.9	[0.0]	0.8	[0.0]	0.8	[0.0]
Ecuador	2.1	[0.1]	1.9	[0.2]	1.8	[0.2]	1.9	[0.2]	0.7	[0.1]	0.6	[0.1]	0.6	[0.1]	0.6	[0.1]
El Salvador	1.5	[0.3]	1.6	[0.4]	1.7	[0.3]	1.7	[0.5]	2.0	[0.4]			2.1	[0.6]		
French Polynesia	1.1	[0.1]	1.1	[0.2]	1.0	[0.2]	1.1	[0.2]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]
Guatemala	2.0	[0.2]	2.1	[0.3]	2.1	[0.3]	2.0	[0.3]	2.0	[0.2]	2.0	[0.2]	2.1	[0.3]	1.9	[0.3]
Kiribati	2.9	[0.3]	3.4	[0.5]	3.1	[0.5]	3.4	[0.6]	0.2	[0.0]	0.2	[0.1]	0.2	[0.0]	0.2	[0.1]
Mexico	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]	0.4	[0.0]	0.4	[0.0]	0.4	[0.0]	0.4	[0.0]
Panama	2.0	[0.2]	2.0	[0.2]	2.1	[0.2]	2.1	[0.2]	2.2	[0.2]	2.2	[0.3]	2.2	[0.2]	2.2	[0.3]
Peru	3.2	[0.1]	3.1	[0.2]	3.0	[0.2]	3.0	[0.2]	1.0	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]

Appendix Table 7. Marginal Product of SST by species for four model specifications using data without international water overlaps

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
All																
Chile	9.9	[1.3]	9.5	[1.6]	9.3	[1.8]	9.5	[1.8]	1.1	[0.3]	1.1	[0.4]				
Clipperton	0.5	[0.1]	0.5	[0.1]	0.5	[0.1]	0.5	[0.1]	2.4	[0.1]	2.6	[0.1]	2.9	[0.2]	2.9	[0.2]
Colombia	3.7	[0.2]	3.7	[0.3]	3.6	[0.3]	3.7	[0.3]	2.9	[0.1]	3.0	[0.2]	3.0	[0.2]	2.9	[0.2]
Costa Rica	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	4.4	[0.1]	4.5	[0.2]	4.5	[0.2]	4.5	[0.2]
Ecuador	5.5	[0.7]	5.4	[0.8]	6.0	[0.7]	6.0	[0.7]	2.7	[0.3]	2.7	[0.3]	2.8	[0.3]	2.9	[0.3]
El Salvador	1.4	[0.3]	1.2	[0.3]	1.2	[0.3]	1.2	[0.3]	5.9	[0.6]	6.3	[0.6]	6.2	[0.6]	6.3	[0.7]
French Polynesia	0.7	[0.2]							0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Guatemala	1.9	[0.2]	2.0	[0.2]	2.0	[0.2]	1.9	[0.2]	6.4	[0.1]	6.7	[0.3]	6.6	[0.2]	6.7	[0.3]
Kiribati	1.0	[0.4]							0.3	[0.0]	0.2	[0.1]	0.2	[0.1]	0.2	[0.1]
Mexico	2.0	[0.1]	1.9	[0.1]	1.9	[0.1]	1.9	[0.1]	3.9	[0.1]	3.8	[0.1]	3.9	[0.1]	3.9	[0.1]
Nicaragua	1.4	[0.2]	1.3	[0.2]	1.4	[0.2]	1.3	[0.2]								
Panama	3.2	[0.1]	3.2	[0.2]	3.2	[0.2]	3.2	[0.2]	9.6	[0.9]	10.0	[0.9]	9.8	[0.9]	9.8	[0.9]
Peru	9.7	[1.9]	8.6	[1.9]	9.1	[2.3]	10.1	[2.1]	4.1	[0.4]	4.0	[0.5]	4.0	[0.6]	4.2	[0.5]
United States	2.9	[0.6]	2.9	[0.7]	2.9	[0.8]	2.9	[0.8]	1.5	[0.4]						
Dolphin																
Clipperton	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	2.3	[0.1]	2.5	[0.1]	2.8	[0.2]	2.8	[0.2]
Colombia	0.1	[0.0]	0.1	[0.0]					1.8	[0.1]	1.8	[0.1]	1.9	[0.1]	1.8	[0.1]
Costa Rica	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	3.7	[0.1]	3.9	[0.2]	4.0	[0.2]	4.0	[0.2]
Ecuador	0.6	[0.1]	0.6	[0.1]	0.6	[0.1]	0.6	[0.1]	1.4	[0.2]	1.5	[0.2]	1.6	[0.2]	1.6	[0.2]
El Salvador	0.2	[0.1]	0.2	[0.1]	0.2	[0.1]	0.2	[0.1]	2.7	[0.0]	2.8	[0.0]	2.7	[0.0]	2.8	[0.0]
Guatemala	0.3	[0.0]	0.3	[0.0]	0.3	[0.1]	0.3	[0.1]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Mexico	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	3.6	[0.1]	3.6	[0.1]	3.8	[0.1]	3.8	[0.1]
Nicaragua	0.4	[0.1]	0.4	[0.1]	0.4	[0.1]	0.4	[0.1]								
Panama	0.1	[0.0]							1.1	[0.2]						
Peru									4.9	[0.6]	5.4	[0.8]	4.9	[1.0]	4.9	[1.0]

Appendix Table 7. ***Continuation***

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
Unassociated																
Chile	11.2	[2.7]	11.9	[3.2]	11.3	[3.3]	12.1	[3.7]			0.3	[0.0]	1.1	[0.0]		
Clipperton	0.3	[0.0]	0.3	[0.1]	0.3	[0.1]	0.3	[0.1]	1.1	[0.0]	1.1	[0.0]	1.1	[0.1]	1.1	[0.1]
Colombia	1.5	[0.1]	1.4	[0.1]	1.4	[0.1]	1.5	[0.1]	1.2	[0.1]	1.1	[0.1]	1.2	[0.1]	1.2	[0.1]
Costa Rica	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]	1.3	[0.2]	1.3	[0.2]	1.4	[0.2]	1.4	[0.2]
Ecuador	4.8	[0.6]	4.8	[0.6]	5.3	[0.6]	5.4	[0.6]	2.4	[0.3]	2.3	[0.3]	2.5	[0.3]	2.5	[0.3]
El Salvador	1.0	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]	3.3	[0.5]	3.5	[0.7]	3.5	[0.5]	3.5	[0.7]
French Polynesia																
Guatemala	1.0	[0.1]	1.1	[0.1]	1.1	[0.1]	1.1	[0.1]	1.3	[0.1]	1.3	[0.2]	1.3	[0.1]	1.3	[0.2]
Kiribati	0.8	[0.2]	0.8	[0.3]	0.8	[0.0]	6.6	[0.7]	0.1	[0.0]	0.1	[0.0]	0.0	[0.0]	0.0	[0.0]
Mexico	2.5	[0.1]	2.5	[0.1]	2.5	[0.1]	2.5	[0.1]	4.3	[0.2]	4.3	[0.2]	4.2	[0.2]	4.2	[0.2]
Nicaragua	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]								
Panama	2.1	[0.1]	2.1	[0.2]	2.1	[0.1]	2.1	[0.1]	8.4	[0.9]	8.6	[0.9]	8.3	[0.9]	8.3	[1.0]
Peru	9.7	[1.8]	8.9	[1.8]	9.2	[2.3]	10.2	[2.1]	5.0	[0.7]	5.0	[0.7]	4.9	[0.8]	5.3	[0.7]
United States	2.9	[0.6]	2.9	[0.7]	2.8	[0.8]	2.8	[0.8]	1.5	[0.4]						
Floating																
Chile	4.2	[0.4]	3.9	[0.4]	3.2	[0.4]	3.3	[0.4]	0.9	[0.3]						
Clipperton	0.5	[0.1]	0.4	[0.1]	0.5	[0.1]	0.4	[0.1]	0.3	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]
Colombia	2.7	[0.1]	2.6	[0.1]	2.6	[0.1]	2.6	[0.1]	1.2	[0.0]	1.2	[0.1]	1.2	[0.1]	1.2	[0.1]
Costa Rica	1.9	[0.1]	1.8	[0.1]	1.8	[0.1]	1.8	[0.1]	0.8	[0.0]	0.9	[0.0]	0.8	[0.0]	0.8	[0.0]
Ecuador	2.0	[0.2]	1.7	[0.2]	1.8	[0.2]	1.8	[0.2]	0.7	[0.1]	0.6	[0.1]	0.6	[0.1]	0.6	[0.1]
El Salvador	1.0	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]	2.0	[0.4]			2.1	[0.6]		
French Polynesia	0.4	[0.1]							0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]
Guatemala	1.3	[0.2]	1.2	[0.2]	1.3	[0.2]	1.2	[0.2]	2.0	[0.2]	2.0	[0.2]	2.1	[0.3]	1.9	[0.3]
Kiribati									0.2	[0.0]	0.2	[0.1]	0.2	[0.0]	0.2	[0.1]
Mexico	1.1	[0.1]	1.1	[0.1]	1.1	[0.1]	1.1	[0.1]	0.4	[0.0]	0.4	[0.0]	0.4	[0.0]	0.4	[0.0]
Nicaragua	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]	1.0	[0.1]								
Panama	2.1	[0.1]	2.2	[0.1]	2.2	[0.1]	2.2	[0.1]	2.2	[0.2]	2.2	[0.3]	2.2	[0.2]	2.2	[0.3]
Peru	2.4	[0.2]	2.4	[0.3]	2.0	[0.3]	2.1	[0.3]	1.0	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]

Appendix Table 8. Marginal Product of SST by species for four model specifications using data without overlaps

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
All																
Clipperton	0.5	[0.1]	0.5	[0.1]	0.5	[0.1]	0.5	[0.1]	2.5	[0.1]	2.6	[0.2]	2.9	[0.2]	2.9	[0.2]
Colombia	4.5	[0.3]	4.4	[0.4]	4.4	[0.4]	4.4	[0.4]	2.8	[0.1]	2.6	[0.1]	2.6	[0.1]	2.6	[0.1]
Costa Rica	1.7	[0.1]	1.7	[0.1]	1.7	[0.1]	1.7	[0.1]	4.3	[0.1]	4.4	[0.2]	4.5	[0.2]	4.5	[0.2]
Ecuador	5.8	[0.5]	5.8	[0.5]	6.1	[0.6]	6.3	[0.5]	3.3	[0.4]	3.3	[0.4]	3.4	[0.4]	3.5	[0.4]
El Salvador	1.6	[0.1]	1.6	[0.1]	1.7	[0.0]	1.5	[0.1]	4.4	[0.3]	4.7	[0.2]	4.5	[0.4]	4.8	[0.2]
French Polynesia	0.4	[0.1]							0.0	[0.0]						
Guatemala	2.1	[0.1]	2.1	[0.1]	2.0	[0.1]	2.1	[0.1]	6.3	[0.1]	6.4	[0.1]	6.5	[0.1]	6.4	[0.2]
Kiribati									0.2	[0.0]	0.1	[0.0]	0.2	[0.0]	0.1	[0.1]
Mexico	1.9	[0.1]	1.9	[0.1]	1.9	[0.1]	1.9	[0.1]	4.4	[0.1]	4.3	[0.2]	4.4	[0.2]	4.4	[0.2]
Nicaragua																
Panama	3.7	[0.2]	3.7	[0.3]	3.7	[0.3]	3.7	[0.3]	8.4	[0.6]	8.6	[0.6]	8.4	[0.7]	8.4	[0.6]
Peru	10.6	[1.0]	10.4	[1.2]	10.1	[1.1]	10.5	[1.1]	5.1	[0.6]	5.0	[0.7]	4.9	[0.8]	5.3	[0.7]
United States	2.1	[0.1]	2.1	[0.2]	2.1	[0.2]	1.9	[0.4]	1.6	[0.4]						
Dolphin																
Clipperton	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	2.1	[0.1]	2.3	[0.1]	2.5	[0.2]	2.5	[0.2]
Colombia	0.1	[0.0]	0.1	[0.0]					1.7	[0.1]	1.7	[0.2]	1.8	[0.1]	1.8	[0.1]
Costa Rica	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	0.1	[0.0]	3.6	[0.1]	3.8	[0.2]	3.9	[0.2]	3.9	[0.2]
Ecuador	0.7	[0.1]	0.8	[0.1]	0.7	[0.1]	0.7	[0.1]	1.7	[0.3]	2.0	[0.4]	1.9	[0.4]	1.9	[0.4]
El Salvador			-0.1	[0.0]	0.0	[0.0]			1.5	[0.3]	1.5	[0.3]	1.4	[0.2]	1.5	[0.3]
French Polynesia																
Guatemala					0.1	[0.0]			4.8	[0.2]	5.0	[0.4]	5.1	[0.3]	5.0	[0.4]
Mexico	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	0.2	[0.0]	2.1	[0.1]	2.1	[0.1]	2.3	[0.1]	2.3	[0.1]
Nicaragua																
Panama	0.1	[0.0]							2.0	[0.2]	2.0	[0.3]	2.1	[0.3]	2.1	[0.3]
Peru	0.5	[0.2]	0.5	[0.3]					2.1	[0.3]	2.1	[0.4]	1.9	[0.5]	2.0	[0.6]
United States																

Appendix Table 8. ***Continuation***

Country	Skipjack								Yellowfin							
	RTO		TIME		GRID		TIME and GRID		RTO		TIME		GRID		TIME and GRID	
	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE	MP	SE
Unassociated																
Clipperton	0.3	[0.0]	0.3	[0.1]	0.3	[0.1]	0.3	[0.1]	1.4	[0.0]	1.4	[0.0]	1.4	[0.1]	1.4	[0.1]
Colombia	1.7	[0.1]	1.7	[0.2]	1.7	[0.2]	1.7	[0.2]	1.5	[0.1]	1.5	[0.1]	1.4	[0.1]	1.4	[0.1]
Costa Rica	0.9	[0.0]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]	1.4	[0.2]	1.5	[0.2]	1.5	[0.2]	1.5	[0.2]
Ecuador	4.8	[0.4]	4.8	[0.5]	5.2	[0.5]	5.4	[0.5]	2.9	[0.4]	2.9	[0.4]	3.1	[0.4]	3.1	[0.4]
El Salvador									3.8	[0.6]	3.8	[0.8]	3.6	[0.6]	3.8	[0.8]
French Polynesia																
Guatemala	1.1	[0.1]	1.2	[0.0]	1.1	[0.0]	1.2	[0.0]	1.5	[0.2]	1.5	[0.4]	1.4	[0.3]	1.5	[0.4]
Kiribati	0.8	[0.2]			0.9	[0.0]	6.8	[0.7]								
Mexico	2.5	[0.1]	2.5	[0.1]	2.5	[0.1]	2.5	[0.1]	4.6	[0.2]	4.6	[0.2]	4.5	[0.2]	4.5	[0.2]
Nicaragua																
Panama	2.8	[0.2]	2.8	[0.2]	2.8	[0.2]	2.8	[0.2]	7.8	[0.6]	8.0	[0.6]	7.7	[0.7]	7.7	[0.7]
Peru	9.9	[1.0]	9.8	[1.2]	9.6	[1.2]	10.1	[1.2]	5.8	[0.9]	5.8	[1.0]	5.6	[1.1]	6.1	[1.0]
United States	2.1	[0.1]	2.2	[0.2]	2.1	[0.2]	2.0	[0.4]	1.6	[0.4]						
Floating																
Clipperton	0.5	[0.1]	0.4	[0.1]	0.5	[0.1]	0.4	[0.1]	0.3	[0.0]	0.2	[0.1]	0.2	[0.1]	0.2	[0.1]
Colombia	3.1	[0.2]	3.1	[0.2]	3.0	[0.2]	3.0	[0.2]	1.3	[0.0]	1.3	[0.1]	1.2	[0.1]	1.2	[0.1]
Costa Rica	1.4	[0.1]	1.4	[0.1]	1.4	[0.1]	1.4	[0.1]	0.8	[0.0]	0.8	[0.0]	0.8	[0.0]	0.8	[0.0]
Ecuador	2.1	[0.2]	1.8	[0.2]	1.8	[0.2]	1.8	[0.2]	0.8	[0.1]	0.6	[0.1]	0.7	[0.1]	0.7	[0.1]
El Salvador	1.0	[0.2]							1.6	[0.1]	1.4	[0.2]	1.7	[0.1]		
French Polynesia	0.7	[0.1]	1.3	[0.2]	1.1	[0.3]	1.4	[0.4]	0.1	[0.0]	0.1	[0.0]	0.1	[0.1]		
Guatemala	1.3	[0.1]	1.1	[0.2]	1.1	[0.1]	1.0	[0.2]	2.1	[0.2]	2.1	[0.3]	2.1	[0.3]	2.0	[0.3]
Kiribati									0.2	[0.0]	0.1	[0.0]	0.2	[0.0]	0.1	[0.0]
Mexico	1.1	[0.1]	1.1	[0.1]	1.1	[0.1]	1.1	[0.1]	0.5	[0.0]	0.4	[0.0]	0.4	[0.1]	0.4	[0.0]
Panama	2.0	[0.1]	2.1	[0.1]	2.1	[0.1]	2.1	[0.1]	1.7	[0.1]	1.8	[0.1]	1.8	[0.1]	1.8	[0.1]
Peru	3.0	[0.2]	2.9	[0.2]	2.7	[0.3]	2.7	[0.3]	1.0	[0.1]	0.9	[0.1]	0.9	[0.1]	0.9	[0.1]

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