Impacts of the Southern Exclusion Zone on the Hawaiian Deep-Set Longline Fleet

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1 Executive Summary

This report utilizes data from the Pacific Islands Regional Observer Program to assess potential impacts of the Southern Exclusion Zone (SEZ) on catch rates and other relevant outcomes for targeted and non-targeted species potentially affected by the closure. We assessed changes in various fishery related metrics over time, including catch per trip, catch per kilometer (km) traveled, mean length of catch, and interactions with non-USA flagged fishing vessels for the Hawaiian deep-set longline fleet. Compared to fishing vessels that historically never used the waters encompassed by the SEZ, we find no clearly evident changes in any of the metrics evaluated here for the average deep-set longline fishing vessel with a history of SEZ use.

2 Introduction

This study utilizes data from the Pacific Islands Regional Observer Program to assess potential impacts of the Southern Exclusion Zone (SEZ) on catch rates and other relevant outcomes for targeted and non-targeted species potentially affected by the closure. The Southern Exclusion Zone (SEZ) is a spatial closure of deep-set longline fishing triggered if in a given year the fishery has two observed interactions with false killer whales (*Pseudorca crassidens*) resulting in death or serious injury to the animals The SEZ was in effect from July 24 2018 to Dec 31, 2018, and again from February 22 2019 until the present.

The purpose of this study is to evaluate what effects this closure appears to have had on relevant metrics for both targeted and non-targeted species. For targeted species, we focus on assessing the effects of the SEZ on catches of bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*). We also briefly consider changes in bycatch metrics of oceanic whitetip sharks (*Carcharhinus longimanus*).

3 Methods

3.1 Data

We utilized data from the Pacific Islands Regional Observer Program for this assessment. We do not present any raw data here. Analyses are restricted to deep-set longline sets, defined by markers within the data and a definition of 15 or more hooks per set. Catch per trip is calculated as the number of individuals captured over the course of a trip. Catch per hook is calculated as the number of individuals caught per hook set. Some observations contain length measurements. We use these to calculate the mean length of organisms captured on a trip. As a measure of fishing costs, we calculated the total distance traveled on each fishing trip, calculated as the linear distance of the path of fishing sets reported in the observer data, assuming that each trip begins and ends in Honolulu, Hawaii.

The database contains records for 182 unique vessel IDs, 72% of which caught 10% or more of their reported numbers of bigeye or yellowfin tuna from inside the eventual bounds of the SEZ. However in total only 10% of the total numbers of bigeye or yellowfin tuna in the database were reported to be caught by sets within the eventual bounds of the SEZ.

We also provide a rough metric of interactions with non-USA flagged fishing vessels. For each fishing set reported in the data, we define a buffer circle with radius 0.5 arc degrees latitude / longitude. We then queried records from Global Fishing Watch, and for each fishing set, pulled out records of non-USA flagged fishing vessels within that buffer circle and within the days spanned by a given fishing trip. We then tallied the total number of foreign fishing vessels a given Hawaiian deep-set longline vessel encountered within these buffer circles and time windows throughout their trip. We should note that coverage of global fishing watch data changes over time, and as such trends should be viewed with great caution. However, comparison of trends between groups as done here is more valid.

3.2 Control Group

Many of our analyses are purely correlational, examining how data appear to have changed (or not changed) following SEZ implementation. Where possible though we try and compare metrics to what might expected given a relevant control group, creating a first step at a causal inference strategy. For the control group, we select a set of vessels that never reported any fishing activity within the present-day border of the SEZ. Our assumption in treating this group as our "control" group is that the non-SEZ active vessels serve as an effective control for the how various fishing metrics would have evolved in the SEZ active vessels in the absence of the SEZ.

Examining the vessels, this is the only clear difference in SEZ use between vessels (did or did not use); there is no evident bimodality in the data of for example a group of vessels that use the SEZ substantially more than others that use it slightly. As such, we employ this blunt method, despite the fact that this means that some vessels that barely ever used the SEZ are included in the "SEZ active" category. However, we feel that this is preferable to creating an arbitrary cutoff. We ran a sensitivity analysis setting SEZ active vessels as those with 50% or more of their average trip catches coming from inside the SEZ. The results of this run were more or less identical.

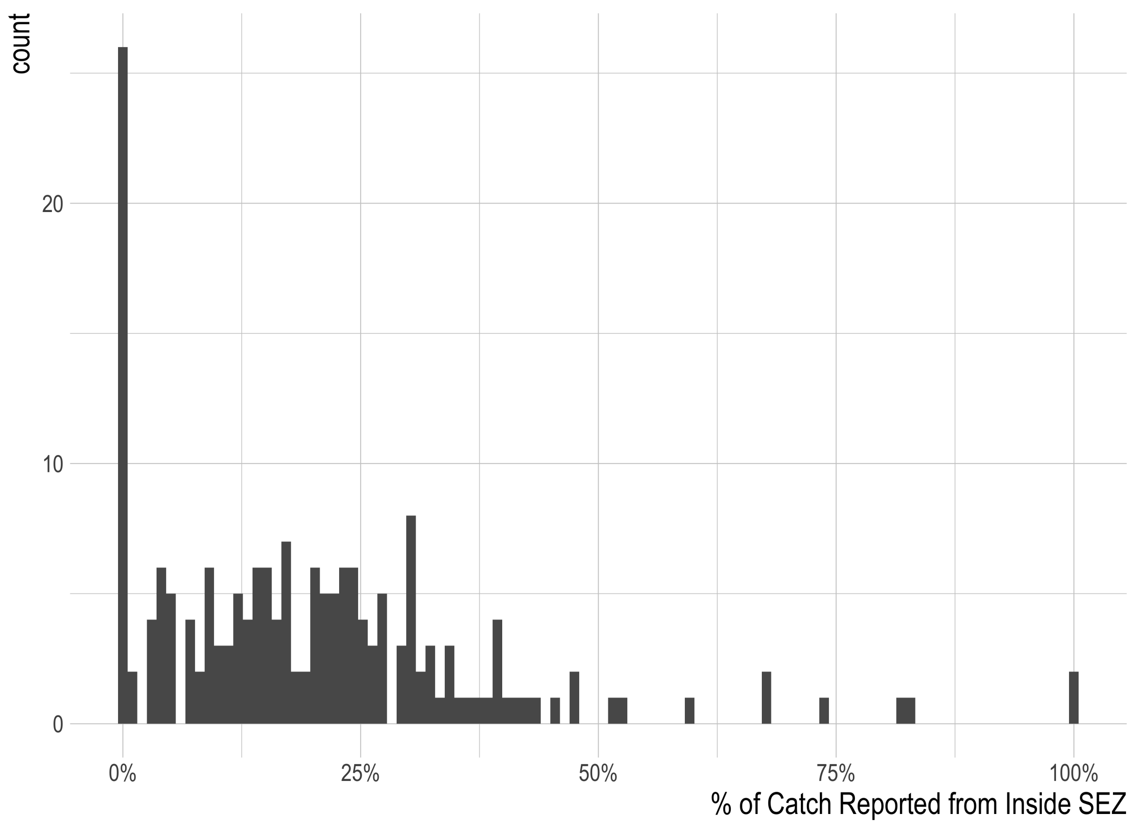

Figure 1: Distribution of percetange of numbers of bigeye caight by individual vvessels within the bounds of the SEZ

To illustrate the nature of the control group concept, for each vessel in the data we calculated the mean catch-per-hook per trip of each vessel during periods when the SEZ was active and inactive, and calculated the percent difference in catch per hook during these two periods for each vessel. We then binned each vessel into a category of SEZ use based on the percentage of reported numbers of bigeye tuna caught that came from within the borders of the SEZ. This allows us to compare the distribution of the difference in catch-per-hook when the SEZ is in effect for vessels that both historically used the SEZ to varying degrees (Fig.2). All groups showed substantial variation, with some vessels having higher catch-per-hook during the SEZ closures and others less. Across all groups of historic SEZ use the mean difference was near 0%.

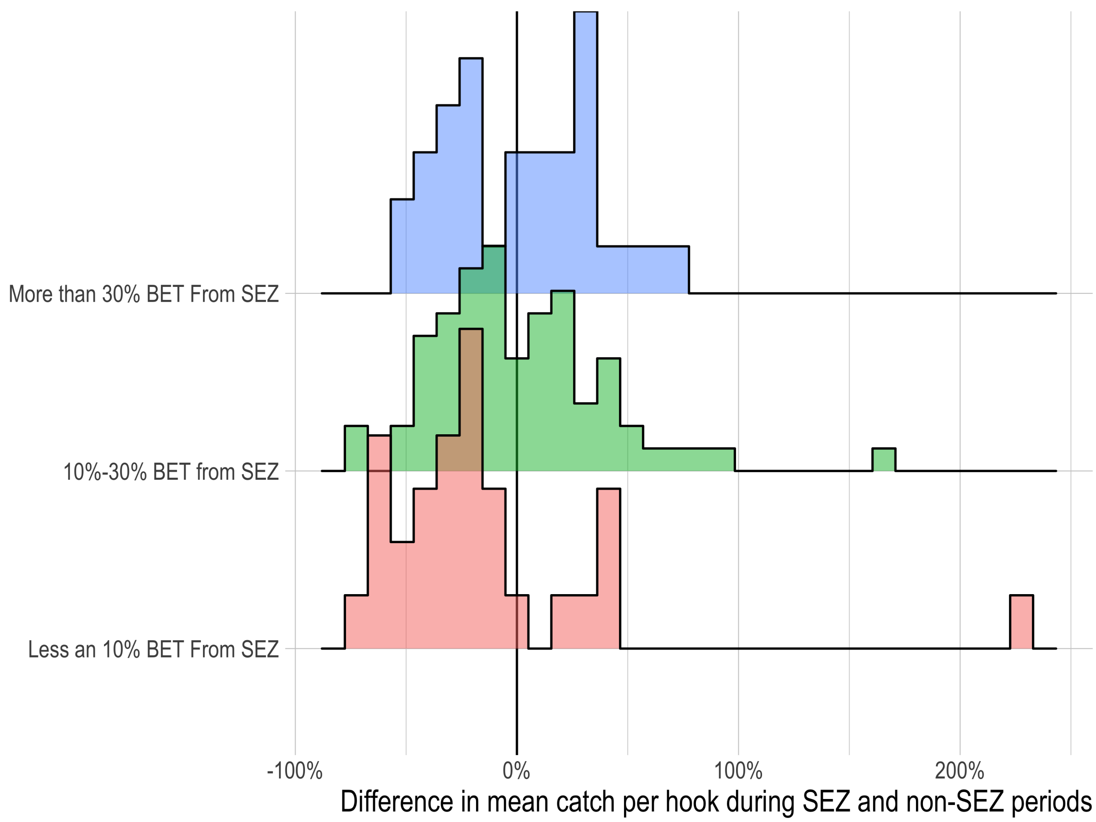

Figure 2: Distribution of difference in mean catch-per-hook of bigeye tuna during SEZ active and inactive periods for individual vessels classified into bins of SEZ use.

The available database contains observations from 2005-01-01 to 2019-12-28. All regression analysis are Bayesian in nature, using the `rstanarm` package in R. Unless otherwise specified in the report priors are set using the default tuning mechanisms of the `rstanarm` package.

Each regression analysis shares the same general structure: we control for the mean value of a given metric across all vessels in a given year and month through a hierarchical term capturing the temporal structures in the data. From there, we include two dummy terms indicating whether a given observation is from an SEZ active vessel and whether the SEZ is in effect for a given observation. Our term of interest is the interaction term between the dummy variables for SEZ active vessels and SEZ in effect. This measures the average difference in a given value in a given time step for an SEZ active vessels when the SEZ is in effect relative to what we would expect for the average SEZ active vessel in a given time period if the SEZ had not been in effect. The critical assumption of this method is that on average the trends in a given metric for the SEZ active and inactive vessels are generally the same, though the two groups may have difference intercepts. Visual and statistical examination of the pre-SEZ periods shows that this assumption appears to be reasonable. For each regression we plot the posterior probability distribution for the key regression term (the interaction of SEZ active vessel dummy and the SEZ in effect dummy). Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

4 Results

Unless otherwise stated all results are purely from data coming from deep-set longline sets observers.

4.1 Proportion of Catch Coming from SEZ

The available dataset of deep-set longline sets covers 4062 trips from 2005-01-01 to 2019-12-28. Across species, sharks and dolphins had the highest percentage of reported numbers caught within the SEZ prior to SEZ implementation. However, these high percentages are generally of relatively small sample size (often less than 10 total individuals caught). 10% or less of the turtles reported caught in the database were caught within the SEZ. Focusing on the tunas, yellowfin tuna were the most commonly caught species within the SEZ (20%). Roughly 9% of the most abundantly caught species of tuna, bigeye, were historically caught within the SEZ Fig.3.

4.2 SEZ Effects on Bigeye Tuna Fishery Metrics

Since bigeye tuna are the most commonly caught and commercially important species for the deep-set longline fleet we focus our analyses on that species. Prior to the SEZ, 9% of the reported number of bigeye caught came from areas encompassed by the SEZ (Fig.3). In order to create a very rough counterfactual of what we might expect trends of relevant metrics to look like in the absence of the SEZ we break our analysis into two groups: vessels that have ever reported catches within the SEZ area (SEZ Active Vessel, n = 7) and those that have not (SEZ Inactive Vessel, n = 175). We report most metrics as summaries of trips, under the assumption that most fishers do not care where catch occurs so much as the total catch from a trip (factoring in the distance required to complete that trip).

Examining the general trends, total catches of bigeye tuna appear to have declined during the SEZ period in SEZ active vessels relative to the trend in SEZ inactive vessels, as has the number of active vessels, and the total total trip distance. However, looking back at the pre-SEZ years, the SEZ inactive vessels appear to be a useful control for the overall trend in total catches / active vessels over time, but frequently exhibit very different year-to-year variations in values from the SEZ active vessels. As such we should interpret these divergence in the post-SEZ period with caution. Looking at averaged metrics, we see no clear divergences in metrics of mean fork length, catch per trip, catch per hook, or catch per distance traveled (Fig.5).

We ran a series of difference-in-difference style regressions treating the sez-inactive vessels as a control for the sez-active. Across these regressions the basic story is the same: we detect no statistically clear change in selected metrics resulting from the SEZ Fig.7-Fig.10. In addition, for all metrics except for Foreign Fishing Activity Encountered there is a high probability that the estimated difference between SEZ active and inactive vessels during SEZ periods is close to zero.

4.3 Yellowfin Tuna

We repeated the same analysis for yellowfin tuna. Similar to bigeye tuna, we find no clear differences in relevant fishery metrics of yellowfin tuna before and after SEZ implementation (Fig.11 - Fig.16).

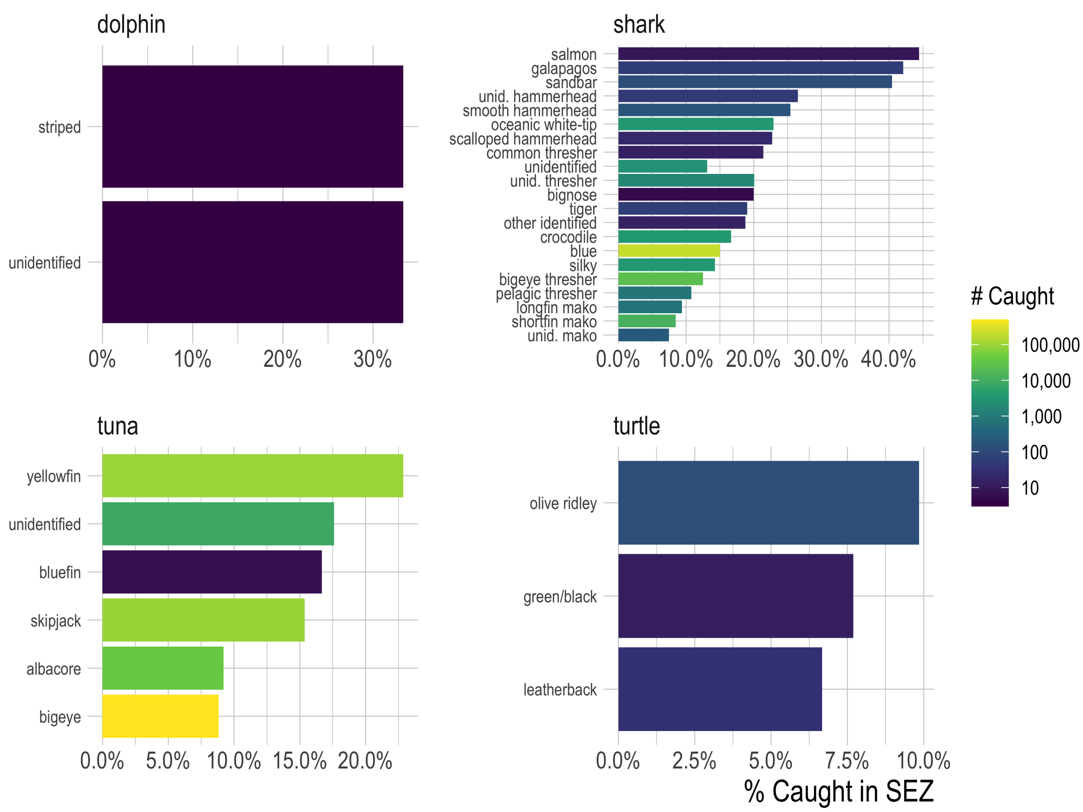

Figure 3: Percent of total reported catch in dataset prior to SEZ reported to have been caught within the present-day SEZ zone. Color refers to the total reported caught for that species.

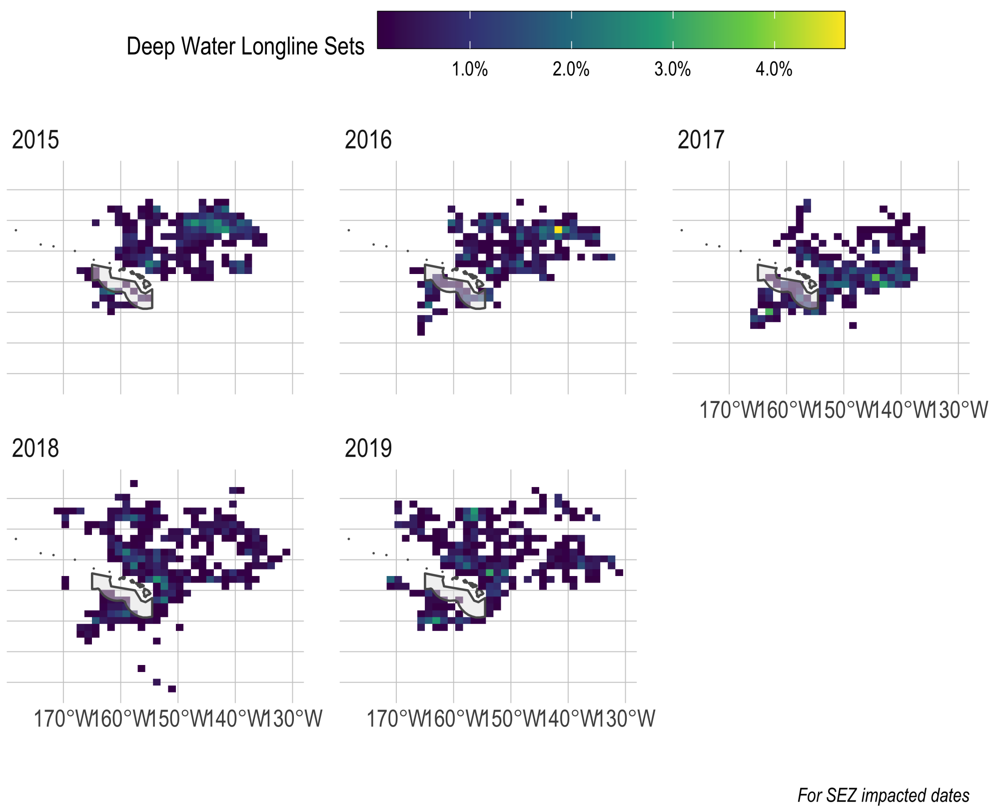

Figure 4: Spatial distribution of deep-set longling sets over time during the year days covered by the SEZ within the available data.

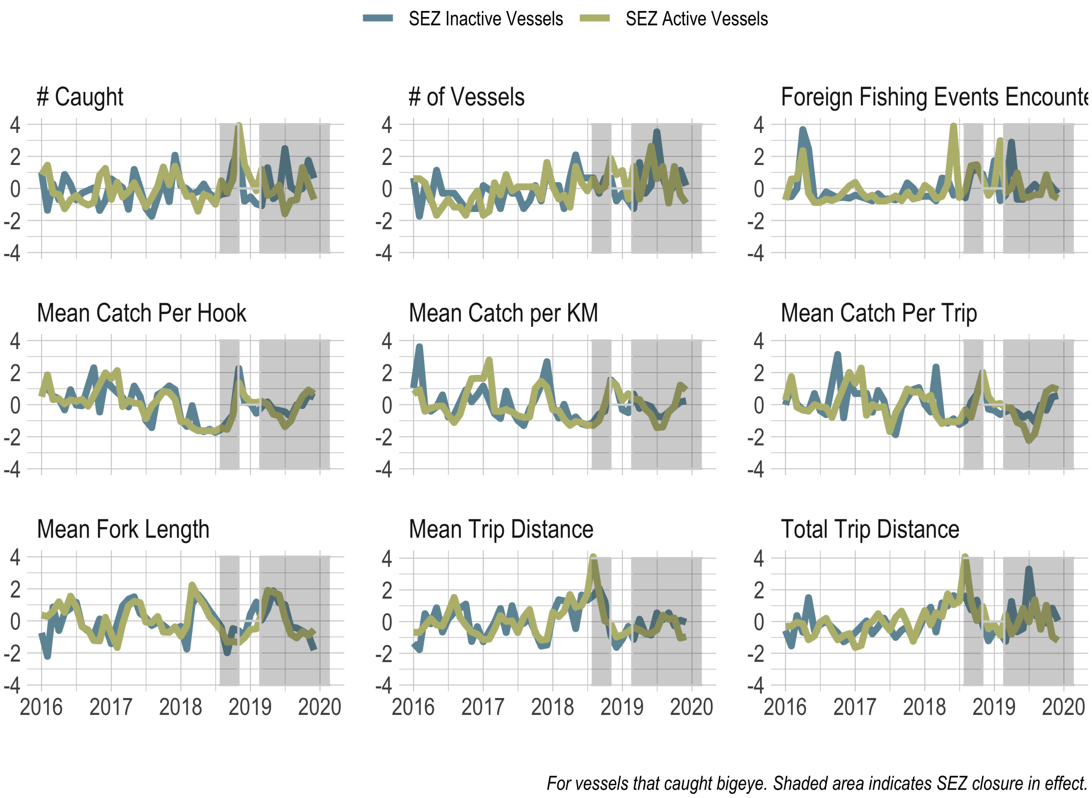

Figure 5: Centered and scaled trends in fishery metrics for SEZ active and inactive vessels for bigeye tuna. Values are at monthly resolutions. Shaded Areas indicated that the SEZ is in effect.

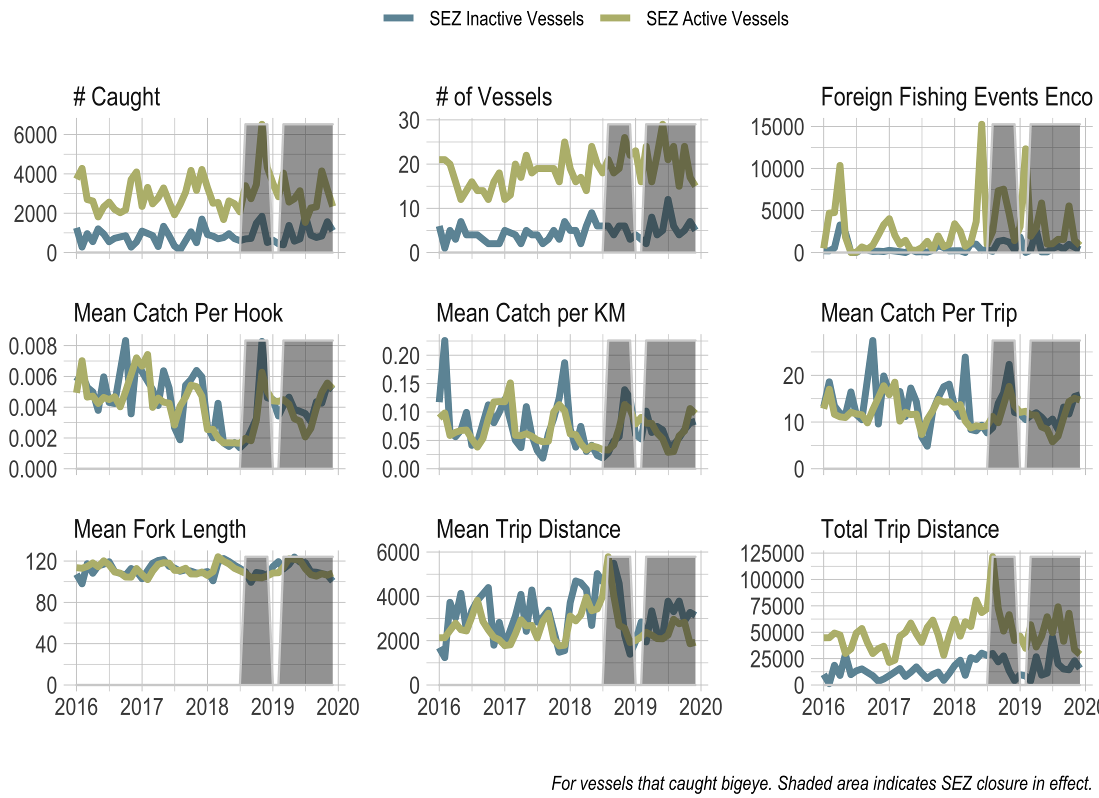

Figure 6: Trends in total fishery metrics for SEZ active and inactive vessels for bigeye tuna. Values are at monthly resolutions. Shaded Areas indicated that the SEZ is in effect.

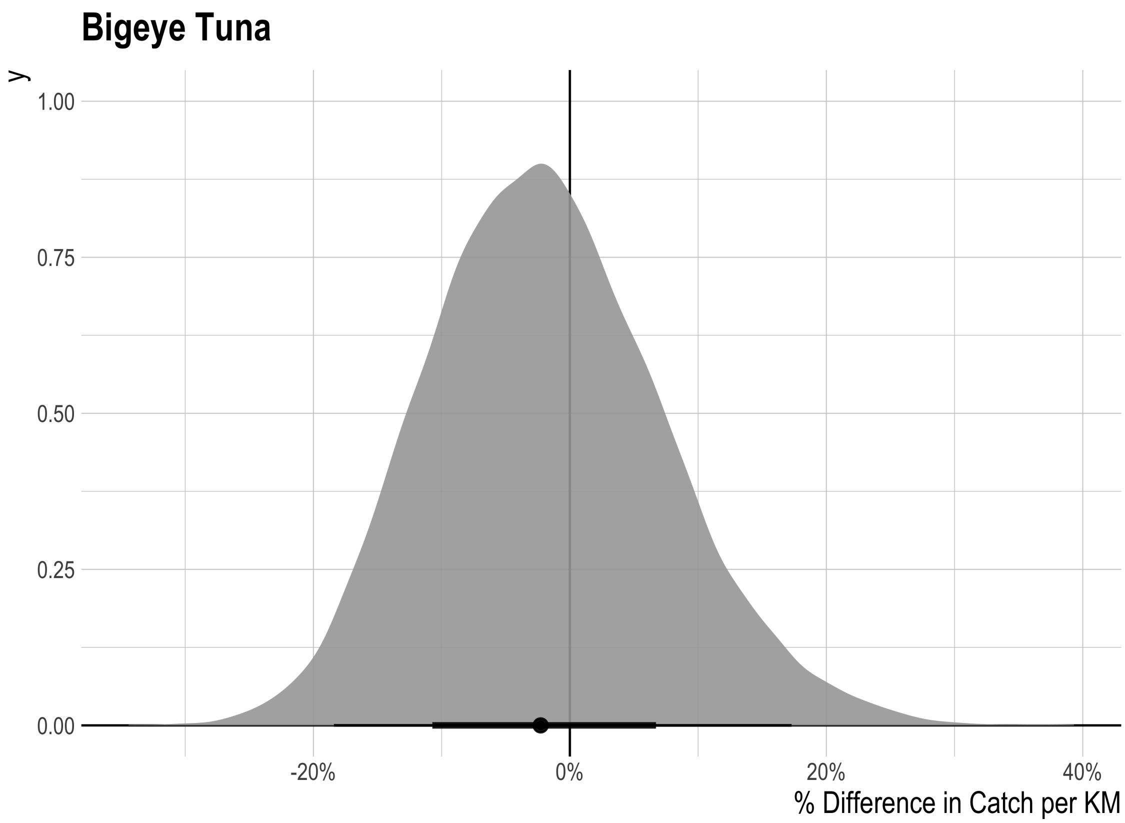

Figure 7: Estimated percent difference-in-difference in bigeye catch per kilometer traveled between the SEZ active and inactive vessels for trips that caught bigeye tuna. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

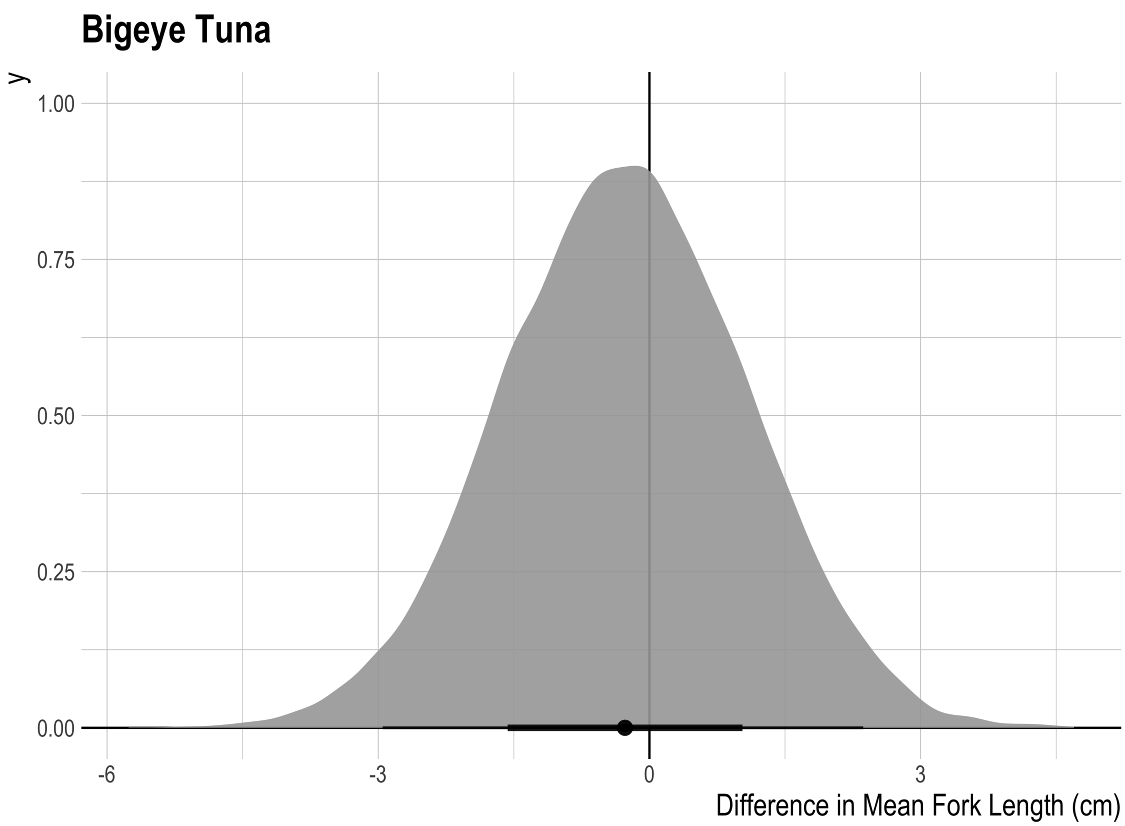

Figure 8: Estimated difference-in-difference in mean fork length of bigeye tuna caught between the SEZ active and inactive vessels. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

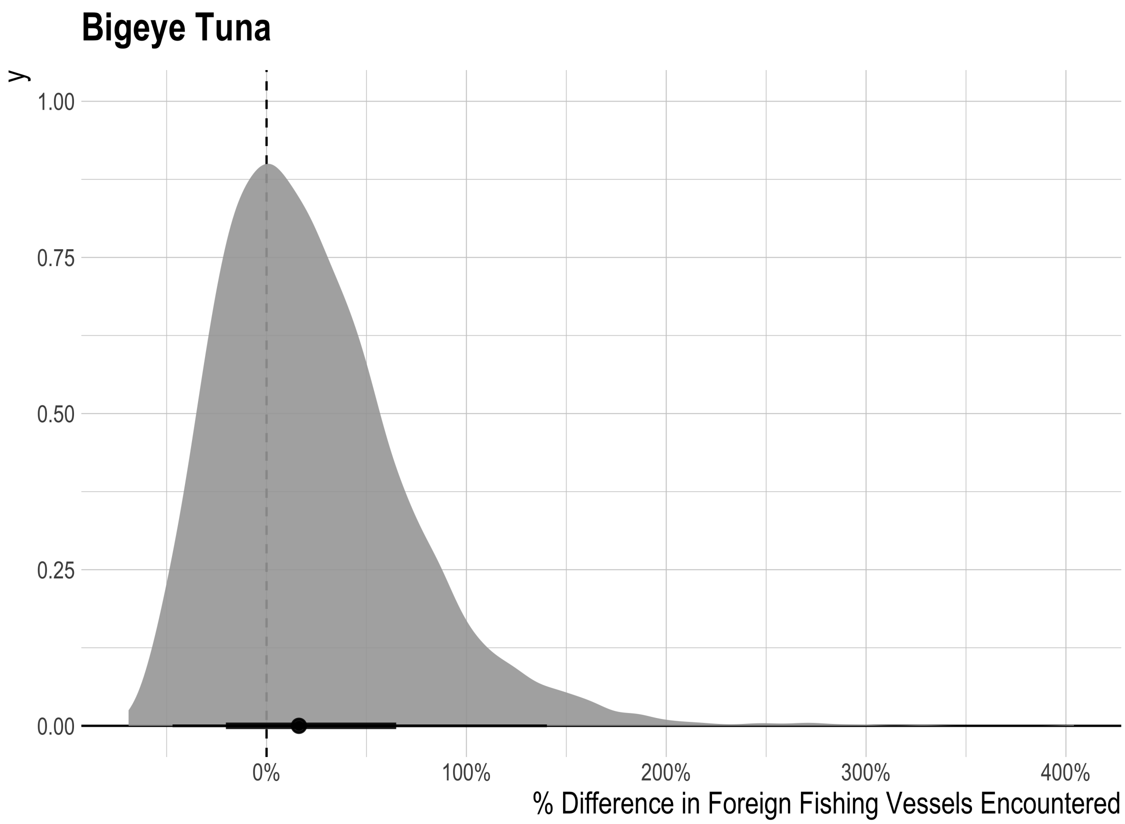

Figure 9: Estimated percent difference-in-difference in foreign fishing activity encountered between the SEZ active and inactive vessels on trips that caught bigeye tuna. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

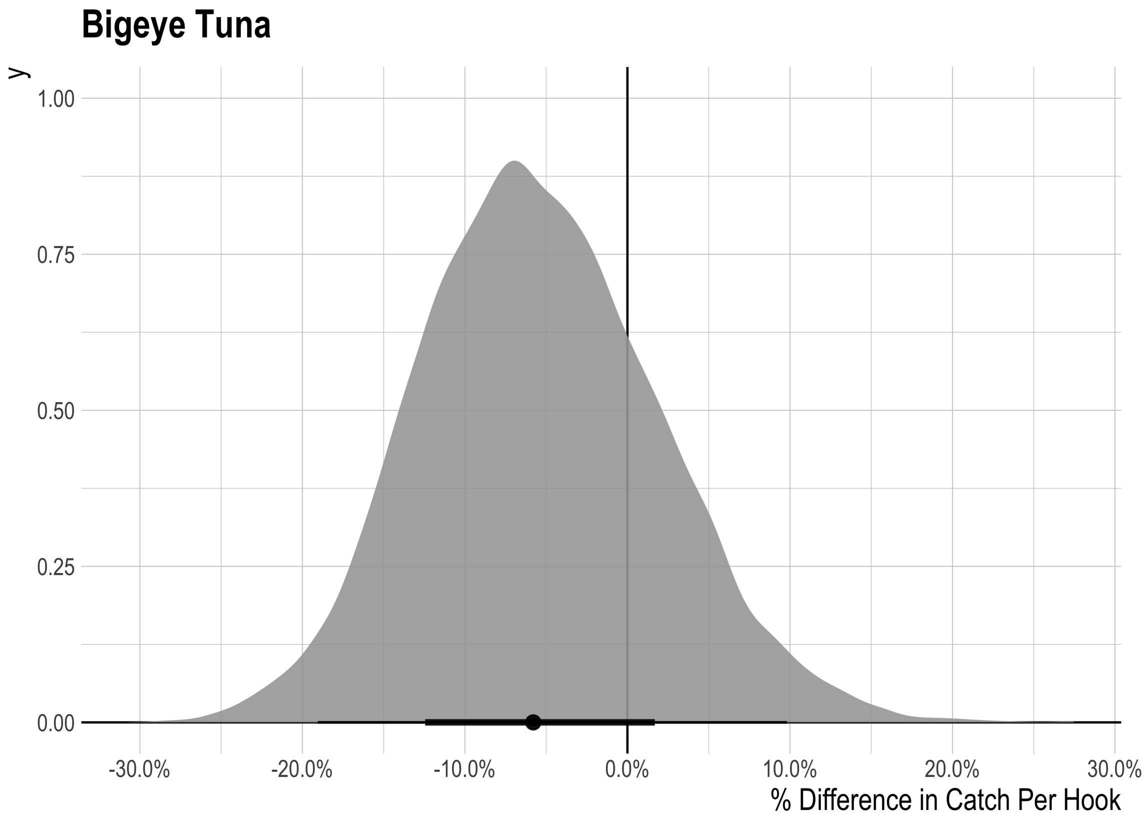

Figure 10: Estimated percent difference-in-difference in bigeye catch per hook caught between the SEZ active and inactive vessels. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

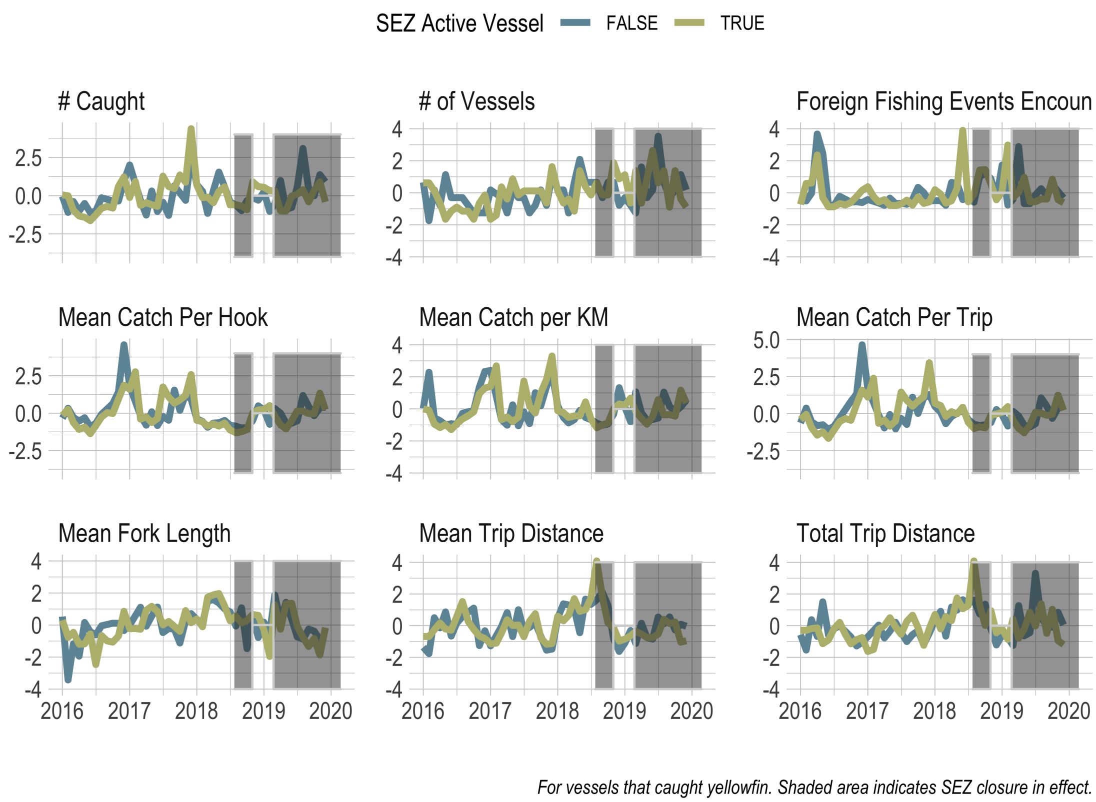

Figure 11: Centered and scaled trends in fishery metrics for SEZ active and inactive vessels for yellowfin tuna. Values are at monthly resolutions. Shaded Areas indicated that the SEZ is in effect.

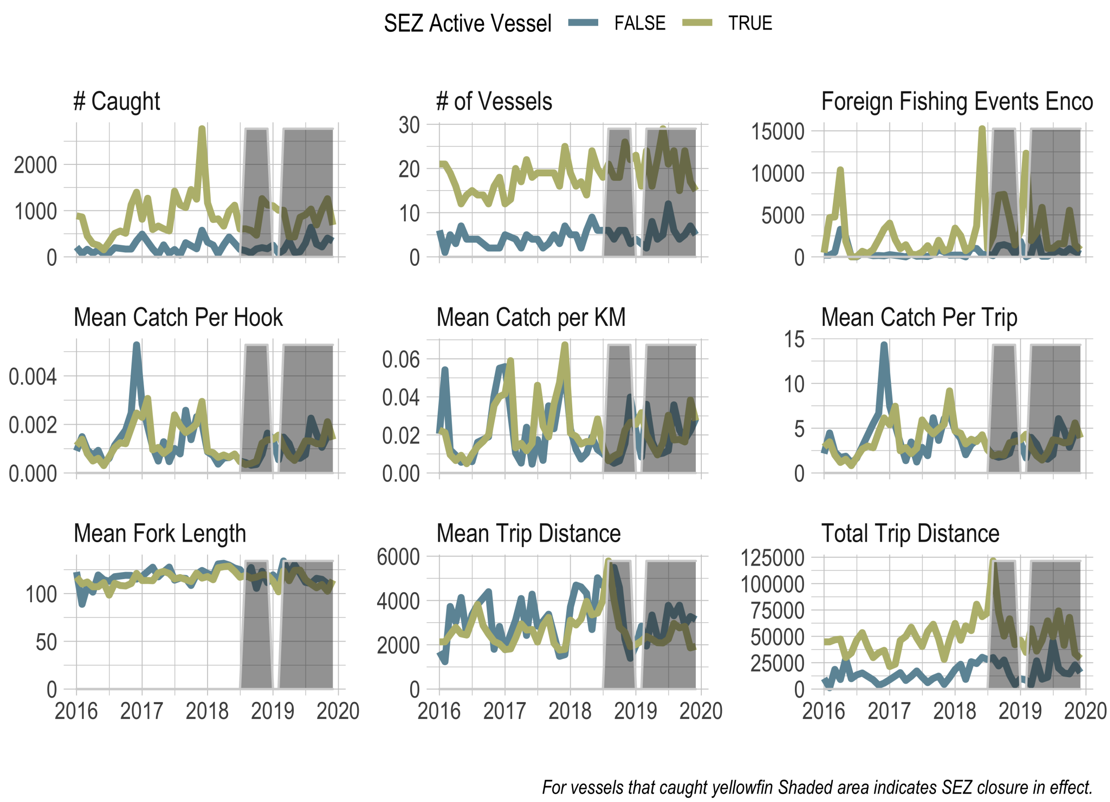

Figure 12: Total trends in fishery metrics for SEZ active and inactive vessels for yellowfin tuna. Values are at monthly resolutions. Shaded Areas indicated that the SEZ is in effect.

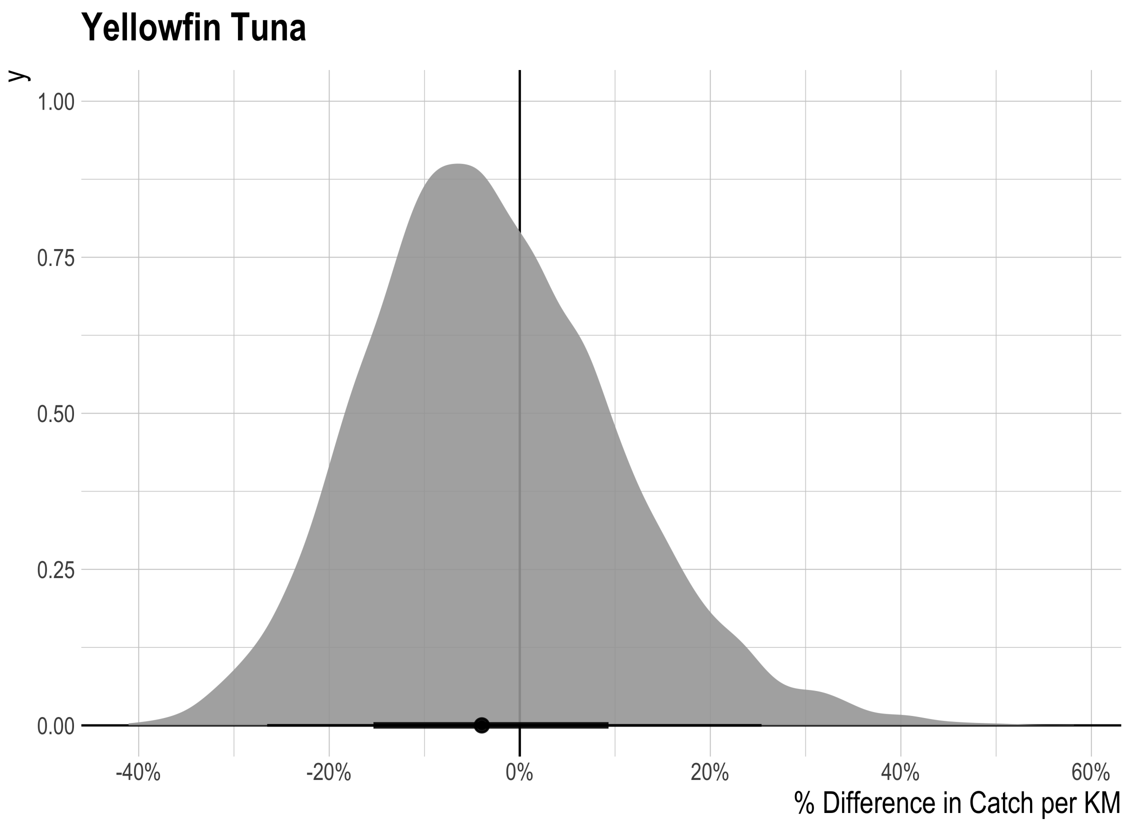

Figure 13: Estimated percent difference-in-difference in yellowfin catch per kilometer traveled between the SEZ active and inactive vessels for trips that caught yellowfin tuna. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

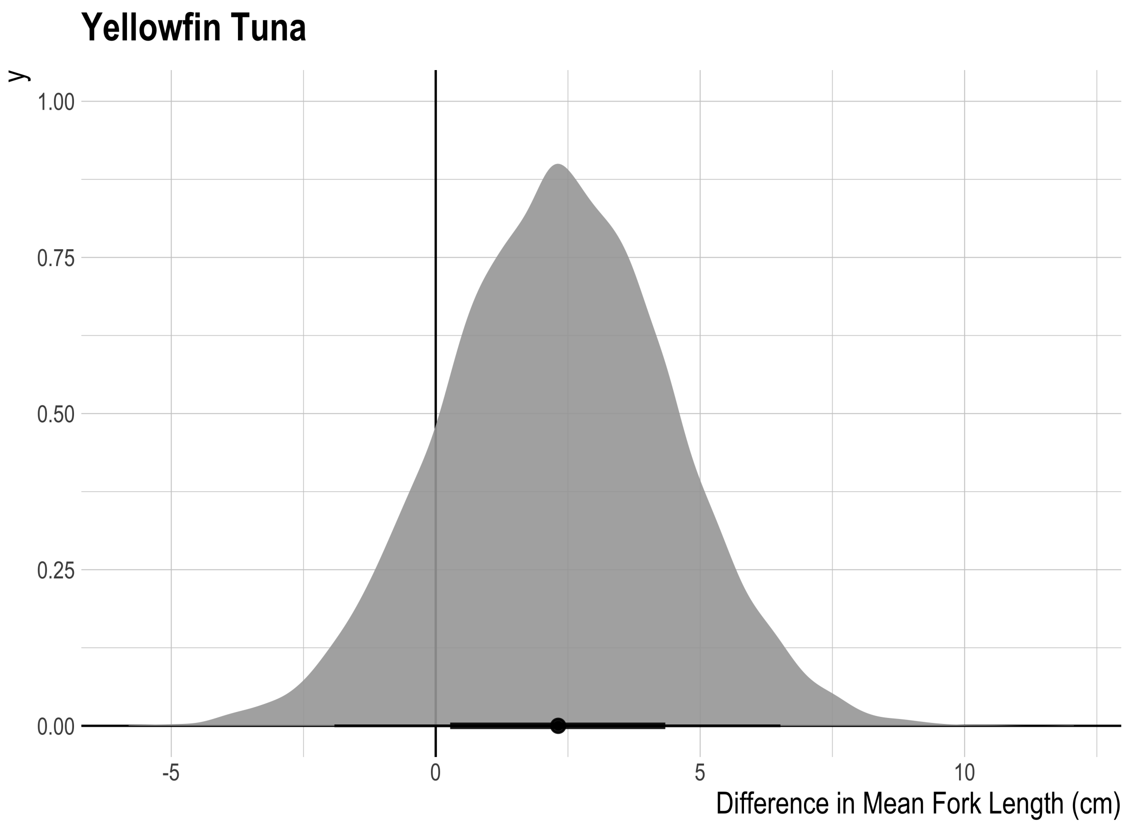

Figure 14: Estimated difference-in-difference (cms) in yellowfin mean fork length caught between the SEZ active and inactive vessels for trips that caught yellowfin tuna. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

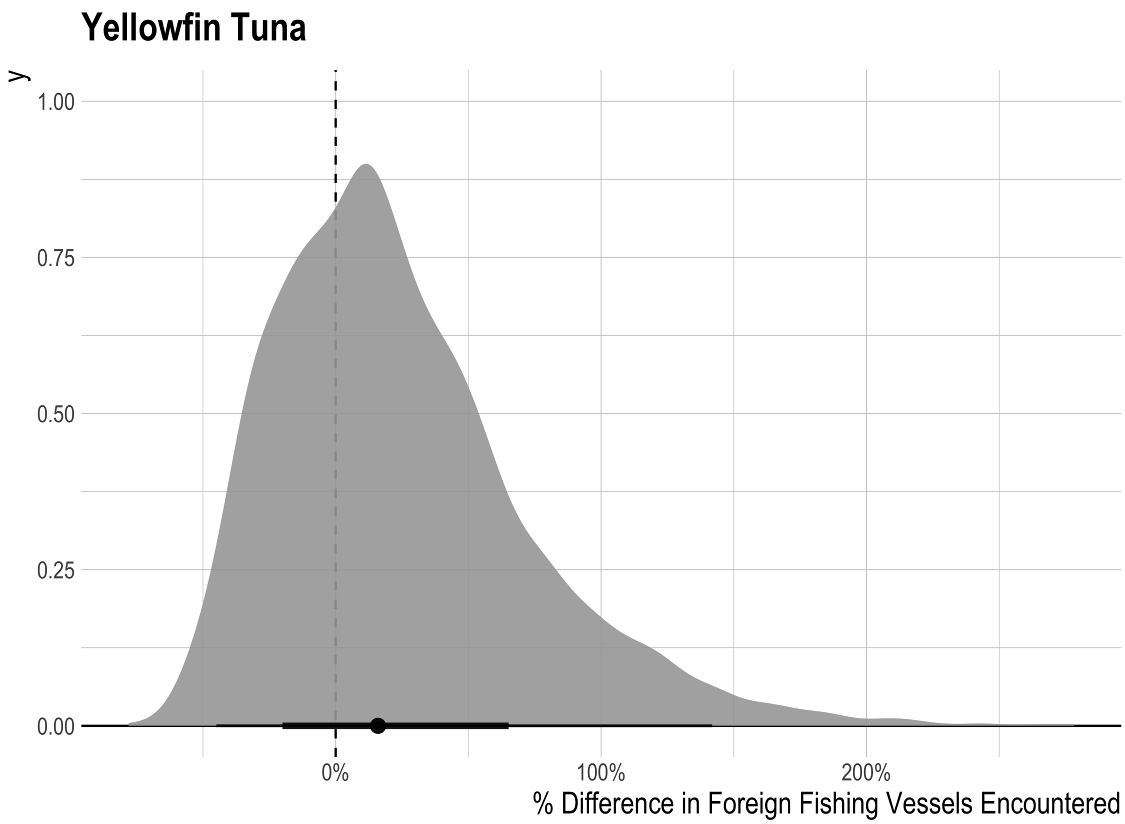

Figure 15: Estimated percent difference-in-difference in foreign fishing activity encountered between the SEZ active and inactive vessels on trips that caught yellowfin tuna. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

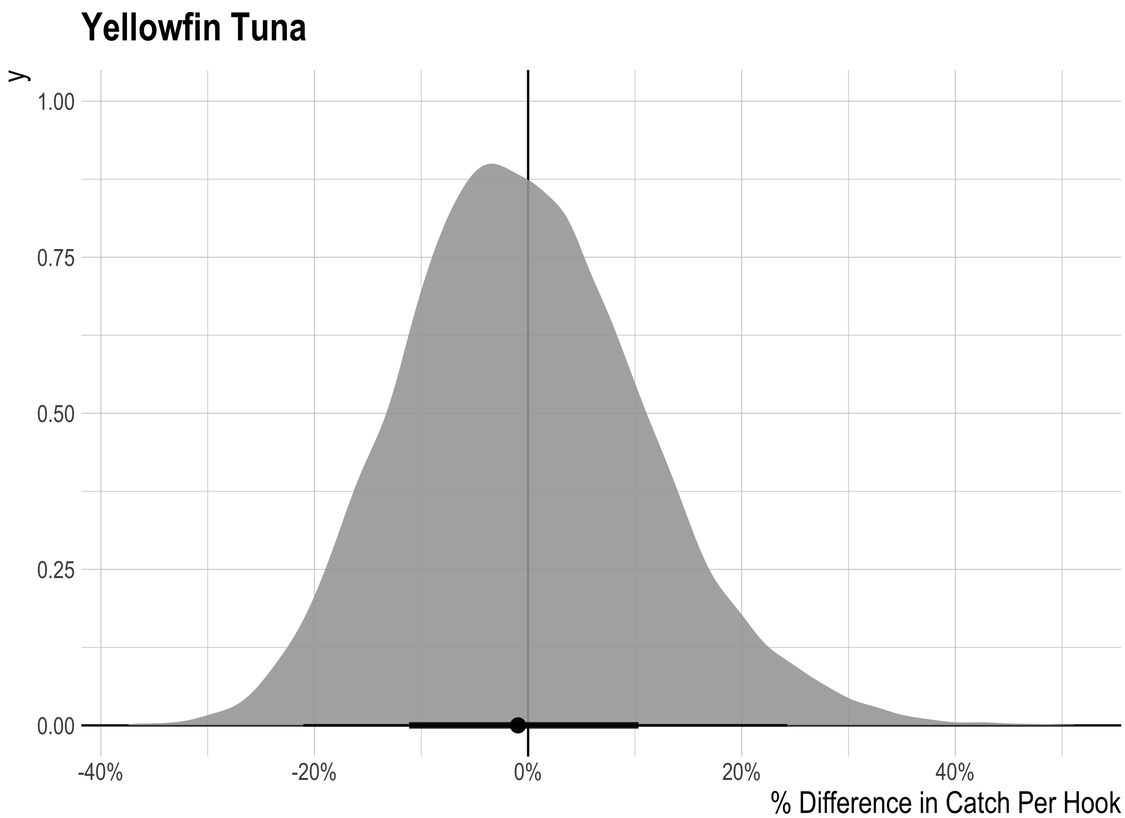

Figure 16: Estimated percent difference-in-difference in yellowfin catch per hook between the SEZ active and inactive vessels for trips that caught yellowfin tuna. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

4.4 Oceanic White-tip Sharks

While there are many candidate bycatch species we could consider, we chose to examine oceanic white-tip sharks, since they are among the more commonly reported species of shark in the data, and are listed as critically endangered by the IUCN. Since they are a bycatch species, we only include a regression analysis on catch-per-hook here, in order to evaluate whether the SEZ mediated any changed in catch-per-hook of oceanic white-tip that could be beneficial or detrimental to the species. The model estimates a substantial decrease in catch-per-hook of oceanic white-tip among SEZ-active vessels during the SEZ period, relative to SEZ-inactive vessels during that same period (Fig.17 - Fig.18). However, relative to the tunas examined in this report, the SEZ-inactive vessels have historically been a poorer control for the trends in oceanic white-tip catches of SEZ-active vessels.

In particular, the estimated reduction in catch-per-hook of oceanic white-tip is largely driven by a spike in catches of oceanic white-tip by the non-SEZ active vessels during the first SEZ period. Given that catches of oceanic white-tip sharks at the monthly level for non-SEZ active vessels are commonly in the single digits, it seems likely that this spike, and the subsequent estimated reduction of oceanic white-tip catch by the SEZ active portions of the fleet, is likely to be an artifact of noise in the data.

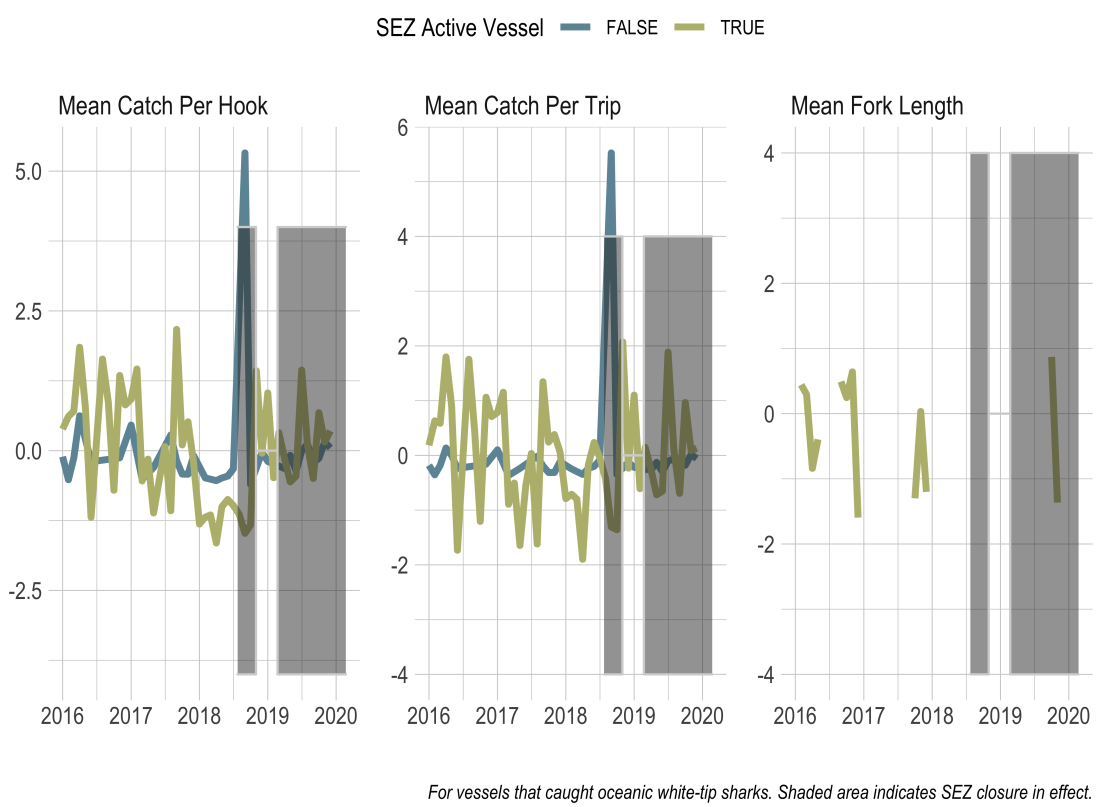

Figure 17: Trends in fishery metrics for SEZ active and inactive vessels for oceanic white-tip. Values are at monthly resolutions. Shaded Areas indicated that the SEZ is in effect.

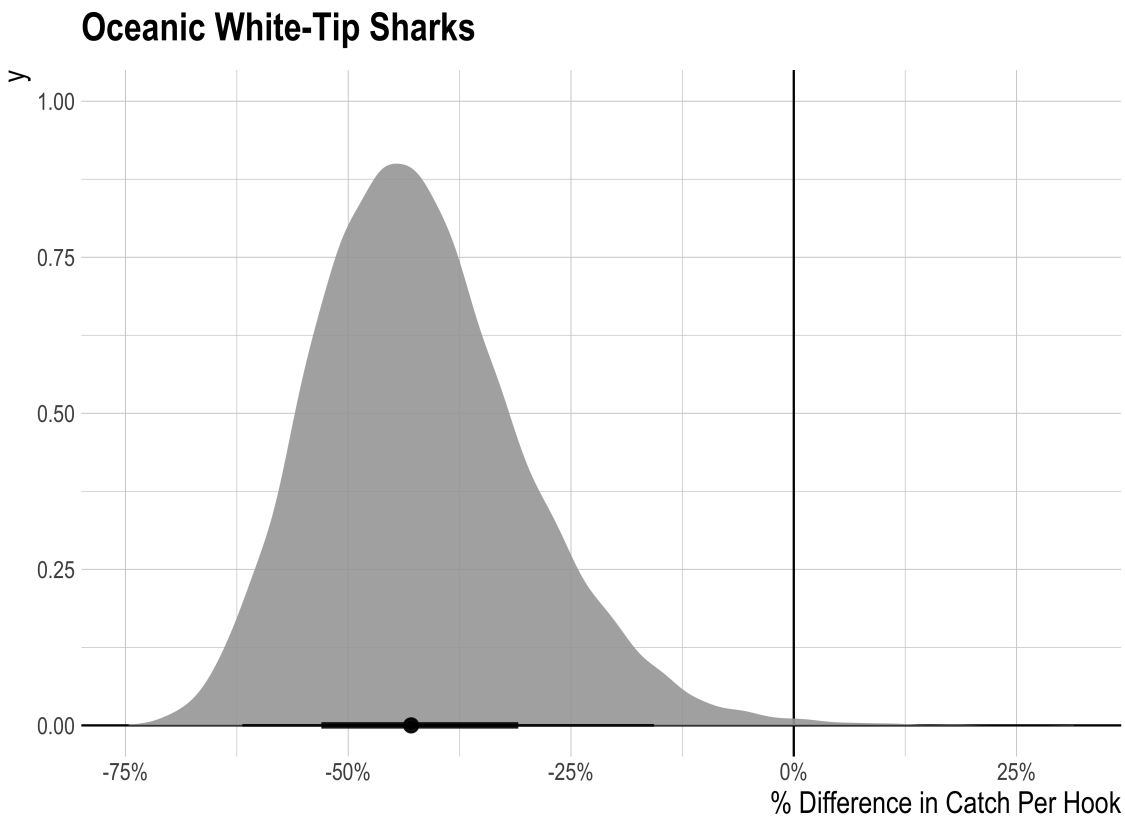

Figure 18: Estimated percent difference-in-difference in oceanic white-tip catch per hook between the SEZ active and inactive vessels for trips that caught oceanic white-tip. Grey area shows the complete posterior probability distribution, point shows the median of the posterior probability distribution, thicker line the 66% credible interval, and extent of the thinner lines the 95% credible interval.

5 Discussion

We detect no clear pattern of changes in trends or total values of relevant metrics for the species evaluated in this report. Given the relatively small proportion of historic deep-set longline catch that came from within the area encompassed by the SEZ, this result does not seem unusual. On the whole, for many metrics SEZ-inactive vessels appear to be a reasonable control for trends in SEZ-active vessels. However, there is substantial variation in this relationship year-to-year and month-to-month.

Further effort could be put into creating a more refined control group. As noted, our control group marks any deep set longline vessel that ever fished within the SEZ as "SEZ-active". As such, this groups vessels that only used this area once with the few vessels that used the area substantially. Given the lack of a clear breakpoint in the SEZ-use distributions (Fig.1), we did not feel it was appropriate to create an arbitrary distinction in SEZ use. However, given additional data we could explore other data-driven metrics for differentiating vessels that depend on the SEZ heavily vs. those that do not as a control group. But, given the trends in the data and exploratory analysis of alternative breakpoints, we do not feel that such an analysis would yield substantially different results.

It is important to note that all of these results are based on evaluations of total and mean metrics. It is entirely possibly that the SEZ had clearer impacts on individual vessels or operators, but we do not assess the impacts at such a fine resolution here. Catch per KM traveled serves here as a rough index of profitability, under the assumption that difference in costs per trip are related to distance traveled. This does not account for potential non-linearities in cost (e.g. if costs climb faster than distance due to labor costs, repairs, etc). However, given the mostly imperceptible changes in the total or mean values of catch per km traveled, we find it unlikely that a more refined analysis of profitability would yield substantially different results.