A Statistical Analysis of the Impacts of Management Decisions on the Distribution of Catch in the California Commercial Dungeness Crab Fishery

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A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Marine Affairs

University of Washington

2018

Committee:

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Program Authorized to Offer Degree:

School of Marine and Environmental Affairs

University of Washington

Abstract

A Statistical Analysis of the Impacts of Management Decisions on Catch in the West Coast Commercial Dungeness Crab Fishery

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Harmful algal blooms happen all along coasts around the world. During harmful algal blooms, sea life can absorb toxins emitted by the algae found in these blooms. Many of these events occur within areas of interest for high-value fisheries. Here, I examine the effect of management decisions to open or close Dungeness crab fishing areas due to domoic acid levels during and after the 2015 harmful algal bloom in California on the ratio of catch by small to large vessels. Using a difference-in-differences statistical analysis, I examine whether small vessels in California were negatively affected by the special closures, using Washington as a control group. I find no statistically significant difference between the catch ratio before the start of the harmful algal bloom (fall 2010 to spring 2015) and after (fall 2015 to spring 2017). Additionally, the trend of the ratio of catch by smaller vessels to larger vessels increased slightly in California after the harmful algal bloom. When considering just the 2015-16 season in this analysis, California as a whole increased the ratio of catch going to smaller vessels, but the Bodega Bay area ports showed a decreased statistically significant

difference in the catch ratio. This analysis illustrates that while on the whole, California small vessel fishermen might have a slight, not statistically significant increase in catch ratio, there are some small vessel fishermen who are negatively affected with the change in the timing of open areas for the commercial harvest of Dungeness crabs.

Introduction

Harmful Algal Blooms (HABs) are biological events that impact organisms and water chemistry in coastal ecosystems and negatively impact human activities due to the emission of toxins from various species of phytoplankton. These toxins accumulate in fish and crustaceans, which, when ingested by humans, can lead to illness or death (Zingone & Oksfeldt Enevoldsen, 2000). Characteristics of HABs can vary, such as the plankton species causing the HAB or the type of impact it has on humans or marine life (Zingone & Oksfeldt Enevoldsen, 2000). Only a small fraction of known phytoplankton species is responsible for producing toxins or negatively affecting marine life (Horner, Garrison, & Plumley, 1997).

Recent reports indicate an increase in frequency and diversity of these events and the severity of the impacts of HABs, including those that produce domoic acid (DA), on the West Coast of the United States (Anderson, 2005, 2009; Hallegraeff, 1993; Lewitus et al., 2012; Sellner, Doucette, & Kirkpatrick, 2003; Zingone & Oksfeldt Enevoldsen, 2000). The increased impact felt from HABs in sectors such as, public health, tourism, and fisheries, has led to increased academic and regulatory interest in understanding and management of HABs (Anderson, Cembella, & Hallegraeff, 2012; Trainer, Pitcher, Reguera, & Smayda, 2010).

According to a report by the National Oceanic and Atmospheric Administration's Coastal Ocean Program (Boesch et al., 1997), management of HABs can be divided into three categories of action: prevention, control, and mitigation. To better understand fisheries, understanding the mitigation of the impacts of HABs is crucial. Researchers have suggested that mitigation can have great positive impact on the ability of

communities to predict or forecast when HAB events may occur (Jin & Hoagland, 2008). Managers would be able to model the movement and abundance of the HAB and close fishing in a more precise areas, which would minimize list landings and negative economic impact on fishermen (Jin & Hoagland, 2008; Moore et al., 2008). However, such predictive models remain challenging for researchers to define. These could prove useful in determining which areas to close, but does not give insight into how fishermen from various sized vessels fare with delayed and staggered openings.

HAB impacts can range from an impact on the population of a specific species to financial impacts on individual fishermen, regional fisheries, and nations. More than ever before, is it necessary to understand the impacts of HAB events due to the potential significant economic threat HABs pose to the fishing industry (Hoagland, Anderson, Kaoru, & White, 2002). Economic impacts, which range from decreased sale prices to decreased tourism, are difficult to quantify, but were estimated at about $1.33 billion in lost sales in the United States over all sectors in 2000 due to HABs (Anderson, 2005).

A greater understanding of how management decisions are made during and after HAB events is needed to provide a better guide to the impacts of those decisions on the distributional impacts on fishermen. I examine the indirect impacts of HABs through California's fishery managers' decisions to delay and stagger openings for the commercial Dungeness crab fishery along the coast. Specifically, I determine if the distribution of catch by small vessels (less than 45 feet) is statistically significantly different following the 2015 HAB event in California compared to the previous five commercial seasons.

Background

Traditionally, the commercial Dungeness crab fishery in California opens in two stages: the central California district opens on November 15 and the northern California district opens on December 1. However, in the years following the 2015 HAB event, managers opened sections of California's coastal waters based on the measured concentrations of DA found in Dungeness crab tested from certain areas. Concentrations of DA have been detected in commercially important marine life in California almost every year since 1991 (Lewitus et al., 2012).

The fair start provisions stated until January 1, 2017 that an "individual" must wait 30 days if they harvested Dungeness crab before the start of the season (CA Dept of Fish and Wildlife, 2017; Fair Start Provision, n.d.). On January 1, 2017, in the middle of the 2016-17 season, the stipulation about the "individual" having handled Dungeness crab before the season or a certain district opened changed to a "vessel." Now, fishermen can work throughout the season and switch vessels, but the vessel must wait 30 days before participating in the fishery in another management district.

News coverage of the algal bloom in 2015 and 2016 helped inform the public of the potential health risk, some history of the Dungeness crab fishery, and the impact of the bloom on fishermen. Some articles focused on the impact the fishing closures had on fishermen and the fishing communities on the California coast (Parsons, 2015). Other articles took more of a public health awareness approach discussing the possible effects of the toxins on consumers of shellfish and of previous HAB impacts on humans around the world (Colliver & Schultz, 2015). At least one article reported that management decisions in the seasons during and after the HAB could have impacted fishermen on

smaller vessels adversely (Callahan, 2017). One fisherman, Noah Oppenhiem, from central California, was quoted in the Press Democrat in July 2017 as saying:

> "Good numbers mask the fact that many fishermen had an abysmal season…There were opportunities for fishermen who are more mobile to access a number of different openers and have a hell of a season, where there were small-boat fishermen that were really limited in their ability to access the resource and have a good season."

Here, Oppenheim is specifically referring to the series of openers at the beginning of the 2016-17 season compared to the typical two opening dates for the California coast. He thinks the impact on small vessels he mentioned in the article from the 2016-17 season could also be a trend in the 2015-16 season immediately following the HAB event (Noah Oppenheim, 2018).

A dramatic change in the opening date of a fishery can affect fishermen's finances for an entire year. Management decisions about the fishery should take into account the impacts on fishermen along with other variables. In California, the commercial Dungeness crab fishery typically opens below the Sonoma/Mendocino County line on November 15 and opens from the Sonoma/Mendocino County line to the California/Oregon border on December 1. These openings are typically only delayed due to the results of crab quality and DA testing. Six crabs are tested along various locations along the coast at the beginning of each season and if not initially clear, repeated every week to 10 days until there are two consecutive completely clear results. The results of the DA crab testing are published and available to the public.

The 2015-2016 commercial Dungeness crab season was severely delayed due to the high levels of DA found in the tested Dungeness crab along the coast. The first area to open for commercial Dungeness crab harvest was the mainland coastlines south of the Sonoma/Mendocino opened March 26, 2016, about 18 weeks late (CA Dept of Fish and Wildlife, 2015, 2016). This opened areas surrounding port groups near Bodega Bay (BDA), San Francisco (SFA), Monterey Bay (MNA), and Morro Bay (MRA). Almost 6 weeks later on May 12th, the majority of the northern California waters were opened except the areas close to Eureka, CA (Figure 1). Two weeks later, on May 26th, the remaining portion of the coast opened to commercial Dungeness crab harvesting, opening the area around Eureka.

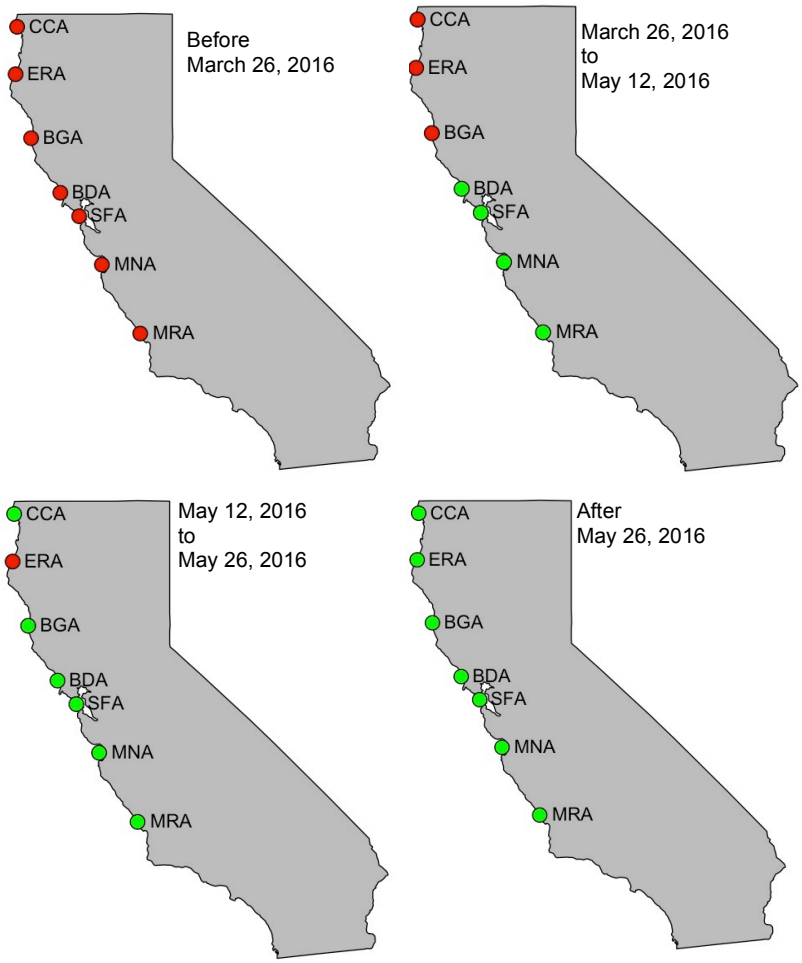

Figure 1: By row left to right, this figure illustrates how the geography of the ports and their relative status after each opener. From the most northern dot to the most southern dot indication the location of each port is Crescent City (CCA), Eureka (ERA), Fort Bragg (BGA), Bodega Bay (BDA), San Francisco (SFA), Monterey Bay (MNA), and Morro Bay (MRA). Closed ports are indicated at their location with a red dot and open ports are indicated by a green dot.

There are two possible hypotheses as to why the distribution of catch between small and large vessels might have changed in the 2015-16 season in California. The first hypothesis would affect the small vessels in the central California management area. Vessels that are more mobile, typically larger vessels, are better able to travel to the central district when it opened on March 26, possibly due to weather concerns or other factors. Rather than waiting in a closed port, larger vessels had more confidence in traveling safely and in a timely fashion to the central California ports. This would increase large vessels in the central California ports leading to a decrease in small vessels and therefore their catch in those ports, most likely those near Bodega Bay and San Francisco as the most northern ports.

The second hypothesis could be an explanation of possible impacts in the northern California management area. The more mobile, larger, vessels could have (1) monitored the published northern ports DA tests while fishing on the central coast, (2) anticipated an opening after a few weeks of good harvests in central California, (3) stopped fishing in accordance with the fair start provisions, and (4) traveled to the northern ports to start fishing only a few weeks into the season for those ports. This would increase large vessels in Crescent City and Fort Bragg area ports leading to a decrease in small vessel catch.

The 2016-17 commercial Dungeness crab season started with close to typical areas open at close to the typical times. On November 15, 2016, the commercial Dungeness crab fishery opened in central California south of Point Reyes, only opening area ports close to San Francisco, Monterey Bay, and Morro Bay (CA Dept of Fish and Wildlife, 2016). On December 1, 2016, the fishery opened in northern California just

north of Humbolt Bay to the California/Oregon border, allowing vessels from the Eureka area to harvest to the north, but not the south (Figure 2). The area near Bodega Bay opened on December 3rd. There was another area opened that decreased the closed area between Bodega Bay and Eureka, but Fort Bragg area ports did not open until December 26, 2016.

There are two possible hypotheses for the change in the distribution of catch for the 2016-17 season as well. The first is that more mobile, larger vessels could have seen that the northern most port group (Bodega Bay) did not open on schedule, and traveled to the open central California ports. They may have decided to travel to the central ports because they were concerned that the northern ports were going to open later than usual, leading to minimal protections from the fair start provisions similar to what occurred the

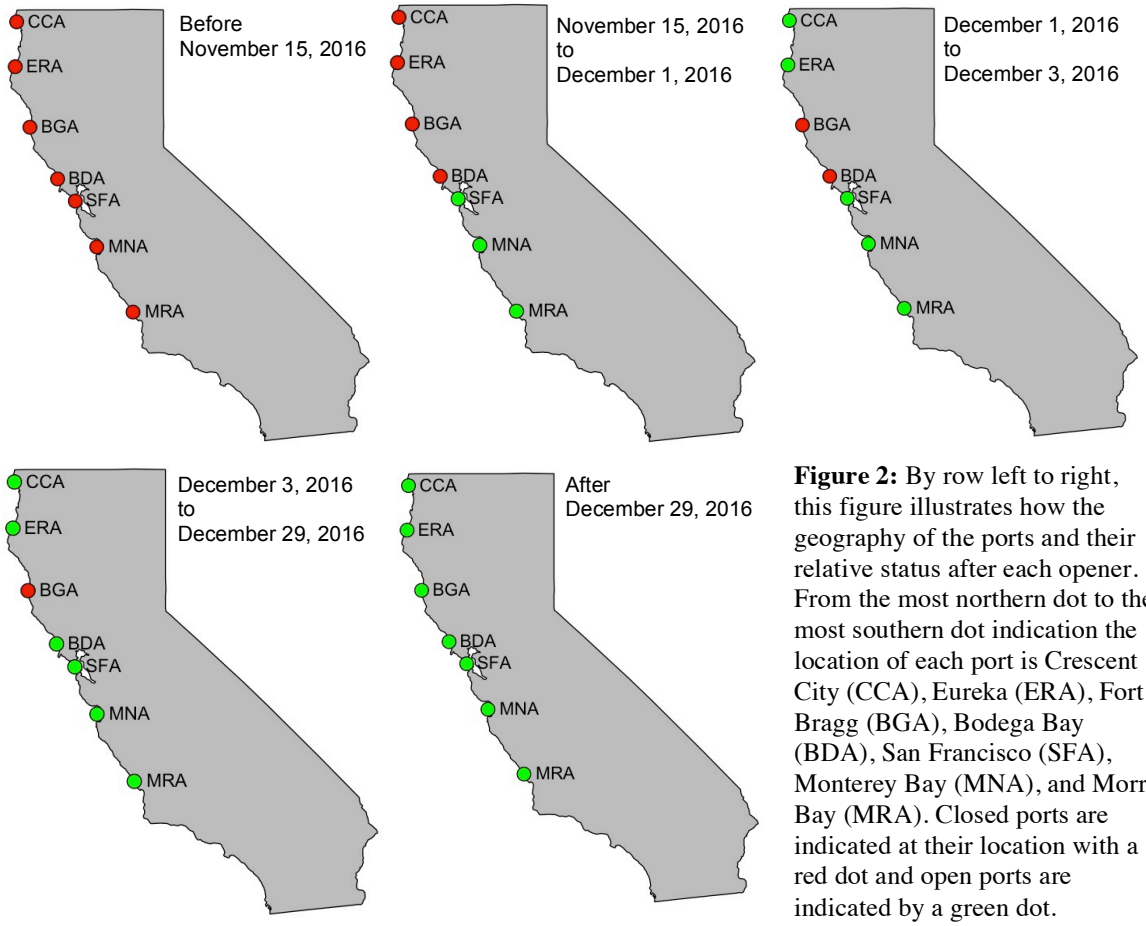

Figure 2: By row left to right, this figure illustrates how the geography of the ports and their relative status after each opener. From the most northern dot to the most southern dot indication the location of each port is Crescent City (CCA), Eureka (ERA), Fort Bragg (BGA), Bodega Bay (BDA), San Francisco (SFA), Monterey Bay (MNA), and Morro Bay (MRA). Closed ports are indicated at their location with a red dot and open ports are indicated by a green dot.

season before and so as not to risk getting caught waiting for the northern ports to open. This would increase large vessels in the three most southern ports leading to a decrease in small vessels and their catch.

The second hypothesis is that the more mobile, larger vessels from the Bodega Bay and Fort Bragg area ports, which both had delayed openings, traveled to the northern ports when their ports did not open on time. That way, they could take advantage of high harvest levels in the opening weeks in Eureka and Crescent City area ports. This would increase large vessels in those two most northern ports leading to a decrease in small vessels and their contribution to the weeks' catch.

I examine the Dungeness crab fishery on the West Coast of the United States with specific focus on how the management decisions by state agencies to have a staggered opening affected the total catch by small vessels compared to larger vessels. I examine data from California and Washington through various statistical methods and examine individual ports within California. This analysis could shed light on how various management decisions can affect fishermen from different sized vessels. Additionally, this analysis could bring a greater understanding of whether management decisions similar to the ones that occurred during and after this HAB event should be used in the future.

Methods

The data was acquired from the Pacific Fisheries Information Network (PacFIN) on the catch of Dungeness crab in pounds by vessels of all sizes. This data was divided into large vessels (equal to or larger than 45 feet) and small vessels (less than 45 feet).

This data included weekly landings in pounds from 2010 to 2016 from port groups within California and Washington. Data was received in calendar year format, but analyzed with particular interest in fishing seasons (November to July in California; December to September in Washington).

To complete the analysis, I examine the data by port group according to PacFIN's categorization, resulting in six California ports and three Washington ports with data. Because each fishing season started on a different week of the calendar year each year, I

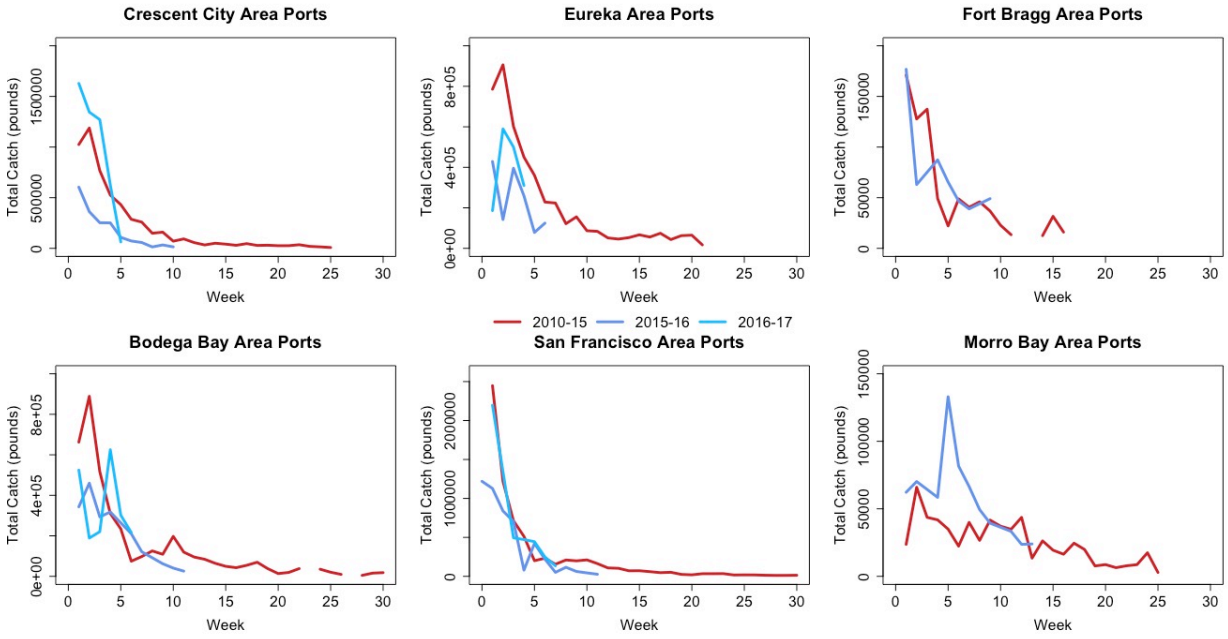

Figure 3: Total catch, including small vessel (< 45 feet) and large vessel (≥ 45 feet) reported catch, in each port by week in pounds. The historical total average catch each week from fall 2010 to spring 2015 indicated in red. The two seasons after the 2015 HAB are in two different shades of blue. The 2015-16 season is indicated in periwinkle and the 2016-17 season is indicated in neon blue.

adjust the data so that each first week of data is aligned as the first week of the season for this analysis. Analysis of the cumulative catch from each port for each season reveals that 50% of the catch was caught by week five and at least 75% by week eight of the season (Figure 3 and 4). Therefore, I analyze both the first five weeks and the first eight weeks of each season in each port as well as complete an analysis of the entire season in each

port. All data from seasons before the start of the 2015-16 commercial season are considered "before." The start of the 2015-2016 season was the first season that California began staggering openings for the commercial Dungeness crab seasons due to domoic acid levels found in tested crab. I include three different "after" periods in this analysis: the combined data of the 2015-16 and the 2016-17 seasons, the 2015-16 season alone, and the 2016-17 season alone.

Of the seven ports in California and three ports in Washington, all except one port group in Washington, South Puget Sound, had data for all fishing seasons specifically in the five and eight week selections. Additionally, the data also included seven observations from the Monterey Bay area ports. However, these seven observations were not recorded in a single season and are not included in the analysis moving forward. I include the remaining nine port groups in these calculations.

I calculate the mean and standard error for the ratio of the catch in pounds by small vessels to large vessels, referred to as the catch ratio, and for the proportion of catch by small vessels compared to the total catch by the same port the same week for each port's observations in the before and after periods. I calculate the mean and standard error for the difference between the before and after periods for each port. Additionally, I complete a Welch two sample t-test and a Wilcoxon rank-sum test to determine if the before and after data sets for each port and state were statistically significantly different (Table 1).

With this data, I complete a difference-in-differences analysis through a difference of means and regression analysis to determine the effect of the HAB on California Dungeness crab commercial catch ratio (small vessel catch in pounds divided

by large vessel catch in pounds) and small vessel proportion (small vessel catch in pounds divided by total catch in pounds) when compared with the control of Washington Dungeness crab commercial catch ratio and small vessel proportion. Washington has the same gear type restrictions and other similar regulations, making it suitable as a control. The analysis compares the difference between the treatment (California catch) and control (Washington catch) groups before and after the event (2015 HAB event) from observational data by determining whether the difference between the treatment and control groups after the event is statistically significantly different than the difference between the two groups before the event.

The difference-in-differences analysis is completed with two sample t-tests, which assumes a t-distribution of data in both sample groups tested and is not as robust with this data due to the different sized samples. I complete a Welch two sample t-test and a Wilcoxon ranks-sum test, which does not depend on a normal distribution of the data being tested and is less likely to incorrectly indicate statistical significance than a t-test with small samples.

To complete the difference-in-differences analysis, I compile the data from each week in each state to determine the mean ratio of small vessel catch to large vessel catch. These data remained in the same "before" and "after" categories, where "after" is defined as after the start of the 2015-16 season. The difference was taken for each week for both categories, resulting in a value for the difference for each week in California and Washington. Then, I calculate the difference of the difference values from the two states. I calculate the mean and standard error of the difference between the states and complete a Welch two sample t-test, Wilcoxon rank-sum test and a second t-test after a bootstrap

resampling of the catch ratio and small vessel proportion data. I compare the data from the 2015-16 season to the five prior seasons using the same methodology along with a mean of the difference between states, a Welch two sample t-test, and Wilcoxon-rank sum test (Table 1). Additionally, I compare the ports with available data in the 2016-17 season (all ports except Fort Bragg Area ports) to the previous five seasons as well as compare the 2015-16 and 2016-17 seasons to each other. Finally, I pool the samples I compare (Before and the various After scenarios) and resample 1000 times to determine if the two groups are statistically significantly different with a t-test on the 1000 resampled data sets. This allows for comparison of small samples with different distributions, by pooling the data from the two samples and resampling from the pooled sample for analysis.

For the difference-in-differences regression model, I use a standard model (Equation 1) by creating dummy variables identifying the treatment and control groups, the time period (pre- or post- HAB event), and an interaction term of those groups. Of the most interest is β_3 as it shows the interaction between the treatment and control groups following the HAB event. If it is negative, California's management decisions following the HAB negatively impacted smaller vessels; if it is positive, California's management decisions to stagger the openings following the HAB actually helped smaller vessels. I complete this analysis with both catch ratio and the small vessel proportion metrics.

$$y_{f,t} = \beta_0 + \beta_1 \text{treatment}_f + \beta_2 \text{post}_t + \beta_3 (\text{treatment} * \text{post})_{f,t} + \varepsilon_{f,t} \quad (1)$$

I also complete a further difference-in-differences regression (Equation 2) for both the catch ratio and small vessel catch proportion for California ports using the fall 2010 to spring 2015 seasons as the control groups and the two seasons of interest (2015-16 and 2016-17) as the treatment groups. These models include port fixed effects accounting for the port group, time fixed effects accounting for the week of the season, and control variables of wave height, water temperature, and wind speed within X.

$$y_{f,t} = \beta_0 + \beta_1 (\text{treatment} * \text{post})_{f,t} + \alpha_1 \text{port}_f + \alpha_2 \text{week}_t + X_{f,t} + \varepsilon_{f,t} \quad (2)$$

The key assumption in a difference-in-differences model is that of common trends between the treatment and control groups. I am assuming that the management decisions during the HAB event did not affect catch in my control group, i.e. Washington state port groups. Therefore, any change in catch ratio in the Washington port groups, I am assuming, would also have occurred in the treatment group, California, if the HAB event had not required managers to alter the standard season opening timing.

There is also a concern about the effect of the delayed start of various ports throughout the state of California on the percent of the state's total catch for the season. To investigate this potential influence, I complete a multivariate linear regression of the fraction of a port's catch by small vessels to the total catch with the number of weeks late and fraction of the state's total catch as variables. I complete this regression with all six port groups.

Results

The difference of means between the five seasons starting in fall 2010 and the season from fall 2015 to spring 2016 indicates that the mean of the first five weeks of the season in California and Washington is large, positive and not statistically significant (Table 1a). The coefficient for the difference-in-differences model regression is positive and not statistically significant (Table 1b).

I examine the catch ratio and small vessel proportion in California and Washington during the commercial Dungeness crab fishery seasons from fall 2010 to spring 2015 (Before period) and the seasons from fall 2015 to spring 2017 for the entire season, the first 8 weeks, and the first 5 weeks (Tables 2-7).

(a)	**Within State Difference**	**Between State Difference**
California	0.240 (0.079) *0.202*	1.92 (0.647) *0.251*
Washington	-1.68 (0.642) *0.312*	

(b)	**Coefficient Value**
Constant	2.84 ***
Treatment	-1.60 ***
Post	-1.29 *
Treatment*Post	1.18

Table 1: (a) The difference in means and (b) regression model for the difference-in-difference analyses between California ports before the change in management with data after the change from the 2015-16 season. The italicized values are the p-value of a two-sample t-test.

Overall, California had an increase in both small vessel catch metrics and Washington had a decrease in both small vessel catch metrics. It is important to note that as the number of weeks included in the analysis for each statistical test changes, so do the values of statistical significance for the differences in small vessel catch metrics.

If analyzing the entire season from all ports for both metrics, there are a number of notable differences. Crescent City has a statistically significant increase in catch ratio in the 2015-16 season according to the bootstrap resampling t-test (Table 2), which is

also the case for the small vessel proportion (Table 5), but has a statistically significant decrease in catch ratio in the 2016-17 season according to both t-tests. Bodega Bay has a statistically significant decrease in catch ratio for the combined seasons and the 2015-16 season according to both t-tests, but this statistical significance was only recognized by the bootstrap resampling t-test for the small vessel proportion. San Francisco had a statistically significant decrease in catch ratio and small vessel proportion through all three statistical tests in the 2016-17 season. These observations do not necessarily hold when analyzing a subset of weeks in a season.

	Difference (2015-17)	**Difference (2015-16)**	**Difference (2016-17)**
Crescent City Area Ports (CCA)	0.009 (0.044)	0.192 (0.044)	-0.356 (0.039)
Eureka Area Ports (ERA)	0.185 (0.075)	-0.018 (0.061)	0.491 (0.096)
Fort Bragg Area Ports (BGA)	0.052 (0.056)	0.052 (0.056)	
Bodega Bay Area Ports (BDA)	-0.232 (0.044)	-0.363 (0.038)	-0.035 (0.051)
San Francisco Area Ports (SFA)	-0.221 (0.110)	0.161 (0.119)	-0.87 (0.085)
Morro Bay Area Ports (MRA)	-0.022 (0.023)	-0.022 (0.077)	
All California Ports	-0.130 (0.076)	-0.102 (0.077)	-0.202 (0.075)
Washington Coastal Ports (CWA)	0.308 (0.056)	0.308 (0.056)	
North Puget Sound Ports (NPS)	-4.24 (0.768)	-4.24 (0.768)	
South Puget Sound Ports (SPS)	-0.016 (0.010)	-0.016 (0.010)	
All Washington Ports	-2.56 (0.532)	-2.56 (0.532)	

Table 2: Full Season Catch Ratio Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet) for the entire season within each port. The "Difference" is the difference between the mean for the 2010-2015 seasons and the 2015-17 combined seasons, 2015-16 season, and the 2016-17 season. Coloring indicates if the difference is statistically significant based on a two-sample t-test, a rank-sum test, and a bootstrap resampled t-test and the direction of the sign of the difference (Green indicates an increase in the metric; Red indicates a decrease in the metric).

	Difference (2015-17)	Difference (2015-16)	Difference (2016-17)
Crescent City Area Ports (CCA)	-0.086 (0.051)	0.079 (0.051)	-0.351 (0.048)
Eureka Area Ports (ERA)	0.386 (0.072)	0.182 (0.057)	0.692 (0.093)
Fort Bragg Area Ports (BGA)	-0.041 (0.060)	-0.041 (0.060)	
Bodega Bay Area Ports (BDA)	0.123 (0.032)	-0.050 (0.021)	0.297 (0.040)
San Francisco Area Ports (SFA)	0.141 (0.044)	0.325 (0.048)	-0.070 (0.037)
Morro Bay Area Ports (MRA)	-0.051 (0.028)	-0.051 (0.028)	
All California Ports	0.086 (0.053)	0.076 (0.048)	0.103 (0.060)
Washington Coastal Ports (CWA)	-0.134 (0.020)	-0.134 (0.020)	
North Puget Sound Ports (NPS)	-2.89 (0.578)	-2.89 (0.578)	
South Puget Sound Ports (SPS)	-0.076 (0.008)	-0.076 (0.008)	
All Washington Ports	-1.43 (0.399)	-1.43 (0.399)	

Table 3: First Eight Weeks Catch Ratio Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet) for the first eight weeks of the season within each port. The "Difference" is the difference between the mean for the 2010-2015 seasons and the 2015-17 combined seasons, 2015-16 season, and the 2016-17 season. Coloring indicates if the difference is statistically significant based on a two-sample t-test, a rank-sum test, and a bootstrap resampled t-test and the direction of the sign of the difference (Green indicates an increase in the metric; Red indicates a decrease in the metric).

	Difference (2015-17)	Difference (2015-16)	Difference (2016-17)
Crescent City Area Ports (CCA)	-0.209 (0.061)	0.034 (0.060)	-0.452 (0.060)
Eureka Area Ports (ERA)	0.617 (0.070)	0.444 (0.054)	0.833 (0.091)
Fort Bragg Area Ports (BGA)	0.004 (0.067)	0.004 (0.067)	
Bodega Bay Area Ports (BDA)	0.166 (0.033)	0.002 (0.019)	0.297 (0.041)
San Francisco Area Ports (SFA)	0.176 (0.032)	0.396 (0.038)	-0.043 (0.021)
Morro Bay Area Ports (MRA)	-0.023 (0.033)	-0.023 (0.033)	
All California Ports	0.145 (0.054)	0.179 (0.048)	0.064 (0.063)
Washington Coastal Ports (CWA)	-0.153 (0.023)	-0.153 (0.023)	
North Puget Sound Ports (NPS)	-3.96 (0.724)	-3.96 (0.724)	
All Washington Ports	-1.94 (0.502)	-1.94 (0.502)	

Table 4: First Five Weeks Catch Ratio Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet) for the first five weeks of the season within each port. The "Difference" is the difference between the mean for the 2010-2015 seasons and the 2015-17 combined seasons, 2015-16 season, and the 2016-17 season. Coloring indicates if the difference is statistically significant based on a two-sample t-test, a rank-sum test, and a bootstrap resampled t-test and the direction of the sign of the difference (Green indicates an increase in the metric; Red indicates a decrease in the metric).

	Difference (2015-17)	Difference (2015-16)	Difference (2016-17)
Crescent City Area Ports (CCA)	0.013 (0.010)	0.078 (0.010)	-0.116 (0.009)
Eureka Area Ports (ERA)	0.031 (0.009)	0.016 (0.009)	0.052 (0.011)
Fort Bragg Area Ports (BGA)	0.060 (0.011)	0.060 (0.011)	
Bodega Bay Area Ports (BDA)	-0.030 (0.008)	-0.030 (0.008)	-0.008 (0.010)
San Francisco Area Ports (SFA)	-0.019 (0.011)	-0.019 (0.011)	-0.111 (0.010)
Morro Bay Area Ports (MRA)	-0.009 (0.009)	-0.009 (0.009)	
All California Ports	-0.010 (0.011)	-0.010 (0.011)	-0.034 (0.012)
Washington Coastal Ports (CWA)	0.059 (0.013)	0.059 (0.013)	
North Puget Sound Ports (NPS)	-0.069 (0.021)	-0.069 (0.021)	
South Puget Sound Ports (SPS)	-0.013 (0.005)	-0.013 (0.005)	
All Washington Ports	-0.044 (0.018)	-0.044 (0.018)	

Table 5: Full Season Small Vessel Proportion Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to the total catch in the specified port or state for the entire season within each port. The "Difference" is the difference between the mean for the 2010-2015 seasons and the 2015-17 combined seasons, 2015-16 season, and the 2016-17 season. Coloring indicates if the difference is statistically significant based on a two-sample t-test, a rank-sum test, and a bootstrap resampled t-test and the direction of the sign of the difference (Green indicates an increase in the metric; Red indicates a decrease in the metric).

	Difference (2015-17)	Difference (2015-16)	Difference (2016-17)
Crescent City Area Ports (CCA)	-0.004 (0.010)	0.059 (0.009)	-0.106 (0.009)
Eureka Area Ports (ERA)	0.065 (0.009)	0.051 (0.009)	0.087 (0.011)
Fort Bragg Area Ports (BGA)	0.038 (0.010)	0.038 (0.010)	
Bodega Bay Area Ports (BDA)	0.023 (0.007)	0.001 (0.005)	0.046 (0.009)
San Francisco Area Ports (SFA)	0.047 (0.008)	0.086 (0.009)	0.004 (0.008)
Morro Bay Area Ports (MRA)	-0.016 (0.009)	-0.016 (0.009)	
All California Ports	0.026 (0.010)	0.034 (0.009)	0.011 (0.011)
Washington Coastal Ports (CWA)	-0.051 (0.007)	-0.051 (0.007)	
North Puget Sound Ports (NPS)	-0.068 (0.017)	-0.068 (0.017)	
South Puget Sound Ports (SPS)	-0.043 (0.004)	-0.043 (0.004)	
All Washington Ports	-0.062 (0.014)	-0.062 (0.014)	

Table 6: First Eight Weeks Small Vessel Proportion Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to the total catch in the specified port or state for the first eight weeks of the season within each port. The "Difference" is the difference between the mean for the 2010-2015 seasons and the 2015-17 combined seasons, 2015-16 season, and the 2016-17 season. Coloring indicates if the difference is statistically significant based on a two-sample t-test, a rank-sum test, and a bootstrap resampled t-test and the direction of the sign of the difference (Green indicates an increase in the metric; Red indicates a decrease in the metric).

	Difference (2015-17)	Difference (2015-16)	Difference (2016-17)
Crescent City Area Ports (CCA)	-0.016 (0.010)	0.082 (0.008)	-0.116 (0.010)
Eureka Area Ports (ERA)	0.101 (0.009)	0.095 (0.008)	0.108 (0.010)
Fort Bragg Area Ports (BGA)	0.045 (0.010)	0.045 (0.010)	
Bodega Bay Area Ports (BDA)	0.026 (0.008)	0.010 (0.005)	0.039 (0.010)
San Francisco Area Ports (SFA)	0.046 (0.007)	0.096 (0.008)	-0.003 (0.006)
Morro Bay Area Ports (MRA)	-0.006 (0.011)	-0.006 (0.011)	
All California Ports	0.035 (0.010)	0.059 (0.009)	0.000 (0.011)
Washington Coastal Ports (CWA)	-0.061 (0.008)	-0.061 (0.008)	
North Puget Sound Ports (NPS)	-0.141 (0.018)	-0.141 (0.018)	
All Washington Ports	-0.087 (0.014)	-0.087 (0.014)	

Table 7: First Five Weeks Small Vessel Proportion Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to the total catch in the specified port or state for the first five weeks of the season within each port. The "Difference" is the difference between the mean for the 2010-2015 seasons and the 2015-17 combined seasons, 2015-16 season, and the 2016-17 season. Coloring indicates if the difference is statistically significant based on a two-sample t-test, a rank-sum test, and a bootstrap resampled t-test and the direction of the sign of the difference (Green indicates an increase in the metric; Red indicates a decrease in the metric).

Analyzing the first eight weeks of the seasons from all ports for both metrics reveals slightly different results. Crescent City has a statistically significant decrease in catch ratio in the 2016-17 season according to the t-test (Table 3). Eureka has a statistically significant increase from the rank sum test in catch ratio in the combined 2015-17 seasons. San Francisco has a statistically significant increase indicated by the rank sum test in catch ratio in the 2015-16 season, which is also statistically significant for the small vessel proportion according to the t-test and rank sum test (Table 6). It is also noteworthy that the combined California ports saw a statistically significant increase in the catch ratio in the first eight weeks according to the rank sum test and a statistically significant increase in both metrics in the first eight weeks for 2015-16 season through the rank sum test.

	2015-17	2015-17	2015-16	2015-16	2016-17	2016-17
Constant	1.326 (0.196)***	1.506 (0.611)**	1.304 (0.206)***	1.531 (0.640)**	1.420 (0.214)***	1.677 (0.656)**
Treatment*Post	0.123 (0.148)	0.111 (0.164)	0.150 (0.175)	0.106 (0.198)	0.077 (0.233)	0.129 (0.252)
Wind Speed		-0.023 (0.035)		-0.028 (0.036)		-0.038 (0.039)
Wave Height		-0.046 (0.114)		-0.049 (0.123)		0.032 (0.127)
Water Temperature		0.001 (0.041)		-0.001 (0.043)		-0.013 (0.044)
BGA	0.075 (0.204)	0.133 (0.218)	0.080 (0.208)	0.146 (0.224)	0.046 (0.230)	0.072 (0.247)
CCA	-0.590 (0.146)***	-0.567 (0.175)***	-0.573 (0.153)***	-0.550 (0.185)***	-0.670 (0.157)***	-0.680 (0.193)***
ERA	0.206 (0.171)	0.301 (0.195)	0.166 (0.179)	0.262 (0.206)	0.164 (0.184)	0.243 (0.215)
MRA	-0.739 (0.171)***	-0.651 (0.224)***	-0.731 (0.175)***	-0.634 (0.231)***	-0.790 (0.191)***	-0.638 (0.274)**
SFA	0.225 (0.135)*	0.220 (0.149)	0.268 (0.141)*	0.271 (0.157)*	0.153 (0.144)	0.155 (0.162)
BGA (After)	0.069 (0.542)	-0.017 (0.572)	0.240 (0.621)	0.177 (0.655)		
CCA (After)	0.160 (0.426)	0.119 (0.451)	0.491 (0.563)	0.458 (0.596)	-0.223 (0.627)	-0.260 (0.666)
ERA (After)	0.385 (0.463)	0.271 (0.493)	0.356 (0.609)	0.228 (0.648)	0.507 (0.675)	0.399 (0.716)
MRA (After)	0.162 (0.505)	0.013 (0.224)	0.338 (0.587)	0.207 (0.637)		
SFA (After)	-0.376 (0.408)	-0.414 (0.431)	-0.034 (0.559)	-0.057 (0.590)	-0.700 (0.575)	-0.726 (0.609)

Table 8 Regression for Catch Ratio: Coefficients and standard deviations for difference-in-differences linear regression model of the catch ratio (catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet)) for the first 8 weeks of the season. The treatment group contains the first eight weeks of the two seasons following the 2015 HAB. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

	2015-17	2015-17	2015-16	2015-16	2016-17	2016-17
Constant	0.552 (0.026)***	0.588 (0.080)***	0.558 (0.027)***	0.566 (0.082)***	0.566 (0.028)***	0.609 (0.084)***
Treatment*Post	0.034 (0.020)*	0.030 (0.021)	0.051 (0.023)**	0.042 (0.025)*	0.002 (0.030)	0.016 (0.032)
Wind Speed		-0.007 (0.005)		-0.009 (0.005)*		-0.009 (0.005)*
Wave Height		-0.015 (0.015)		-0.008 (0.016)		-0.0004 (0.016)
Water Temperature		0.002 (0.005)		0.004 (0.006)		-0.0002 (0.006)
BGA	-0.034 (0.027)	-0.026 (0.028)	-0.037 (0.027)	-0.026 (0.029)	-0.048 (0.030)	-0.044 (0.031)
CCA	-0.168 (0.020)***	-0.163 (0.023) ***	-0.163 (0.020)***	-0.154 (0.024)***	-0.186 (0.021)***	-0.188 (0.025)***
ERA	0.007 (0.023)	0.020 (0.025)	0.001 (0.024)	0.014 (0.026)	-0.003 (0.024)	0.006 (0.027)
MRA	-0.202 (0.023)***	-0.185 (0.029)***	-0.203 (0.023)***	-0.187 (0.030)***	-0.209 (0.025)***	-0.169 (0.035)***
SFA	-0.013 (0.018)	-0.029 (0.019)	-0.008 (0.018)	-0.024 (0.020)	-0.025 (0.019)	-0.040 (0.021)*
BGA (After)	0.083 (0.072)	0.067 (0.075)	0.103 (0.081)	0.096 (0.084)		
CCA (After)	0.040 (0.057)	0.030 (0.059)	0.124 (0.074)*	0.119 (0.076)	-0.073 (0.082)	-0.084 (0.085)
ERA (After)	0.081 (0.062)	0.063 (0.064)	0.087 (0.080)	0.067 (0.083)	0.079 (0.088)	0.068 (0.091)
MRA (After)	0.027 (0.067)	-0.016 (0.072)	0.048 (0.077)	0.009 (0.081)		
SFA (After)	-0.018 (0.054)	-0.010 (0.056)	0.041 (0.073)	0.051 (0.075)	-0.078 (0.075)	-0.070 (0.078)

Table 9 Regression for Small Vessel Proportion: Coefficients and standard deviations for difference-in-differences linear regression model of the catch ratio (catch by small vessels (less than 45 feet) to total catch) for the first 8 weeks of the season. The treatment group contains the first eight weeks of the two seasons following the 2015 HAB. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

Again, taking the first five weeks of the season for analysis results in slightly different findings. Crescent City has a statistically significant increase in catch ratio in the 2015-16 season according to the rank sum test (Table 4), which is also the case for the small vessel proportion with the addition of statistical significance from the bootstrap resampling t-test (Table 7). However, Crescent City has a statistically significant decrease in catch ratio in the 2016-17 season according to the t-tests. Eureka has a statistically significant increase from the rank sum test in catch ratio in the combined 2015-17 seasons, which is also statistically significant for the small vessel proportion for the rank sum test and the bootstrap resampling t-test. Additionally, Eureka has a statistically significant increase through the rank sum test in the small vessel proportion in the 2016-17 season. Overall, the combined California ports showed a statistically significant increase in both metrics for the combined seasons of interest and for the 2015-16 season through the rank sum test, with additional statistical significance for the small vessel proportion in the 2015-16 season through the bootstrap resampling t-test.

As seen in Figure 4, Crescent City, Eureka, Bodega Bay, and San Francisco ports have the most consistent reporting of catch throughout the season. Generally, the catch ratio reported in California ports is reported between 0.5 and 1, with a large fraction of the remaining ratios between 1 and 2. An even smaller portion of the reported ratios are larger than 2. This trend remains true with the mean of the ratios of all of the California ports for before and after the change in management decisions. Figure 5 mirrors those trends in each port, but is bound by zero and one for the small vessel proportion.

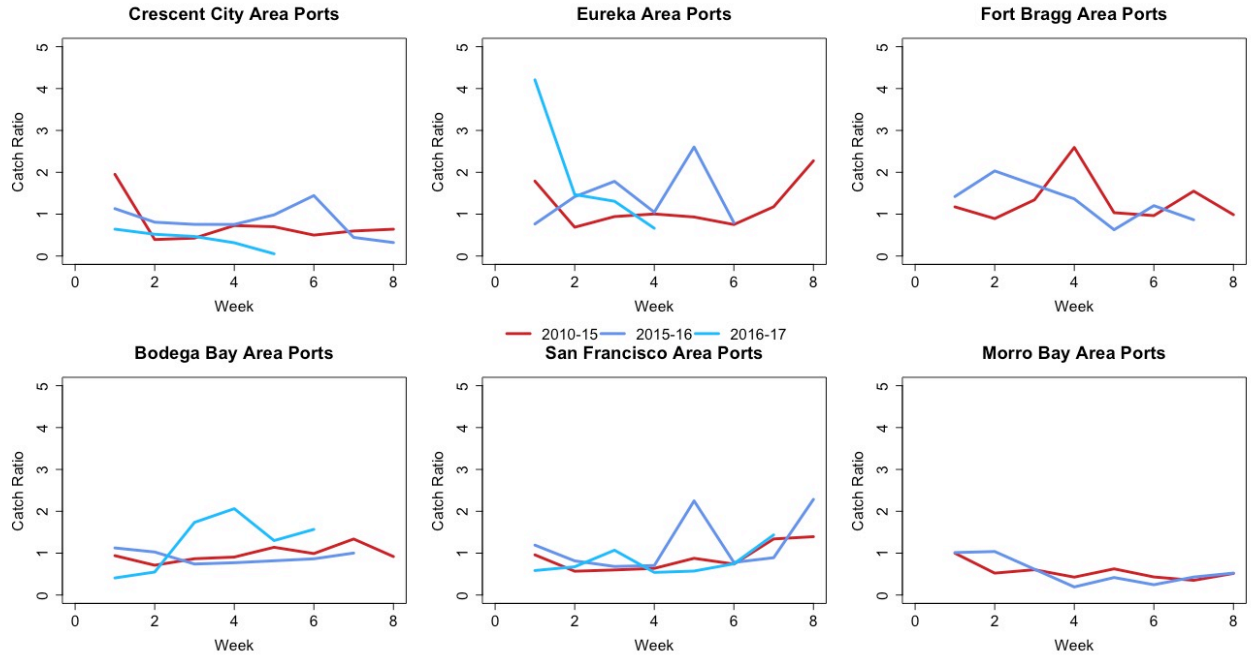

Figure 4: The ratio of the catch by small vessels (< 45 feet) to large vessels (≥ 45 feet)in the specific week of the season. Week one of each season was assigned to the first week the port was open, regardless of when the season started each year. The historical total average catch each week from fall 2010 to spring 2015 indicated in red. The two seasons after the 2015 HAB are in two different shades of blue. The 2015-16 season is indicated in periwinkle and the 2016-17 season is indicated in neon blue.

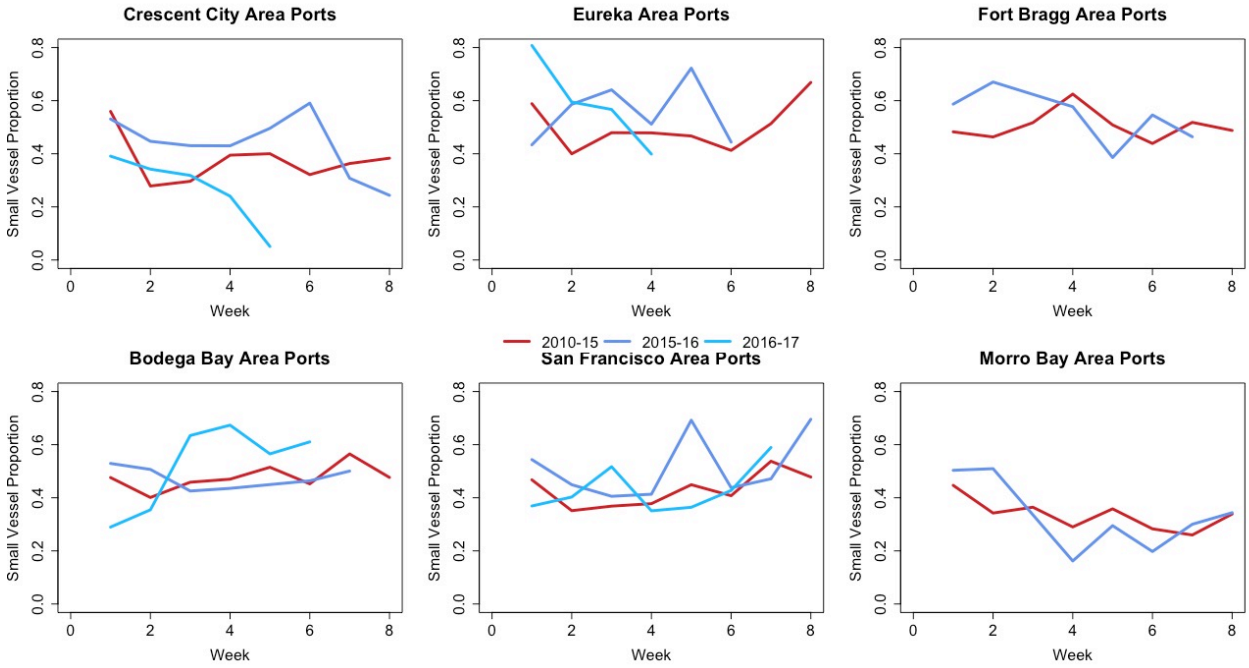

Figure 5: The ratio of the catch by small vessels (< 45 feet) to total catch in the specific week of the season. Week one of each season was assigned to the first week the port was open, regardless of when the season started each year. The historical total average catch each week from fall 2010 to spring 2015 indicated in red. The two seasons after the 2015 HAB are in two different shades of blue. The 2015-16 season is indicated in periwinkle and the 2016-17 season is indicated in neon blue.

Over the entire season, ports in the Crescent City area showed about a 0.2 decrease in the catch ratio, while the ports in the Eureka area saw about a 0.6 increase in the catch ratio. The ports in the areas of San Francisco and Bodega Bay reported about a 0.16 increase in catch ratio and the Fort Bragg port group observed almost no change at less than a 0.01 change. Overall, California showed about a 0.15 increase in catch ratio, while Washington ports showed about a 1.94 decrease. The t-test result confirms that there is not a statistically significant change in catch ratio as seen in the graph in Figure 5.

The difference-in-differences regression of the California ports for both metrics follow the trends established by the previous analysis (Table 8 and 9). With the use of the small vessel catch proportion, the difference-in-differences coefficient is statistically significantly positive for both the combined seasons and the 2015-16 season.

Discussion

I find that there is no significant difference in the catch ratio between the five harvest seasons from fall 2010 to spring 2015 and the two seasons after the start of the HAB, 2015-16 and 2016-17. This is contrary to how some fishermen felt during these seasons, which demands a look at the analysis in greater detail. When examining the data by port group within California, it is most likely the small vessel fishermen around the Crescent City area felt the most negatively affected as shown through this analysis. Further, small vessel fishermen at other ports, such as those around Eureka, Bodega Bay, and San Francisco, benefited from the staggered starts throughout the state the most. The difference-in-difference estimate shows that the altered opening for the season actually

benefitted the smaller vessels in California. However, this advantage was not statistically significant.

There are also no ports that show a statistically significant difference in the catch ratio between the five harvest seasons from fall 2010 to spring 2015 and the first season after the start of the HAB, 2015-16. In fact, all ports in California report an increase in the catch ratio at all ports. However, ports in the Fort Bragg and Bodega Bay areas had a very small increase and much smaller when compared to the other ports. It is possible that these ports were affected differently due to the fact that those fishermen were limited in their ability to travel north, but fishermen in San Francisco were able to travel more freely. San Francisco ports catch ratio improved for the small vessel fishermen. Fishermen near San Francisco could have had an easier time harvesting crab as well as being able to travel north and south from their port of origin.

Overall, in the difference-in-difference analyses, there is not a statistically significant difference between the before and after catch ratios or between states. Additionally, California appears to have a positive change in catch ratio indicating that the result of the change in opening times for the commercial Dungeness crab fishery was actually beneficial as opposed to deleterious to fishermen on small vessels. This is supported by the findings of the difference-in-differences regressions. However, with the difference-in-differences regression for the small vessel catch proportion, the coefficient is statistically significantly positive indicating that small vessels in California were positively affected.

With the new fair start provisions and the fact that California ports generally benefited from the staggered starts due to high levels of DA found in tested crab, small

vessel fishermen would benefit the most from continued staggered starts. However, the question remains that if the staggered starts allow the small vessels to harvest a greater ratio of the catch, would that remain the case if the staggered starts became more predictable.

Conclusion

There is no definitive conclusion as to how exactly management decisions affected the catch ratio of vessel size. There is a large discrepancy in the catch ratio of small vessel to large vessel catch between seasons before the 2015 HAB event and seasons after the HAB event. However, the direction and magnitude appears to depend more on the port location than the state as a whole. This aligns with our understanding that vessels of different sizes will depend on the proximity of open areas, particularly small vessels. Although I found a statistically significant difference in one port group for the 2015-16 season, further exploration is suggested. Upon analysis of both 2015-16 and 16-17 together and 2015-16 individually with the five seasons before the HAB event, the difference-in-differences analysis revealed no statistically significant difference between before and after the HAB event between the states. This indicates that the change in openings for the commercial Dungeness crab harvest in California did not create a statistically significant change in catch ratio compared to Washington.

Further research on this topic could illuminate a better understanding of effects on staggered starts on catch ratios and how it might effect fishermen associated with different size vessels. Greater understanding of these effects will only improve and lead to better decision making with time as ocean waters warm and HABs become more

frequent. Continued research of these issues will lead to better understanding of the effects of management decisions in the face of environmental challenges.

Acknowledgments

I thank Sunny Jardine for supporting me and giving me the opportunity to learn about these powerful statistical analyses. She had endless patience when I ran into challenges and gave critical insights throughout this process. I thank Chris Anderson for agreeing to be part of my committee and pushing me for further illustrative analyses. Finally, I want to thank my family who has supported me in a multitude of ways throughout this degree. I could not have completed this thesis without any of you.

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Appendix

	Before (2010-15)	After (2015-17)	Difference	After (2015-16)	Difference	After (2016-17)	Difference
Crescent City Area Ports (CCA)	0.756 (0.165)	0.765 (0.104)	0.009 (0.044) *0.948, 0.418* *0.949*	0.948 (0.098)	0.192 (0.044) *0.236, 0.037*** *0.233*	0.399 (0.051)	-0.356 (0.039) *0.018**, 0.125* *0.038***
Eureka Area Ports (ERA)	1.42 (0.213)	1.60 (0.247)	0.185 (0.075) *0.619, 0.561* *0.622*	1.40 (0.161)	-0.018 (0.061) *0.955, 0.839* *0.951*	1.91 (0.360)	0.491 (0.096) *0.578, 0.486* *0.546*
Fort Bragg Area Ports (BGA)	1.09 (0.217)	1.15 (0.118)	0.052 (0.056) *0.839,0.358* *0.839*	1.15 (0.118)	0.052 (0.056) *0.839, 0.358* *0.839*		
Bodega Bay Area Ports (BDA)	1.30 (0.167)	1.07 (0.100)	-0.232 (0.044) *0.098*, 0.365* *0.098**	0.942 (0.028)	-0.363 (0.038) *0.000***, 0.168* *0.000****	1.27 (0.152)	-0.035 (0.051) *0.903, 0.834* *0.893*
San Francisco Area Ports (SFA)	1.68 (0.362)	1.45 (0.317)	-0.221 (0.110) *0.526, 0.598* *0.549*	1.84 (0.372)	0.161 (0.119) *0.746, 0.578* *0.748*	0.803 (0.076)	-0.87 (0.085) *0.000***, 0.099** *0.000****
Morro Bay Area Ports (MRA)	0.581 (0.076)	0.559 (0.071)	-0.022 (0.023) *0.837, 0.949* *0.836*	0.559 (0.071)	-0.022 (0.077) *0.838, 0.949* *0.830*		
All California Ports	1.24 (0.262)	1.11 (0.208)	-0.130 (0.076) *0.263, 0.830* *0.271*	1.14 (0.213)	-0.102 (0.077) *0.454, 0.851* *0.474*	1.04 (0.201)	-0.202 (0.075) *0.310, 0.464* *0.332*
Washington Coastal Ports (CWA)	0.594 (0.114)	0.903 (0.217)	0.308 (0.056) *0.067*, 0.131* *0.089**	0.903 (0.217)	0.308 (0.056) *0.067*, 0.131* *0.094**		
North Puget Sound Ports (NPS)	8.14 (2.87)	3.89 (1.71)	-4.24 (0.768) *0.089*, 0.395* *0.112*	3.89 (1.71)	-4.24 (0.768) *0.089*, 0.395* *0.111*		
South Puget Sound Ports (SPS)	0.459 (0.023)	0.442 (0.038)	-0.016 (0.010) *0.812, 0.528* *0.808*	0.442 (0.038)	-0.016 (0.010) *0.813, 0.528* *0.809*		
All Washington Ports	4.12 (2.14)	1.55 (0.889)	-2.56 (0.532) *0.000***, 0.537* *0.000****	1.55 (0.889)	-2.56 (0.532) *0.000***, 0.537* *0.000****		

Table A1: Full Season Catch Ratio Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet) for the entire season within each port. The "After" period contains data reported after during the 2015-16 and 2016-17 seasons or one of those season individually as indicated. A two-sample t-test, a rank-sum test, and a bootstrap resampled t-test were conducted on the two categories of data to determine whether they are statistically significantly different. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

	Before (2010-15)	After (2015-17)	Difference	After (2015-16)	Difference	After (2016-17)	Difference
Crescent City Area Ports (CCA)	0.751 (0.206)	0.664 (0.018)	-0.086 (0.051) *0.635, 0.685* *0.657*	0.830 (0.082)	0.079 (0.051) *0.688, 0.106* *0.706*	0.399 (0.051)	-0.351 (0.048) *0.060*, 0.206* *0.127*
Eureka Area Ports (ERA)	1.21 (0.192)	1.60 (0.065)	0.386 (0.072) *0.322, 0.042*** *0.340*	1.40 (0.125)	0.182 (0.057) *0.591, 0.427* *0.582*	1.91 (0.360)	0.692 (0.093) *0.446, 0.185* *0.475*
Fort Bragg Area Ports (BGA)	1.29 (0.236)	1.25 (0.033)	-0.041 (0.060) *0.897, 0.598* *0.896*	1.36 (0.111)	-0.041 (0.060) *0.897, 0.580* *0.899*		
Bodega Bay Area Ports (BDA)	0.972 (0.087)	1.09 (0.032)	0.123 (0.032) *0.442, 0.564* *0.441*	0.921 (0.035)	-0.050 (0.021) *0.579, 0.810* *0.573*	1.27 (0.152)	0.297 (0.040) *0.328, 0.255* *0.311*
San Francisco Area Ports (SFA)	0.873 (0.145)	1.01 (0.028)	0.141 (0.044) *0.439, 0.209* *0.442*	1.19 (0.155)	0.325 (0.048) *0.241, 0.091** *0.2233*	0.803 (0.076)	-0.070 (0.037) *0.673, 0.687* *0.680*
Morro Bay Area Ports (MRA)	0.603 (0.093)	0.552 (0.078)	-0.051 (0.028) *0.750, 0.956* *0.746*	0.552 (0.078)	-0.051 (0.028) *0.750, 0.956* *0.751*		
All California Ports	0.937 (0.172)	1.02 (0.043)	0.086 (0.053) *0.401, 0.074** *0.410*	1.01 (0.125)	0.076 (0.048) *0.457, 0.085** *0.459*	1.04 (0.201)	0.103 (0.060) *0.602, 0.577* *0.612*
Washington Coastal Ports (CWA)	0.368 (0.087)	0.234 (0.007)	-0.134 (0.020) *0.080*, 0.446* *0.117*	0.234 (0.022)	-0.134 (0.020) *0.080*, 0.486* *0.120*		
North Puget Sound Ports (NPS)	3.58 (2.52)	0.688 (0.018)	-2.89 (0.578) *0.161, 0.484* *0.350*	0.688 (0.121)	-2.89 (0.578) *0.161, 0.581* *0.346*		
South Puget Sound Ports (SPS)	0.439 (0.025)	0.362 (0.030)	-0.076 (0.008) *0.499, 0.8* *0.537*	0.362 (0.030)	-0.076 (0.008) *0.499, 0.428* *0.890*		
All Washington Ports	1.85 (1.73)	0.422 (0.083)	-1.43 (0.399) *0.133, 0.630* *0.325*	0.422 (0.083)	-1.43 (0.399) *0.133, 0.786* *0.330*		

Table A2: First Eight Weeks Catch Ratio Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet) for the first 8 weeks of the season within each port. The "After" period contains data reported after during the 2015-16 and 2016-17 seasons or one of those season individually as indicated. A two-sample t-test, a rank-sum test, and a bootstrap resampled t-test were conducted on the two categories of data to determine whether they are statistically significantly different. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

	Before (2010-15)	After (2015-17)	Difference	After (2015-16)	Difference	After (2016-17)	Difference
Crescent City Area Ports (CCA)	0.852 (0.258)	0.643 (0.072)	-0.209 (0.061) *0.420, 0.685* *0.471*	0.886 (0.038)	0.034 (0.060) *0.890, 0.061** *0.893*	0.399 (0.051)	-0.452 (0.060) *0.089*, 0.238* *0.212*
Eureka Area Ports (ERA)	1.07 (0.170)	1.69 (0.253)	0.617 (0.070) *0.155, 0.042*** *0.181*	1.52 (0.164)	0.444 (0.054) *0.262, 0.120* *0.268*	1.91 (0.360)	0.833 (0.091) *0.369, 0.042* *0.431*
Fort Bragg Area Ports (BGA)	1.35 (0.261)	1.36 (0.131)	0.004 (0.067) *0.991, 0.598* *0.991*	1.36 (0.131)	0.004 (0.067) *0.991, 0.598* *0.991*		
Bodega Bay Area Ports (BDA)	0.913 (0.071)	1.07 (0.125)	0.166 (0.033) *0.409, 0.564* *0.397*	0.916 (0.043)	0.002 (0.019) *0.983, 0.974* *0.983*	1.21 (0.165)	0.297 (0.041) *0.414, 0.447* *0.396*
San Francisco Area Ports (SFA)	0.732 (0.076)	0.908 (0.118)	0.176 (0.032) *0.339, 0.209* *0.373*	1.12 (0.151)	0.396 (0.038) *0.253, 0.101* *0.337*	0.688 (0.050)	-0.043 (0.021) *0.724, 0.801* *0.733*
Morro Bay Area Ports (MRA)	0.689 (0.107)	0.666 (0.097)	-0.023 (0.033) *0.929, 0.956* *0.926*	0.666 (0.097)	-0.023 (0.033) *0.929, 0.956* *0.924*		
All California Ports	0.911 (0.172)	1.05 (0.166)	0.145 (0.054) *0.258, 0.074** *0.267*	1.09 (0.125)	0.179 (0.048) *0.161, 0.014*** *0.168*	1.00 (0.214)	0.064 (0.063) *0.674, 0.959* *0.687*
Washington Coastal Ports (CWA)	0.370 (0.099)	0.216 (0.027)	-0.153 (0.023) *0.190, 0.446* *0.264*	0.216 (0.027)	-0.153 (0.023) *0.190, 0.446* *0.272*		
North Puget Sound Ports (NPS)	4.41 (3.15)	0.444 (0.074)	-3.96 (0.724) *0.238, 0.484* *0.407*	0.444 (0.074)	-3.96 (0.724) *0.238, 0.484* *0.414*		
All Washington Ports	2.28 (2.19)	0.340 (0.050)	-1.94 (0.502) *0.217, 0.630* *0.385*	0.340 (0.050)	-1.94 (0.502) *0.217, 0.630* *0.387*		

Table A3: First Five Weeks Catch Ratio Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to large vessels (equal to or larger than 45 feet) for the first 5 weeks of the season within each port. The "After" period contains data reported after during the 2015-16 and 2016-17 seasons or one of those season individually as indicated. A two-sample t-test, a rank-sum test, and a bootstrap resampled t-test were conducted on the two categories of data to determine whether they are statistically significantly different. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

	Before (2010-15)	**After (2015-17)**	**Difference**	**After (2015-16)**	**Difference**	**After (2016-17)**	**Difference**
Crescent City Area Ports (CCA)	0.385 (0.030)	0.398 (0.035)	0.013 (0.010) *0.756, 0.418* *0.755*	0.463 (0.027)	0.078 (0.010) *0.756, 0.418* *0.083**	0.268 (0.030)	-0.116 (0.009) *0.121, 0.125* *0.181*
Eureka Area Ports (ERA)	0.539 (0.031)	0.570 (0.029)	0.031 (0.009) *0.502, 0.561* *0.501*	0.556 (0.026)	0.016 (0.009) *0.502, 0.561* *0.746*	0.592 (0.038)	0.052 (0.011) *0.580, 0.486* *0.578*
Fort Bragg Area Ports (BGA)	0.451 (0.041)	0.512 (0.026)	0.060 (0.011) *0.277, 0.358* *0.274*	0.512 (0.026)	0.060 (0.011) *0.277, 0.358* *0.269*		
Bodega Bay Area Ports (BDA)	0.529 (0.028)	0.498 (0.023)	-0.030 (0.008) *0.299, 0.365* *0.298*	0.483 (0.007)	-0.030 (0.008) *0.299, 0.365* *0.009***	0.521 (0.036)	-0.008 (0.010) *0.908, 0.834* *0.890*
San Francisco Area Ports (SFA)	0.543 (0.039)	0.523 (0.033)	-0.019 (0.011) *0.600, 0.598* *0.599*	0.577 (0.034)	-0.019 (0.011) *0.600, 0.598* *0.459*	0.431 (0.020)	-0.111 (0.010) *0.015**, 0.099** *0.042***
Morro Bay Area Ports (MRA)	0.344 (0.027)	0.334 (0.030)	-0.009 (0.009) *0.836, 0.949* *0.827*	0.334 (0.030)	-0.009 (0.009) *0.836, 0.949* *0.830*		
All California Ports	0.483 (0.037)	0.472 (0.034)	-0.010 (0.011) *0.572, 0.830* *0.577*	0.482 (0.032)	-0.010 (0.011) *0.572, 0.830* *0.963*	0.448 (0.039)	-0.034 (0.012) *0.355, 0.464* *0.354*
Washington Coastal Ports (CWA)	0.329 (0.034)	0.388 (0.045)	0.059 (0.013) *0.097*, 0.131* *0.103*	0.388 (0.045)	0.059 (0.013) *0.097*, 0.131* *0.096**		
North Puget Sound Ports (NPS)	0.592 (0.072)	0.522 (0.062)	-0.069 (0.021) *0.395, 0.395* *0.389*	0.522 (0.062)	-0.069 (0.021) *0.395, 0.395* *0.386*		
South Puget Sound Ports (SPS)	0.311 (0.011)	0.298 (0.019)	-0.013 (0.005) *0.700, 0.528* *0.699*	0.298 (0.019)	-0.013 (0.005) *0.700, 0.528* *0.694*		
All Washington Ports	0.452 (0.063)	0.407 (0.049)	-0.044 (0.018) *0.160, 0.537* *0.156*	0.407 (0.049)	-0.044 (0.018) *0.160, 0.537* *0.152*		

Table A4: Full Season Small Vessel Proportion Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to the total catch in the specified port or state for the entire season within each port. The "After" period contains data reported after during the 2015-16 and 2016-17 seasons or one of those season individually as indicated. A two-sample t-test, a rank-sum test, and a bootstrap resampled t-test were conducted on the two categories of data to determine whether they are statistically significantly different. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

	Before (2010-15)	After (2015-17)	Difference	After (2015-16)	Difference	After (2016-17)	Difference
Crescent City Area Ports (CCA)	0.374 (0.029)	0.370 (0.032)	-0.004 (0.010) *0.929, 0.576* *0.928*	0.434 (0.026)	0.059 (0.009) *0.213, 0.106* *0.215*	0.268 (0.030)	-0.106 (0.009) *0.153, 0.206* *0.201*
Eureka Area Ports (ERA)	0.504 (0.030)	0. 570 (0.029)	0.065 (0.009) *0.189, 0.187* *0.184*	0.554 (0.026)	0.051 (0.009) *0.356, 0.427* *0.349*	0.592 (0.038)	0.087 (0.011) *0.382, 0.185* *0.395*
Fort Bragg Area Ports (BGA)	0.500 (0.037)	0.538 (0.022)	0.038 (0.010) *0.507, 0.316* *0.506*	0.538 (0.022)	0.038 (0.010) *0.507, 0.580* *0.499*		
Bodega Bay Area Ports (BDA)	0.475 (0.022)	0.499 (0.026)	0.023 (0.007) *0.525, 0.486* *0.518*	0.476 (0.009)	0.001 (0.005) *0.944, 0.810* *0.946*	0.521 (0.036)	0.046 (0.009) *0.520, 0.255* *0.495*
San Francisco Area Ports (SFA)	0.427 (0.029)	0.475 (0.025)	0.047 (0.008) *0.190, 0.752* *0.191*	0.513 (0.027)	0.086 (0.009) *0.095*, 0.091** *0.104*	0.431 (0.020)	0.004 (0.008) *0.920, 0.687* *0.916*
Morro Bay Area Ports (MRA)	0.346 (0.029)	0.330 (0.031)	-0.016 (0.009) *0.786, 0.784* *0.783*	0.330 (0.031)	-0.016 (0.009) *0.786, 0.956* *0.780*		
All California Ports	0.436 (0.031)	0.463 (0.032)	0.026 (0.010) *0.206, 0.354* *0.212*	0.471 (0.029)	0.034 (0.009) *0.130, 0.085** *0.128*	0.448 (0.039)	0.011 (0.011) *0.764, 0.577* *0.761*
Washington Coastal Ports (CWA)	0.236 (0.029)	0.184 (0.015)	-0.051 (0.007) *0.132, 0.330* *0.136*	0.184 (0.015)	-0.051 (0.007) *0.132, 0.486* *0.139*		
North Puget Sound Ports (NPS)	0.433 (0.065)	0.364 (0.038)	-0.068 (0.017) *0.419, 0.837* *0.412*	0.364 (0.038)	-0.068 (0.017) *0.419, 0.581* *0.420*		
South Puget Sound Ports (SPS)	0.303 (0.012)	0.260 (0.017)	-0.043 (0.004) *0.451, 0.4* *0.742*	0.260 (0.017)	-0.043 (0.004) *0.451, 0.428* *0.408*		
All Washington Ports	0.329 (0.054)	0.266 (0.030)	-0.062 (0.014) *0.131, 0.806* *0.128*	0.266 (0.030)	-0.062 (0.014) *0.131, 0.786* *0.136*		

Table A5: First Eight Weeks Small Vessel Proportion Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to the total catch in the specified port or state for the first 8 weeks of the season within each port. The "After" period contains data reported after during the 2015-16 and 2016-17 seasons or one of those season individually as indicated. A two-sample t-test, a rank-sum test, and a bootstrap resampled t-test were conducted on the two categories of data to determine whether they are statistically significantly different. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.

	Before (2010-15)	After (2015-17)	Difference	After (2015-16)	Difference	After (2016-17)	Difference
Crescent City Area Ports (CCA)	0.384 (0.034)	0.367 (0.032)	-0.016 (0.010) *0.420, 0.685* *0.756*	0.466 (0.010)	0.082 (0.008) *0.890, 0.061** *0.040***	0.268 (0.030)	-0.116 (0.010) *0.132, 0.238* *0.161*
Eureka Area Ports (ERA)	0.483 (0.026)	0. 584 (0.029)	0.101 (0.009) *0.155, 0.042*** *0.070**	0.578 (0.025)	0.095 (0.008) *0.262, 0.120* *0.138*	0.592 (0.038)	0.108 (0.010) *0.291, 0.042*** *0.304*
Fort Bragg Area Ports (BGA)	0.509 (0.037)	0.555 (0.027)	0.045 (0.010) *0.991, 0.598* *0.567*	0.555 (0.027)	0.045 (0.010) *0.991, 0.598* *0.562*		
Bodega Bay Area Ports (BDA)	0.463 (0.020)	0.490 (0.028)	0.026 (0.008) *0.509, 0.564* *0.384*	0.474 (0.011)	0.010 (0.005) *0.983, 0.974* *0.127*	0.503 (0.039)	0.039 (0.010) *0.639, 0.447* *0.720*
San Francisco Area Ports (SFA)	0.403 (0.023)	0.450 (0.024)	0.046 (0.007) *0.339, 0.209* *0.259*	0.500 (0.027)	0.096 (0.008) *0.253, 0.101* *0.185*	0.400 (0.015)	-0.003 (0.006) *0.933, 0.801* *0.928*
Morro Bay Area Ports (MRA)	0.374 (0.031)	0.367 (0.038)	-0.006 (0.011) *0.929, 0.956* *0.940*	0.367 (0.038)	-0.006 (0.011) *0.929, 0.956* *0.947*		
All California Ports	0.433 (0.029)	0.468 (0.033)	0.035 (0.010) *0.258, 0.074** *0.159*	0.493 (0.027)	0.059 (0.009) *0.161, 0.014*** *0.025***	0.433 (0.040)	0.000 (0.011) *0.998, 0.959* *0.998*
Washington Coastal Ports (CWA)	0.232 (0.030)	0.171 (0.018)	-0.061 (0.008) *0.190, 0.446* *0.226*	0.171 (0.018)	-0.061 (0.008) *0.190, 0.446* *0.220*		
North Puget Sound Ports (NPS)	0.423 (0.070)	0.282 (0.034)	-0.141 (0.018) *0.238, 0.484* *0.203*	0.282 (0.034)	-0.141 (0.018) *0.238, 0.484* *0.203*		
All Washington Ports	0.324 (0.056)	0.236 (0.026)	-0.087 (0.014) *0.217, 0.630* *0.095**	0.236 (0.026)	-0.087 (0.014) *0.217, 0.630* *0.096**		

Table A6: First Five Weeks Small Vessel Proportion Analysis Mean and standard error of the ratio of the catch by small vessels (less than 45 feet) to the total catch in the specified port or state for the first 5 weeks of the season within each port. The "After" period contains data reported after during the 2015-16 and 2016-17 seasons or one of those season individually as indicated. A two-sample t-test, a rank-sum test, and a bootstrap resampled t-test were conducted on the two categories of data to determine whether they are statistically significantly different. The p-values are denoted with one, two, or three asterisks for a significance of 0.1, 0.05, and 0.001 respectively.