Fishing participation choice during a climate shock:

A case study of the 2015/16 California Dungeness crab fishery delay

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Abstract

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Consistent with other individuals dependent on natural resources, fishers face high income variability, as shifts in fishing returns are driven by ecological and climatic shocks, management decisions, and market demand. To buffer these risks, fishers may diversify their fishing portfolios, i.e., the set of fisheries to which they have access. While diversification of access is difficult to measure, current literature suggests that, on average, diversification of participation is associated with decreased revenue variability. However, fishing portfolio diversification differs from financial portfolio diversification if harvesters respond to shocks by reallocating effort across their portfolio, i.e., if diversification in participation is endogenous to shocks to the economic returns from fisheries participation.

Here I examine the importance of endogenous fisheries participation choice using California Dungeness crab as a case study. Specifically, in the 2015/16 fishing season, a harmful algal bloom (HAB) delayed the fishery by over five months at some ports. In response to this shock, some vessels exited the crab fishery in pursuit of other fisheries. I explore both the role of past fishing participation diversity in the decision to exit the 2015/16 crab fishery using a logistic participation model, and the impact of the exit decision on seasonal fishing revenue using a counterfactual analysis.

Results indicate that past participation diversity is a statistically significant predictor of exit in response to the HAB, and that although all active vessels, on average, earned less during the 2015/16 season than previous seasons, vessels that exited the Dungeness crab fishery to participate in other fisheries in their portfolios actually had larger revenue losses than vessels that fished California Dungeness crab. In the face of more frequent climate shocks, these results bring nuance to our understanding of the benefits from diversified fishing portfolios.

I. Introduction

While coastal ecosystems are naturally subject to climatic and oceanographic variability (both cyclical and stochastic) (Francis et al., 1998; Hollowed et al., 2001), climate change and other anthropogenic impacts have amplified the variability in atmospheric and oceanographic conditions and are affecting coastal ecosystems (Doney et al., 2012; Salinger et al., 2005). Often termed natural disasters, unexpected and sudden changes in which the rate of change outpaces the ability to cope are termed "climate shocks" (Fuente, 2007). For individuals with incomes dependent on harvesting natural resources (e.g., fishers, farmers, foresters), variable climate conditions and climate shocks heighten the risk of these inherently dynamic livelihoods (Kasperski & Holland, 2013; Sethi et al., 2012). These individuals are additionally subject to shifts in management decisions and consumer preferences; they are subject to supply and demand variability, and subsequently face high income volatility (Key et al., 2017).

Across a spectrum of disciplines and contexts, diversification is widely accepted as a strategy for risk management and social-ecological resilience (Adger, 2000; Fisher et al., 2021). In agriculture, crop and farming diversification is an important strategy for achieving food security (Waha et al., 2018), both at the individual and industry level. In fisheries, fishery portfolio diversification buffers fishing communities from abrupt ecological regime changes (Kasperski & Holland, 2013), market changes (Cline et al., 2017), and declines in catch (Robinson et al., 2020), while decentralization of fishery resource dependence is important for reducing vulnerability to climate shocks (Fisher et al., 2021). In financial investing, diversified investment portfolios can reduce the risk of loss by insuring each asset by the remaining assets (Koumou, 2020). Generally, diversification buffers the inherent risk that both human-derived systems (e.g., stock market) and natural systems (e.g., climate, weather) hold.

Mechanisms for diversification, and thus the ease of diversification, vary across markets. In financial markets, portfolio diversification enables investors to neutralize individual stock volatility, following the "expected returns - variance of returns" rule (Markowitz, 1952), and either invest actively or passively through portfolio managers. Passive managers choose well-performing portfolios on a relatively uninformed basis while active portfolio managers, on the other hand, acquire detailed price information at a cost (i.e., price discovery) and try to "beat the market" (French, 2008; Garleanu & Pedersen, 2018). Diversification in financial portfolios, whether active or passive, is essentially a one-step process: buying multiple financial stocks or index funds (either uninformed or informed) and capitalizing on them simultaneously.

In fishery harvest contexts, however, fishers cannot easily capitalize on the various assets within their fishing portfolio simultaneously. Fishing diversification is always active and is a two (or more) step process with temporal boundaries. In the first step, one must gain access to the fishery, e.g., by buying a permit (if necessary) and proper gear, but initial access to the permit and gear purchase opportunity is often restricted by industry knowledge and resource management systems (i.e., limited entry regulations). The second step, *utilizing* a diversified fishery portfolio (i.e., spreading fishing effort across fisheries in one's portfolio, herein referred to as participation choice), requires not only the desire to capitalize on access to multiple fisheries, but fishery knowledge as well.

Despite the benefits of diversification for resilience and adaptive capacity across professions, specialization often persists among fishers. As of 2013, the U.S. West Coast and Alaskan vessel fleet was less diverse than at any point in the preceding three decades (S. C. Anderson et al., 2017; Kasperski & Holland, 2013). Limited entry regulations, which restrict the number of vessels within each fishery, have essentially forced fishers into specialization (Kasperski & Holland, 2013). While specializing may be associated with increased revenue variability, it is also associated with increased revenue (S. C. Anderson et al., 2017); gains from efficiency, through both fishery-specific knowledge and specialized vessels and gear, provide incentives for specialization (Cline et al., 2017; Kasperski & Holland, 2013). Complimentarily, disincentives to diversification include high barriers to access and highly valuable common species (Fisher et al., 2021).

Additionally, the degree of income risk benefit from diversification varies by amount of diversification. Kasperski and Holland (2013) note a "dome-shaped relationship between the variability of individuals' income and income diversification, which implies that a small amount of diversification does not reduce income risk but that higher levels of diversification can substantially reduce variability of income from fishing" (p. 2078). Fishers operating at a small level of portfolio diversity may see increased variability when diversifying fishery participation. For participation choice, i.e., choosing to fish one permit over another, fishing portfolios must be composed of permits with overlapping fishing seasons; the *degree* to which season overlap is present for U.S. West Coast vessels, however, is important but beyond the scope of this thesis.

In this thesis, I examine the relationship between portfolio diversity and fishery participation choices during a climate shock, and relative seasonal revenue outcomes, through a case study of the harmful algal bloom (HAB)-induced 2015/16 California Dungeness crab fishery delay. During this event, further described in *Section II, Background,* the California Dungeness crab fishery (a target fishery for many California fishers) was delayed up to five months in some ports (California Ocean Science Trust, 2016). Fisher et al. (2021) note three adaptive strategies used by fishing vessels during this climate shock to cope with the California Dungeness crab fishery closure: temporarily halting all fishing, shifting effort into other fisheries, and shifting fishing locations to target Dungeness crab in open areas. The latter two adaptive strategies are considered endogenous fishery participation choice in this thesis.

Helpful for understanding the decision to alter fishery participation during this climate shock is Coale's (1973) *readiness, willingness, and ability* (RWA) framework. First used to describe preconditions for shifting to a new behavior mode in a fertility transition context, the RWA framework has been applied widely to understand the impetus for behavior change (Lesthaeghe & Vanderhoeft, 2001; Williams & Gray, 2020). The three preconditions, *readiness, willingness, and ability,* can be applied to the adaptive strategies that involve shifting fishery participation as follows: *Readiness* refers to the cost-benefit analysis, whether mental or otherwise, that fishers perform; the new behavior must be advantageous for behavior to change (Lesthaeghe & Vanderhoeft, 2001). In deciding to fish different permits, fishers weigh the net benefit of shifting based on their knowledge of and experience in other fisheries, and the costs of switching, among other factors. Unfortunately, phenomena like the sunk-cost effect, an "unwillingness to abandon something if a great deal has been invested in it" (Janssen & Scheffer, 2004), and loss aversion

(C. Anderson et al., 2014) may cloud this cost-benefit analysis. *Willingness* refers to the acceptability of the new behavior, through the lens of codes of conduct and beliefs (Lesthaeghe & Vanderhoeft, 2001). If a fisher's family has fished Dungeness crab every year for multiple decades and usually participates in another fishery only after fishing Dungeness crab, family tradition may dictate that the fisher is not willing to participate in the alternate fishery *instead. Ability* refers to accessibility of any behavior-change enabling technology. In order to shift fishing participation, fishers need to have access to temporally-overlapping fisheries via proper gear, fishery permits, and vessel capability (Lesthaeghe & Vanderhoeft, 2001).

This thesis examines the decision to switch fisheries decisions during a climate shock-induced fishery delay. Specifically, using data surrounding the 2015/16 harmful algal bloom (HAB)-induced California Dungeness crab fishery delay, this thesis examines how past fishery participation diversity is correlated with fishery exit decision. This thesis then analyzes whether the decision to switch fisheries was a profitable decision or if, perversely, switching during a climate shock actually harmed individuals in this case.

II. Background

U.S. West Coast Commercial Dungeness Crab Fisheries

Unlike many other fisheries along the U.S. West Coast, which are managed at the federal level, the Dungeness crab fishery is managed by States and Tribes. Cumulatively, across the entire coastal network of U.S. West Coast fishing ports, the Dungeness crab fishery has the highest vessel participation and generates the most revenue of all fisheries (Fuller et al., 2017). The state and tribal Dungeness crab fisheries can be subdivided into further management schemes: with regard to season timing, the California ocean fishery is divided north and south of the Sonoma-Mendocino County border (California Department of Fish and Wildlife, 2020); in Oregon, commercial catches are divided between the Ocean & Columbia River fishery and the Bay fishery; and in Washington, the commercial fishery is co-managed with Tribes and is divided into the coastal fishery and the Puget Sound fishery. Because the Oregon Bay fishery and Washington Puget Sound fishery have different seasons and management regimes than the coastal/ocean Dungeness crab fisheries, they do not heavily overlap with the California Dungeness crab season. Therefore, they are not a viable participation choice and are not explicitly discussed here.

All three states manage their coastal/ocean Dungeness crab fisheries as a limited-entry derby, in which crab permits may only be renewed or transferred (California Department of Fish and Wildlife, 2020; Jardine et al., 2020; Richerson et al., 2020). Additionally, all states manage the fishery in a "3S" scheme, referring to size, sex, and season, and have tiered crab pot limits, implemented in 1999 (WA), 2006 (OR), and 2013 (CA), respectively (Richerson et al., 2020). This management structure results in an early pulse of landings, in which the majority of Dungeness crab is landed during the season's first six weeks (Dewees et al., 2004) and therefore coincides with revenue-important holidays (Thanksgiving, Christmas, New Year, and Lunar New Year).

California's Commercial Dungeness Crab Fishery

The California Dungeness crab Fishery is one of the largest revenue-producing fisheries on the United States West Coast. Between the 2011/12 and 2019/20 seasons, the California fishery had a yearly average ex-vessel value of $61.7 million dollars and annually supported between 407 and 467 vessels (California Department of Fish and Wildlife, 2020). The California Dungeness crab fishery is divided into two zones with two-week offset opening and closing dates: north of the Sonoma-Mendocino County border, the fishery is open from December 1 to July 15 (Districts 6,7,8, and 9); south of the Sonoma-Mendocino County border (all other districts), the fishery is open from November 15 to June 30 (California Department of Fish and Wildlife, 2020). Many California Dungeness crab fishers hold permits in other fisheries and in other states, allowing for a transition between fisheries and geographic areas. However, the benefits of moving between geographic regions following fishery delays are tempered by Fair Start Provisions; to provide equitable opportunity for vessels in delayed regions, Fair Start Provisions restrict fishery participation for vessels moving between regions by requiring that these vessels wait 30 days to fish after the previously closed region opens (Cal. Fish and Game Code FGC § 8279.1). Although fishery managers acknowledge that portfolio diversity is an important metric for understanding differential impacts of both regulations and climate shocks, CDFW does not collect fishing portfolio or participation diversity data (California Regulatory Notice Register, 2020).

Oregon, Washington, and Tribal Commercial Dungeness Crab Fisheries

Oregon's commercial Ocean & Columbia River fishery is open from December 1 to August 14, and is the most valuable single species commercial fishery in Oregon (Oregon Department of

Fish and Wildlife, 2019). While 424 permits are allowed in Oregon, an average of 315 permits fish for Dungeness crab each year (Oregon Department of Fish and Wildlife, 2019). In waters between the Oregon-Washington border and Point Chehalis, WA, Washington State Department of Fish and Wildlife (WDFW) manages the fishery, while between Point Chehalis and the U.S.-Canada border, the coastal Dungeness crab fishery is co-managed by Tribes and WDFW. Additionally, Tribal Usual & Accustomed (U&A) areas are restricted to tribal fishing fleets only. The co-managed coastal crab fishery is typically open from December 1 to September 15 (Washington Department of Fish and Wildlife, 2021a), and supports 228 state licenses. In 2019, the tribal fleet commercially harvested 4.2 millions pounds of crab, while the state fleet harvested about 10.5 millions pounds of crab (Northwest Indian Fisheries Commission, 2021; Washington Department of Fish and Wildlife, 2021b).

2015/16 HAB-Induced Dungeness Crab Fishery Delays

From 2014-2016, an unprecedented and lingering mass of warm water, later termed the 2014-2016 North Pacific marine heatwave or colloquially, "the blob", overwhelmed the U.S. West Coast (McCabe et al., 2016; Trainer et al., 2020). Paired with high levels of coastal nutrients, the blob created ideal conditions for a *Pseudo-nitzschia* bloom (McCabe et al., 2016; Trainer et al., 2020). *Pseudo-nitzschia* is a toxigenic diatom that produces the neurotoxin domoic acid (DA) under certain oceanographic conditions and is a concern to U.S. West Coast shellfish and Dungeness crab fisheries (McCabe et al., 2016; Trainer et al., 2020). As it progressively transfers up the food chain, DA can lead to Amnesic Shellfish Poisoning (ASP) in humans (California Ocean Science Trust, 2016; McCabe et al., 2016; Trainer et al., 2020).

Prior to opening the Dungeness crab fishery to harvest, state agencies regularly test Dungeness crab (*Cancer magister* or *Metacarcinus magister)* tissue and organs to ensure DA bioaccumulation below toxic levels, 20 ppm and 30 ppm, respectively (California Ocean Science Trust, 2016). In 2015, U.S. West Coast fishery managers repeatedly measured unsafe levels of DA in *C. magister* tissue and other shellfish. This DA event resulted in the longest lasting and most geographically widespread fishery closures of shellfish and crab on record (Moore et al., 2019). While the crab delays were less severe in Oregon and Washington (about a one-month delay during the 2015/16 season, from December 1, 2015 to January 4, 2016), the crab season delay in California lasted over five months in some ports. The CA fishery opened in a port-staggered fashion, the earliest ports opening on March 26, 2016 and the latest ports opening on May 26, 2016 (California Ocean Science Trust, 2016). Nearly two years later, this event was declared a federal fishery disaster for the California Dungeness and rock crab fishery and the Quileute Tribe Dungeness crab fishery (Holland & Leonard, 2020; Moore et al., 2019).

Through interviews with fishing community members in California and Washington, Ritzman et al. (2017) documented this event's pervasive economic impacts, in both the fishing industry and the hospitality industry of fishing communities, and sociocultural impacts (i.e., impacts to cultural connections, community identity, and emotional wellbeing). Interviews also identified sources of both community resilience and vulnerability (i.e., aging workforce, lack of diversification, institutional barriers, ineffective communication, and geographic isolation) (Ritzman et al., 2018). Interviewees cited ineffective communication between government agencies and coastal community members regarding the cause and health risk of HABs, and the reasoning behind geographic closure boundaries as reasons for increased vulnerability to the DA event and distrust in the government (Ritzman et al., 2018).

Although the impacts of the delay were felt coastwide, community social vulnerability, dependence on Dungeness crab, and DA event-induced crab deprivation varied across coastal communities (Moore et al., 2019). Within the fishing industry, large vessels had greater mobility, different adaptive strategies, and saw a relatively smaller reduction in revenue and participation during the DA event than small vessels (Fisher et al., 2021; Jardine et al., 2020). As noted earlier, Fisher et al. (2021) found three adaptive strategies used by fishing vessels during the DA event: temporarily halting all fishing, shifting effort into other fisheries, and shifting fishing locations to target Dungeness crab in open areas.

This thesis examines the effect of adaptive strategies by estimating the impact of exiting the crab fishery on fishing revenues. This analysis explores both the role of past fishing participation diversity in the decision to exit the 2015/16 crab fishery using a logistic participation model, and the impact of the exit decision on seasonal fishing revenue using a counterfactual analysis.

III. Methods and Data

Data

Fish tickets, which document every fish landing for each vessel, were acquired from the Pacific Fisheries Information Network (PacFIN), through data sharing agreements with California Department of Fish and Wildlife (CDFW), Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fish and Wildlife (WDFW). California Dungeness crab trap pot tier designations were also acquired through data sharing agreements with CDFW. Oregon and Washington fish tickets included landings for only those vessels that were active, at any point, in the California Dungeness crab fishery between 2011 and 2016. Port location data were acquired from the CDFW Marine Resource Division, GIS Clearinghouse (Biogeographic Data Branch, 2021), and used to assign a geospatial location to each landing. Analyses were performed in R version 4.0.3 (R Core Team, 2020).

Landings data were filtered to include commercial catches only, during California's Dungeness crab season window (Nov. 15-July 15); November 15 is the start of California's southern season, and July 15 is the terminus of California's northern season. Price per pound and ex-vessel revenue were adjusted to July 2016 values, using the Bureau of Labor Statistics series CUUR0400SA0, "Consumer Price Index for All Urban Consumers: All Items in West". Price per pound values beyond +/- 4SD from the mean price per pound, for each species at each year, were set to the mean price per pound.

Vessels included in the analysis met three conditions: they made more than $5000 in the commercial California Dungeness Crab fishery during both the 2014/15 crab season and at least one other season between 2011-2014, and took three or more trips during those seasons. Following Kasperski and Holland (2013), this revenue threshold excluded those who are not actively engaged in commercial crab fishing. The treatment group is composed of vessels that left the California Dungeness crab fishery for the entire 2015/16 crab season to fish other species in either California, Oregon, or Washington, and/or Dungeness crab in Oregon or Washington. Treatment vessels made a minimum of $5000 in non-California Dungeness crab fishing revenue between Nov. 15, 2015 and July 15, 2016 and took at least three trips during this window. The control group is composed of vessels that fished California Dungeness crab once the fishery opened and made a minimum of $5,000 in California Dungeness crab revenue between Nov. 15, 2015 and July 15, 2016.

Fishing diversity as a driver of the fishery exit decision

A logistic regression was used to understand how fishing diversity impacts their decision to leave the fishery in the event of a fishery shock. Because true *portfolio* diversity would require access to fishery permit data (beyond the confines of the DSA), past fishery *landings* diversity was used as a proxy for true fishery portfolio diversity. A logistic regression is a type of generalized linear model which has a two-level categorical outcome and creates a predictive model of which vessels will leave the fishery during the closure, based on their past fishing diversity and other predictors. This model relates the probability that a vessel will exit the fishery (p_i) to predictors through the logit link function:

$$\textit{Equation 1: } log_e\left(\frac{p_i}{1-p_i}\right) = \boldsymbol{X\beta} \text{ ,}$$

where p_i is the probability that the vessel is in the treatment group, and $\boldsymbol{X\beta}$ is a matrix of predictor coefficients and variables, including a vessel's past participation diversity (our variable of interest) and other variables considered likely to influence the decision to leave the California Dungeness crab fishery. The left side of the equation is the log odds ratio of leaving the fishery versus staying in the fishery during the HAB event. Variables controlled for were vessel horsepower, vessel length, the vessel's mean latitude of crab landings weighted by the revenue of the landing, and the vessel's standard deviation of crab latitude weighted by the revenue of the landing. By controlling for these variables, the impact of diversity on the exit decision can be identified. If this coefficient is positive and statistically significant, the regression indicates that diversity is a significant contributor to the decision to leave the California Dungeness crab fishery.

A single diversity index was quantified for each vessel across the previous four seasons (2011/12-2014/15), using Shannon's diversity index (SDI):

$$\textit{Equation 2: } H' = \sum_{i=1}^{s_j} \sum_j^2 [p_{ij}\, ln(p_{ij})],$$

where p_{ij} is the percent of a vessel's total gross revenues from species group i in state j during the open season for crab. The state landed was included as a dimension of diversity because the required fishery access permit or license and management practices vary by state, depending on the fishery. U.S. West Coast species were grouped into 17 species groupings, following methods by Kasperski and Holland (2013). Species groupings are listed in Appendix Table 1. Not all species groupings are caught in each state within fish tickets, so there were 28 possible species group-state combinations. The index approaches zero as the revenue source concentrates towards fewer species groups in fewer states and the index approaches *ln(i)ln(j)* as the revenue source differentiates into more species groups in more states.

Impact of fishery exit decision on revenue outcome

A difference-in-differences (DiD) identification strategy was used to identify how vessels that exited the California Dungeness crab fishery in pursuit of other fisheries may have fared had they stayed in the California Dungeness crab fishery. A DiD approach is a counterfactual analysis that compares how the difference in means between two groups (treatment group relative to a control group) changes in time (treatment period relative to a baseline period) and assumes that the change in the difference in means is a response to the treatment.

The ideal dependent variable was total profit; however, because fishing operation and administrative cost data (e.g., license and gear purchase costs, gear maintenance, catch transportation, selling catch) (C. Anderson et al., 2014) was not available, vessel revenue was used as a proxy for profit. In fisheries economics research, it is commonly assumed that revenue and profits evolve similarly (Pfeiffer & Gratz, 2016). To create a cumulative revenue for each vessel at each year, during the temporal bounds of the crab season, revenue from all commercial species landings were aggregated across California's cumulative Dungeness crab season (Nov. 15- July 15). This dependent variable is herein referred to as the revenue sum within the crab window. The treatment period in this analysis is the 2015/16 California Dungeness crab season, while the baseline period is the five crab seasons from 2010/11-2014/15, where the 2015/16 season is November 15, 2015 to July 15, 2016.

To estimate the impact of leaving the California Dungeness crab fishery in 2015/16 on total seasonal fishing revenue, a multivariate linear regression (MVLR) analysis was used in concert with the DiD framework. A regression controls for the effect of variables that may influence crab season revenue, and therefore better isolates the DiD coefficient (the interaction term of the treatment group in the treatment period). The DiD model without fixed effects is as follows:

$$\textit{Equation 3: } y_{i,t} = \beta_0 + \beta_1 P + \beta_2 T + \beta_3 PT + \beta X_{it} + \epsilon_{it},$$

where y_i is the natural log of a vessel's fishing revenue sum within the crab window, *P* is a dummy variable that equals one during the treatment period (2015/16 season), *T* is a dummy variable that equals one for treatment group vessels, *PT* is the interaction term and our variable of interest, and $\boldsymbol{\beta X}$ is a vector of other potentially influential variables. The model lastly includes an error term assumed to be independent and identically distributed and follows a normal distribution with a mean of zero and a standard deviation of σ, i.e., ~N(0, σ). When fixed effects are added to the model, the regression becomes:

$$\textit{Equation 4: } y_{i,t} = \beta_0 + \boldsymbol{\tau_t} + \beta_3 PT + \boldsymbol{\mu_i} + \boldsymbol{\beta X} + \epsilon_{it},$$

where $\boldsymbol{\tau_t}$ introduces yearly fixed effects and is a vector of dummy variables for each fishing season to capture any time-varying differences in outcomes across years that were constant across vessels, μ_i is a vector of individual vessel fixed effects to capture any time-invariant differences in outcomes across vessels, and $\boldsymbol{\beta X}$ becomes a vector of only fisher-specific time-varying variables. Variables considered potentially influential on revenue were the number of fishing trips taken per crab season, vessel horsepower, vessel length, number of crab pots allowed under the vessel's crab permit, and the vessel's mean latitude of crab landings weighted by the revenue of the landing. Table 1 presents summary statistics of all variables informing regressions. Summary statistics tables grouped by treatment group are shown in Appendix Table A1.

Certain conditions must be met to conduct an unbiased DiD analysis. Most critically, the parallel trends assumption dictates that outcomes in the control and treatment vessels must follow the same trends over time even though the outcome levels can be different. This assumption allows us to assume that had the treatment group not exited the California Dungeness crab fishery during the 2015/16 season, but instead participated in the California Dungeness crab fishery once it opened, the treatment group's revenue outcome would have followed the same trend as the control group. Ideally, the pre-period trend would show parallel trends for the treatment and control group revenue sum within the crab window. Visual analysis of revenue sums within the crab window reveals that the 2013/14 crab season deviates from a parallel trend (Appendix Figure A1). The regression analysis, however, allows us to control for variables that may cause this noise in parallel trends and better isolate the DiD coefficient. Comparability between control and treatment group characteristics (e.g., vessel lengths), can be seen in Appendix Table A4. Further assumptions are that control variables are exogenous to the treatment.

Additionally, the treatment application must be exogenous. Since the treatment group vessel self-selected into the treatment group by definition (endogenous fishery participation choice), this assumption is of course violated. Vessels were not selected into the treatment group via policy change, as DiD analysis quasi-experiment subjects generally are. This analysis, however, looks at the treatment effect *on the treated vessels,* not the treatment effect on the vessel population as a whole. As Abbott and Wilen (2010) explain for a similar analysis, the impact of the choice to be in our treatment group therefore is not something to be dealt with, but instead integral to the treatment. As long as the variables responsible for selecting into the treatment group (observed or unobserved) do not independently influence revenue, they can be ignored.

Finally, the Stable Unit Treatment Values Assumption (SUTVA) dictates that there must be no interference between groups, and that there are no variations in the treatment. If the treatment group vessels leaving the California Dungeness crab fishery impacted the control group's fishing revenue, e.g., since the crab fishery is derby-style, SUTVA would be violated. Because the treatment group is a small fraction of the total fleet, this bias is likely minimal. If any of the assumptions do not hold, the findings of the analysis may be biased.

Table 1: Summary Statistics - Descriptive statistics of all variables informing regressions, for all vessels. N represents the number of unique vessel-years (vessel characteristics or behaviors at each season) analyzed. "Mean Revenue Per Delivery" is the mean revenue per delivery for each vessel-year; the "mean" column averages the variable across all vessel-years. Total seasonal revenue is revenue from all species, from November 15-July 15. Number of trip days is the number of days between November 15-July 15 with a fish landing. Vessel horsepower and length are medians of the reported value, as errors in reported occurred. Number of permitted pots lacks all vessel years because crab trap tier data is only available for California for three seasons, from 2013/14-2015/16. Means crab latitude lacks all vessel years because port of landing was not recorded for all vessel-years.

Statistic	N	Mean	St. Dev.	Min	Median	Max
Mean Revenue Per Delivery (USD)	1,945	8,498	11,423	160	4,731	125,151
Total Seasonal Revenue (USD)	1,945	209,817	212,391	332	139,083	1,797,997
Number of Trip Days	1,945	26	16	1	23	114
Vessel Horsepower (hp)	1,839	255	152	10	225	1,200
Vessel Length (ft)	1,945	41	10	16	40	78
Number of Permitted Pots	1,006	341	106	175	350	500
Mean Crab Latitude (°N)	1,885	39	2	35	38	48

IV. Results

Fishing diversity as a driver of the fishery exit decision

Figure 1 and Figure 2 offer complementary ways to visualize the difference in treatment and control group landings diversity. Figure 1 shows that in the pre-period the treatment group has greater revenue from non-California Dungeness revenue streams than the control group. During the HAB year, the treatment group non-California Dungeness cumulative strategy revenue proportions remain similar to the pre-period proportions.

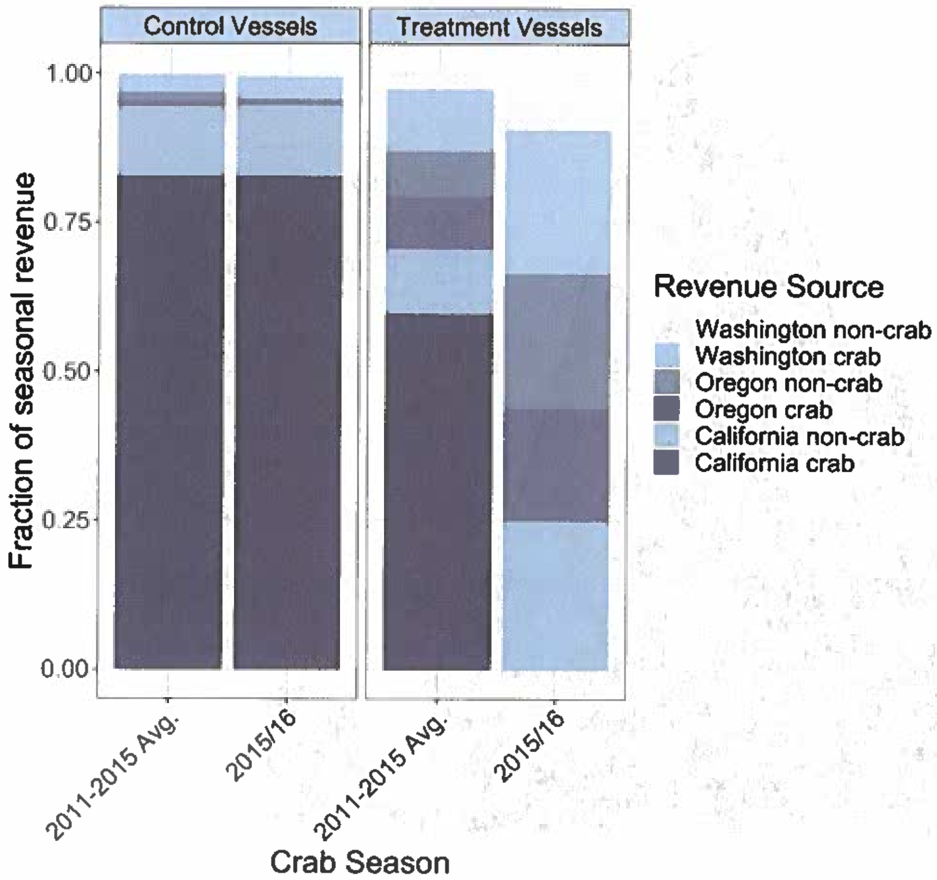

Figure 1: Aggregated crab season fishing revenue categories, as a fraction of the total revenue.

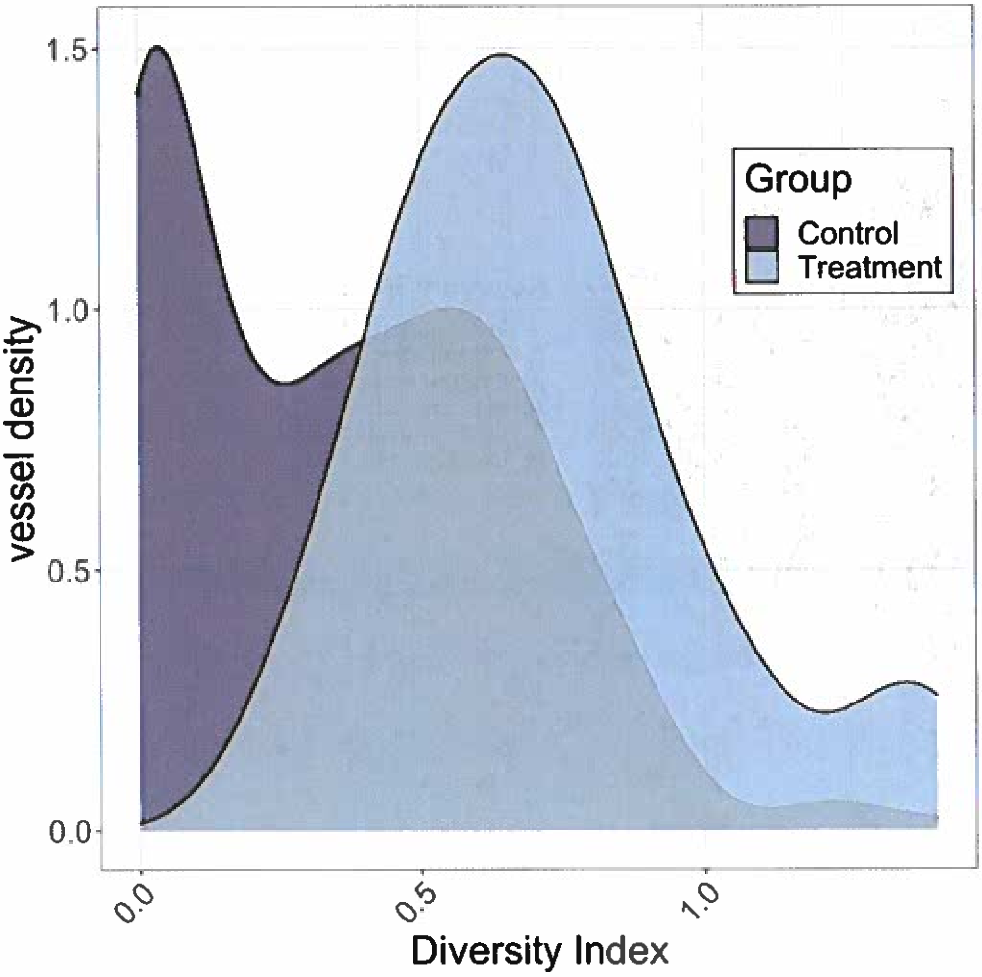

Figure 2: Shannon Diversity Index Vessel Density, by treatment group, (2011/12-2014/15 average).

Figure 2 shows that the treatment group peak vessel density is at a greater diversity index than the bimodal control group peaks. Both figures visually indicate what is underscored in Table 2, that there is a difference in diversity between treatment groups. Table 2 shows model coefficients for four-year cumulative values in Shannon Diversity Index (SDI), standard deviation of crab landing latitude (SD of crab Latitude), and mean crab landing latitude (mean crab Latitude) values. Across all logistic model specifications, the coefficient on Shannon Diversity Index

(SDI) is positive and statistically significant. The marginal effects of logit model covariates are shown in Appendix Table A6. The average marginal effect of SDI for specification 6, which has the lowest AIC, is .1298***, suggesting that at the mean, a one unit increase in the diversity index lead to about a .13 increase in the probability of exit.

Table 2: Logistic Regression Model Outputs (4 year averages, 2011/12-2014/15)- Outputs of all model specifications for four-year averages of Shannon Diversity Index (SDI), standard deviation of crab landing latitude (SD of crab latitude), and mean crab landing latitude (Mean Crab Latitude). Standard errors are in parenthesis.

	Dependent variable:					
	treatment					
	(1)	(2)	(3)	(4)	(5)	(6)
SDI	3.644***	3.600***	3.615***	3.261***	3.683***	3.377***
	(0.847)	(0.802)	(0.791)	(0.726)	(0.776)	(0.703)
SD of Crab Latitude	0.311	0.299	0.311	0.118		
	(0.253)	(0.243)	(0.233)	(0.195)		
Mean Crab Latitude	-0.281*	-0.283*	-0.258		-0.157	
	(0.165)	(0.165)	(0.163)		(0.138)	
Vessel Horsepower	0.0002	0.0001				
	(0.002)	(0.002)				
Vessel Length	-0.004					
	(0.027)					
Constant	6.463	6.457	5.407	-4.350***	1.672	-4.318***
	(6.158)	(6.176)	(6.111)	(0.509)	(5.236)	(0.506)
Observations	322	322	344	344	344	344
Log Likelihood	-73.193	-73.206	-74.534	-75.895	-75.391	-76.070
Akaike Inf. Crit.	158.385	156.412	157.068	157.789	156.782	156.141
Note:				*p<0.1**p<0.05***p<0.01		

Impact of fishery exit decision on revenue outcome

Mean crab season revenue for each treatment group across all years is shown in Figure 3, panel A, while differences in means and 95% confidence intervals are shown in panel B. A table of the numerical results is shown in Appendix Table A2-A3. In four of the five pre-period years, the treatment group has higher mean revenues than the control group, although the difference is not statistically significant. In the HAB year (2015/16), however, the treatment group mean revenue is statistically significantly lower than both the control group mean and any previous treatment group means.

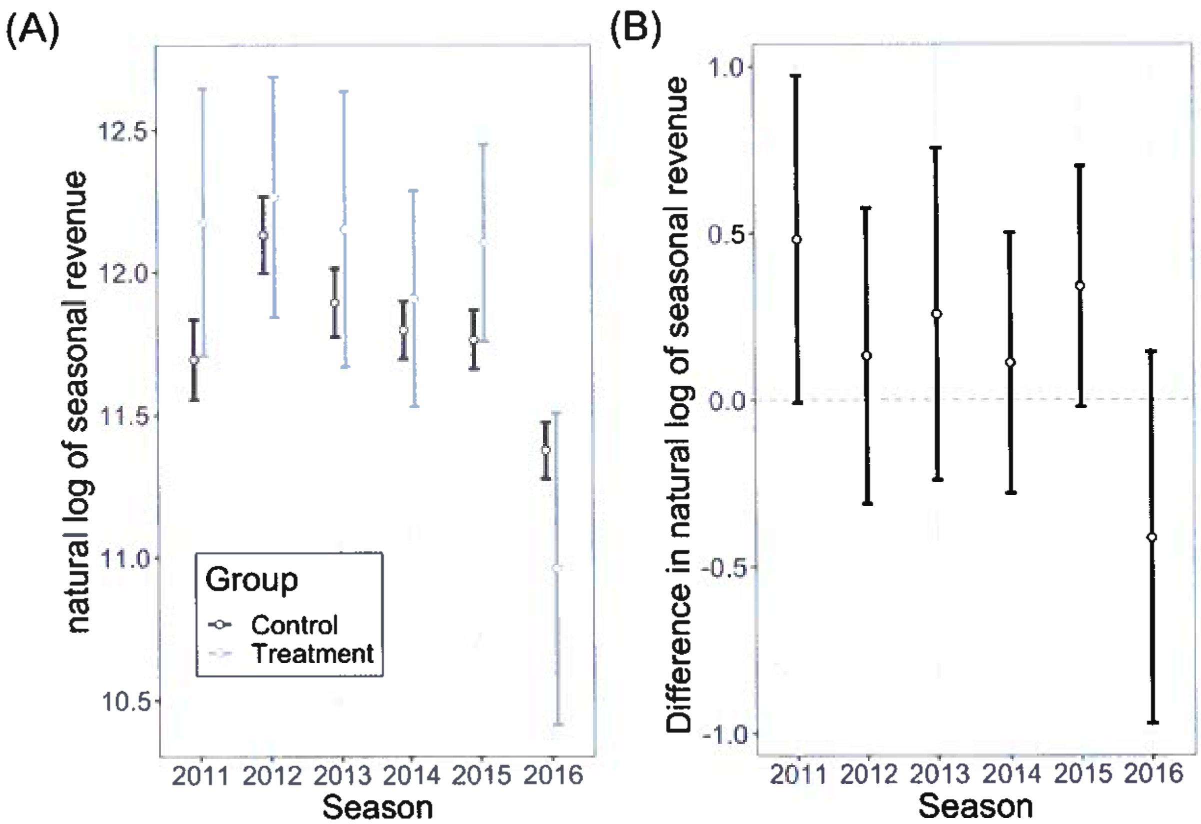

Figure 3: (A) mean seasonal revenue (ln($)) across seasons, by treatment. (B) Difference in seasonal revenue (ln($)).

Three regression specifications are shown in Table 3, and all regression specifications are detailed in Appendix Table A5. The base model (the generic DiD model), shows that the time term ($p<.01$), the interaction term ($p<.01$), and the treatment group ($p<.01$) are significant. When vessel fixed effects and year fixed effects are added to the model (specification 4), all non-FE terms are significant ($p<.01$). Specification 6, which replaces vessel fixed effects with vessel length, shows significance in all terms except treatment group. This is possibly due to multicollinearity between a fisher's decision to exit and their vessel length, although the difference in vessel lengths between treatment groups is not statistically significant. Vessel length is positive and statistically significant ($p<.01$).

Notably, the interaction term (the treatment group during the 2015/16 season) coefficient is consistently negative and statistically significant across all models, indicating that during the HAB year, on average, vessels that exited the fishery (but remained fishing) had larger revenue losses than vessels that fished California Dungeness crab. DiD estimates are between -.678 and -.698, suggesting that the decision to leave the California Dungeness crab fishery during the 2015/16 season in pursuit of other fisheries resulted in 50% more severe crab season revenue losses than the control group experienced.

Table 3: Multivariate Linear Regression Outputs, top specifications –Notes: Standard errors are in parentheses. Individual vessel and year fixed effects coefficients have been removed from the table and instead noted as either included ("Yes") or excluded ("No") for each model. In comparison with the "2015/16 season" coefficient (-.480***), when fixed effects are added to the model, the fixed effect for the 2015/16 season is -.225*** (.046) in specification 4 and -.286*** in specification 6 (.067).

Multivariate Linear Regression Outputs, top specifications			
	Dependent variable:		
	natural log of revenue		
	(1)	(4)	(6)
2015/16 Season	-0.480***		
	(0.064)		
Treatment Group	0.264***		-0.019
	(0.098)		(0.077)
Vessel Length (ft)			0.062***
			(0.002)
Interaction (Treatment Group in HAB year)	-0.678***	-0.698***	-0.680***
	(0.237)	(0.127)	(0.185)
Constant	11.854***	12.045***	9.168***
	(0.027)	(0.228)	(0.088)
Vessel Fixed Effects	No	Yes	No
Year Fixed Effects	No	Yes	Yes
Observations	1,945	1,945	1,945
R^2	0.042	0.775	0.415
Adjusted R^2	0.040	0.726	0.412
Residual Std. Error	1.038 (df = 1941)	0.555 (df = 1595)	0.813 (df = 1936)
F Statistic	28.246*** (df = 3; 1941)	15.762*** (df = 349; 1595)	171.330*** (df = 8; 1936)
Note:			*p<0.1 **p<0.05 ***p<0.01

Robustness Checks

Alternate number of years included in diversity index

To understand the sensitivity of these results to the number of pre-HAB years included in the diversity index, standard deviation of crab landing latitude and mean crab landing latitude values, the logistic regression was run with a diversity index calculated using one, two, three, and five-year cumulative scores. The cumulative four-year index had the lowest AIC of all regressions. While the magnitude of the diversity index coefficient changes, the diversity index is significant across all regressions. The full results are in Appendix Tables A7-A10.

Placebo Tests

Placebo tests were used to test the assumption that autocorrelation, as a result of measurement error in an independent variable, is not driving the results (Bertrand et al., 2004). The placebo test used in Jardine et al. (2020), which asked "what if we wrongly assumed that the HAB event occurred during a season which did not have a HAB event; would we find an "impact" of this placebo event?" was used in this analysis. The base model, Table 3 specification 1, was used for all placebo tests. The coefficients of the placebo test interaction terms, as well as the non-placebo base model interaction term, is shown in Figure 4. Figure 4 shows that all placebo tests pass.

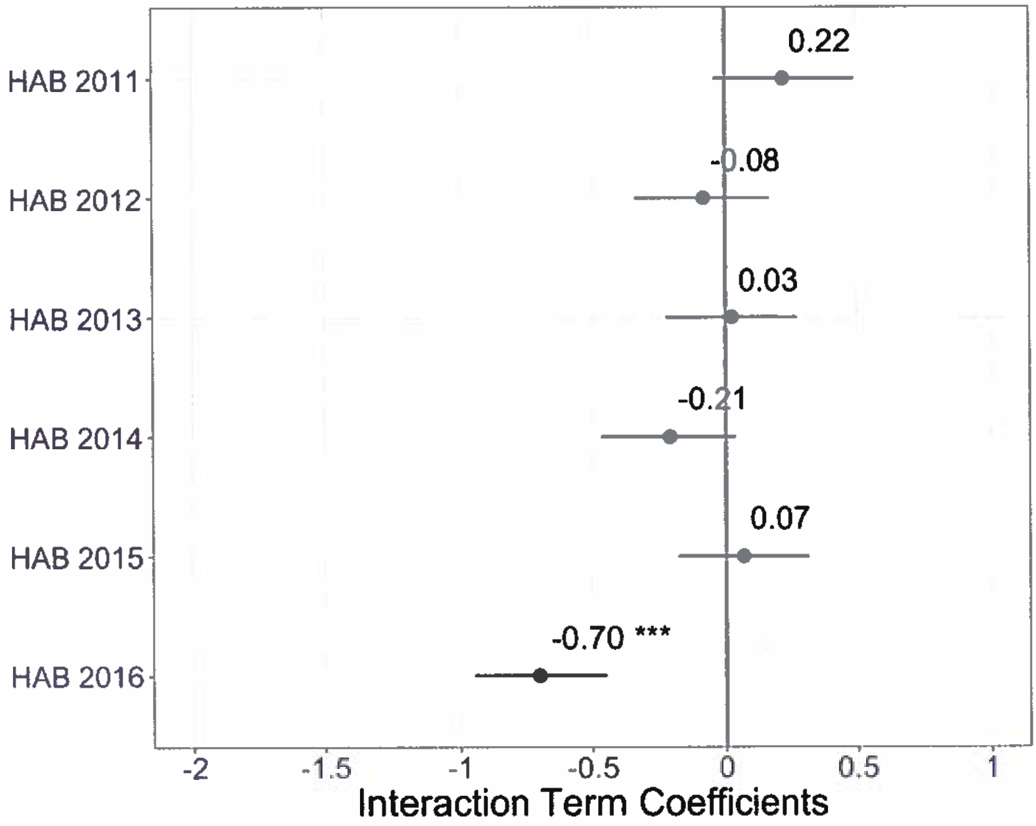

Figure 4: Placebo test interaction term coefficients and 95% confidence intervals, using robust standard errors.

V. Discussion and Conclusion

These results indicate that diversity in past fishing participation is a significant predictor of exit in response to the HAB, and that although all active vessels, on average, earned less during the 2015/16 season than previous seasons, vessels that exited the fishery but remained fishing had larger revenue losses than vessels that fished California Dungeness crab. Although portfolio diversification has been shown to decrease revenue variability at large levels of diversification (Kasperski & Holland, 2013), buffer catch declines (Robinson et al., 2020), and buffer abrupt fishery resource and markets changes at the community level (Cline et al., 2017), these results corroborate the findings of Anderson et al. (2017), that the relationship between vessel level diversification and variability in revenue is complex and context-specific.

The findings of this research, however, are subject to some limitations. First, this case study reflects outcomes for the 2015/16 HAB event, and does not suggest a specific revenue outcome for adaptive strategies during future delays. Second, this analysis was performed at the vessel-level and therefore does not include possible livelihood diversification (i.e., obtaining an alternate non-fishing job) as an adaptive strategy, but only fishing-based adaptive strategies. Future directions for this analysis include exploring fishing diversity through other lenses of diversity (e.g., vulnerability-based diversity indices) and analyzing the degree to which fishery season overlap is present for U.S. West Coast vessels.

Fishery harvest and processing regulations in the Dungeness crab fishery and other U.S. West coast fisheries are swiftly changing in response to an array of exogenous factors, including whale migration changes and HABs. During the 2015/16 Dungeness crab fishery season shift, late season revenue coincided with Humpback whale migration and indirectly led to greater whale entanglement with crab pots (Saez et al., 2020). In response to both whale migration timing changes and whale entanglement with crab pots, state managers are adopting regulatory changes that can both delay the crab season opening and push up the crab season closing, based on whale migration dynamics. Had the 2015/16 HAB event occurred during recent years, late season revenue recovery may have not been an option because of whale migration regulations and season compression.

In response to the increasing frequency and severity of HABs and fishing season compression (Lewitus et al., 2012), state policy-makers and managers are enabling evisceration orders, to keep Dungeness crab fisheries open during HABs. Evisceration orders dictate that crab exceeding the action level in crab viscera (30ppm), but below the action level in crab meat (20ppm) (California Ocean Science Trust, 2016), may be eviscerated and sold. Evisceration keeps the fishery open but limits crab product forms. Regulations are rapidly changing, and the coupling of anthropogenic climate and environmental change, and natural phenomenon, hint toward continuing regulatory change.

During the 2015/16 climate shock-induced fishery delay, the decision to shift participation was likely underpinned by ecological uncertainty (e.g., when will the climate shock end?), market uncertainty (e.g., how will consumers respond to the climate shock?), and financial duress (e.g., lost income from the target fishery). If financial stress impacts cognitive clarity, as suggested by Mani et al. (2019), the cost-benefit analysis required in the *readiness* precondition for switching fishery participation may be influenced. Mani et al. (2019) also suggest that in the face of poverty, both temporary and extended, cognitively demanding tasks like "filling out long forms, preparing for a lengthy interview, deciphering new rules, or responding to complex incentives" all demand cognitive resources (p. 980). Further, cognitive capacity varies temporally (across seasons, with the ebb and flow of financial capital), and that information dissemination should be carefully timed (Mani et al., 2019).

The results of this thesis show undesirable revenue outcomes following fishery exit during a climate shock, and could underscore the importance of ease of use in informational interfaces. As

California fishers have acknowledged and requested, scientific and regulatory communication in a reliable and clear form will enable trust and sound decision making during future HAB events (Ritzman et al., 2018). HAB forecasts (e.g., C-HARM) and bulletins (e.g., Pacific Northwest HABs Bulletin, California HAB Bulletin) provide valuable information to fishery managers and fishers. As forecasts and bulletins are further developed and widespread, foregrounding frequent interpretation for managers and fishers could be critical in enabling best-informed fishery participation decisions.

For Northern California fishing communities, the Dungeness crab fishery may already be a gilded trap, a socioeconomic trap that forms as social drivers increase the value of the resource, even as the resource itself moves closer to an ecological tipping point (Fisher et al., 2021; Steneck et al., 2011). If the outcomes that this analysis reveals disincentivizes future fishery exit during HABs and instead incentivizes a focus of effort on Dungeness crab, this case study may perpetuate the Dungeness crab fishery as a gilded trap.

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Appendix

Table A1: Species Groupings – species groupings used to calculate diversity indices (adapted from Kasperski and Holland 2013)

	Group
1	California Halibut, Croaker
2	Coastal Pelagics
3	Dungeness Crab
4	Echinoderms
5	Herring
6	Other Crab
7	Other Prawns and Shrimp
8	Other Shellfish
9	Other Species
10	Pacific Halibut
11	Pink Shrimp
12	Rockfish, Flatfish
13	Salmon
14	Skates, Sharks
15	Squid
16	Thornyheads, Sablefish
17	Tuna
18	Whiting

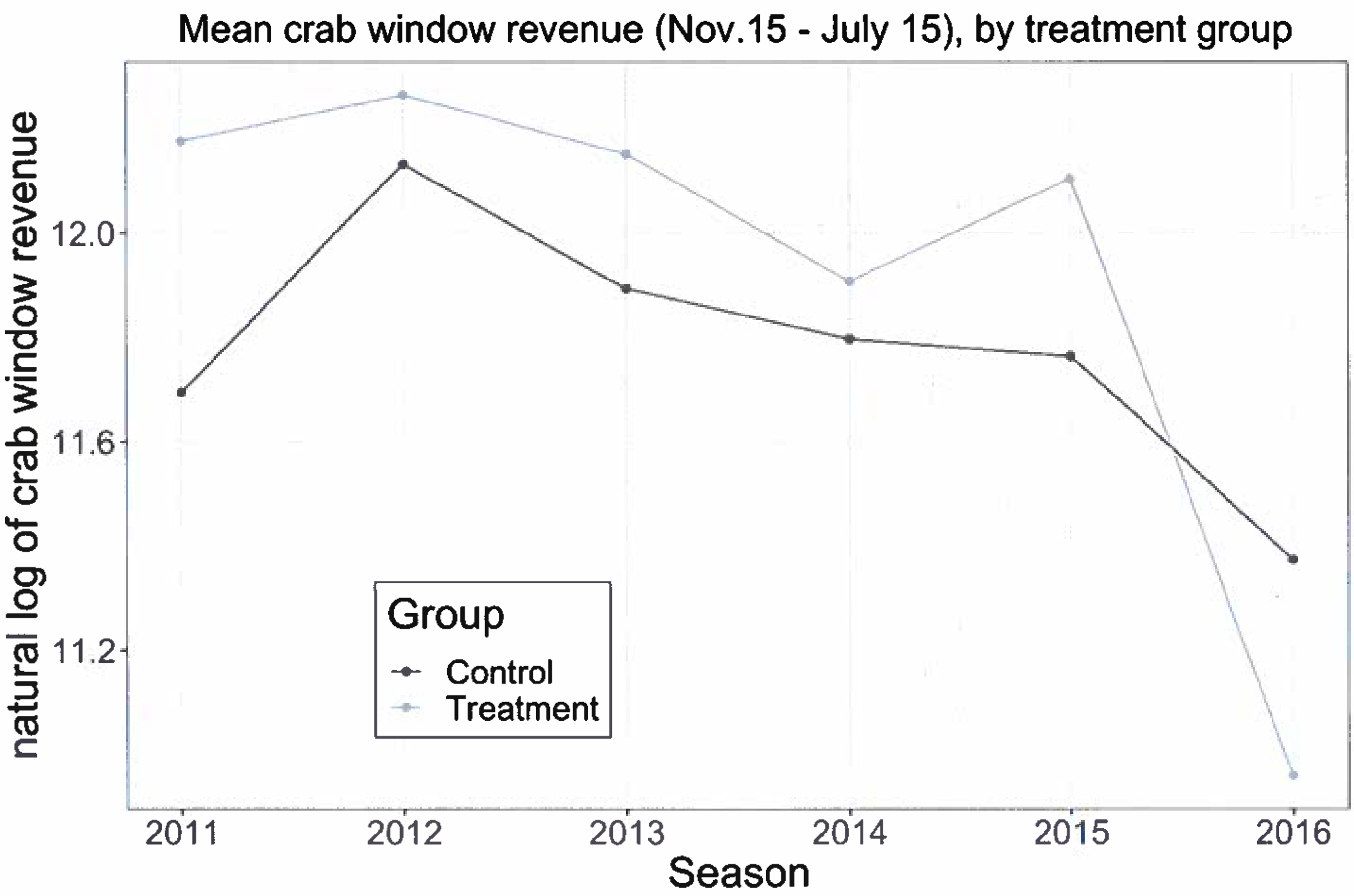

Figure A1: mean revenue sum (natural log($)) within the crab window across seasons and 95% confidence intervals of the mean, by treatment.

Table A2: Difference-in-difference table ($) – Mean seasonal revenue sum differences between groups, across all seasons. Differences are calculated as treatment (1) – control (0); Positive values in "Diff in Means" indicate that the control group mean was greater than the treatment group mean.

Season	Treatment	Mean	SD	N Vessels	SE	Diff in Means	SE of Diff in Means
2011	0	208,049	221,486	261	13,710		
2011	1	345,180	405,669	22	86,489	137,131	87,569
2012	0	296,119	261,646	278	15,692		
2012	1	352,030	420,974	24	85,931	55,911	87,352
2013	0	223,608	189,970	304	10,896		
2013	1	290,121	243,028	25	48,606	66,512	49,812
2014	0	194,318	171,423	318	9,613		
2014	1	219,458	219,181	25	43,836	25,140	44,878
2015	0	195,649	201,418	319	11,277		
2015	1	266,476	256,465	25	51,293	70,827	52,518
2016	0	126,912	120,519	319	6,748		
2016	1	134,411	181,298	25	36,260	7,499	36,882

Table A3: Difference-in-difference table (natural log of $) – Mean seasonal revenue sum differences between groups, across all seasons. Differences are calculated as treatment (1) – control (0); Positive values in "Diff in Means" indicate that the control group mean was greater than the treatment group mean.

Season	Treatment	Mean	SD	N Vessels	SE	Diff in Means	SE of Diff in Means
2011	0	11.69	1.17	261	0.07		
2011	1	12.18	1.12	22	0.24	0.48	0.25
2012	0	12.13	1.15	278	0.07		
2012	1	12.26	1.05	24	0.22	0.13	0.23
2013	0	11.89	1.07	304	0.06		
2013	1	12.15	1.23	25	0.25	0.26	0.25
2014	0	11.80	0.93	318	0.05		
2014	1	11.91	0.96	25	0.19	0.11	0.20
2015	0	11.76	0.94	319	0.05		
2015	1	12.10	0.88	25	0.18	0.34	0.18
2016	0	11.37	0.90	319	0.05		
2016	1	10.96	1.40	25	0.28	-0.41	0.28

Table A4: Summary statistics, by treatment group - Descriptive statistics of all variables informing regressions, for all vessels. N represents the number of unique vessel-years (vessel characteristics or behaviors at each season) analyzed. "Mean Revenue Per Delivery" is the mean revenue per delivery for each vessel-year; the "mean" column averages the variable across all vessel-years. Total seasonal revenue is revenue from all species, from November 15-July 15. Number of trip days is the number of days between November 15-July 15 with a fish landing. Vessel horsepower and length are medians of the reported value, as errors in reported occurred. Number of permitted pots lacks all vessel years because crab trap tier data is only available for California for three seasons, from 2013/14-2015/16. Means crab latitude lacks all vessel years because port of landing was not recorded for all vessel-years.

Control Group

Statistic	N	Mean	St. Dev.	Min	Median	Max
Mean Revenue Per Delivery (USD)	1,799	8,315	10,864	160	4,731	104,824
Total Seasonal Revenue (USD)	1,799	205,275	202,752	332	137,912	1,424,656
Number of Trip Days	1,799	26	16	1	23	114
Vessel Horsepower (hp)	1,693	253	152	10	225	1,200
Vessel Length (ft)	1,799	40	10	16	40	78
Number of Permitted Pots	936	342	106	175	350	500
Mean Crab Latitude (°N)	1,758	39	2	35	38	48
SD of Crab Latitude (°)	1,758	0	1	0	0	5

Treatment Group

Statistic	N	Mean	St. Dev.	Min	Median	Max
Mean Revenue Per Delivery (USD)	146	10,760	16,746	249	4,705	125,151
Total Seasonal Revenue (USD)	146	265,783	302,712	1,836	158,257	1,797,997
Number of Trip Days	146	26	16	1	22	76
Vessel Horsepower (hp)	146	285	155	90	250	671
Vessel Length (ft)	146	45	11	26	43	67
Number of Permitted Pots	70	329	113	175	350	500
Mean Crab Latitude (°N)	127	40	2	36	39	47
SD of Crab Latitude (°)	127	0	1	0	0	4

Table A5: Multivariate linear regression output, all specifications - Outputs of all model specifications. Standard errors are in parenthesis. Note: individual vessel fixed effects coefficients have been removed from the table and instead noted as either included ("Yes") or excluded ("No") for each model.

	Dependent variable:							
	natural log of revenue							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2015/16 Season	-0.480***							
	(0.064)							
Treatment Group	0.264***	0.260***	0.086		0.195**	-0.019	0.068	0.019
	(0.098)	(0.098)	(0.086)		(0.092)	(0.077)	(0.098)	(0.093)
2012 FE		0.410***	0.485***	0.443***	0.391***	0.418***		
		(0.085)	(0.076)	(0.046)	(0.082)	(0.067)		
2013 FE		0.182**	0.240***	0.251***	0.150*	0.218***		
		(0.084)	(0.074)	(0.045)	(0.080)	(0.066)		
2014 FE		0.075	-0.019	0.178***	0.039	0.130**		
		(0.083)	(0.073)	(0.045)	(0.080)	(0.065)		
2015 FE		0.058	-0.104	0.169***	0.028	0.114*	-0.023	-0.060
		(0.083)	(0.073)	(0.045)	(0.080)	(0.065)	(0.051)	(0.048)
2016 FE		-0.337***	-0.352***	-0.225***	-0.366***	-0.285***	-0.431***	-0.389***
		(0.085)	(0.075)	(0.046)	(0.082)	(0.067)	(0.052)	(0.050)
SD Crab Latitude			0.515***					0.269***
			(0.030)					(0.029)
Vessel Horsepower (hp)					0.002***			
					(0.0001)			
Number of Allowed Pots							0.003***	0.003***
							(0.0002)	(0.0002)
Vessel Length (ft)						0.062***	0.040***	0.031***
						(0.002)	(0.002)	(0.002)
Interaction (Treatment Group in HAB year)	-0.678***	-0.674***	1.133***	-0.698***	-0.661***	-0.680***	-0.566***	0.607**
	(0.237)	(0.235)	(0.354)	(0.127)	(0.222)	(0.185)	(0.177)	(0.272)
Constant	11.854***	11.711***	11.667***	12.045***	11.192***	9.168***	9.101***	9.406***
	(0.027)	(0.062)	(0.055)	(0.228)	(0.069)	(0.088)	(0.093)	(0.092)
Vessel Fixed Effects	No	No	No	Yes	No	No	No	No
Observations	1,945	1,945	1,885	1,945	1,839	1,945	1,006	988
R^2	0.042	0.056	0.198	0.775	0.153	0.415	0.533	0.572
Adjusted R^2	0.040	0.053	0.194	0.726	0.149	0.412	0.530	0.569
Residual Std. Error	1.038	1.031	0.899	0.555	0.968	0.813	0.657	0.618
F Statistic	28.246***	16.548***	57.752***	15.762***	41.231***	171.330***	189.767***	187.171***

Note: *p<0.1; **p<0.05; ***p<0.01

Table A6: Logistic regression marginal effects – Marginal effects of all model specifications for four-year averages of Shannon Diversity Index (SDI), standard deviation of crab landing latitude (SD of crab latitude), and mean crab landing latitude (Mean Crab Latitude), including coefficients, standard errors, and adjusted R2.

	Marginal Effects on Treatment					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant						
SDI	0.1390***	0.1388***	0.1300***	0.1234***	0.1388***	0.1298***
SD of Crab Latitude	0.0126**	0.0125**	0.0117***	0.0057		
Mean Crab Latitude	-0.0121***	-0.0121***	-0.0101***		-0.0068**	
Vessel Horsepower	0.000001	0.000000				
Vessel Length	-0.00004					
N	322	322	344	344	344	344
Log Likelihood	-73.1925	-73.2060	-74.5340	-75.8947	-75.3909	-76.0704
Akaike Inf. Crit.	158.3850	156.4119	157.0681	157.7893	156.7818	156.1409

Notes: *p<0.1**p<0.05***p<0.01

Table A7: Model Coefficients (1-year averages, 2014/15)

	Dependent variable:				
	treatment				
	(1)	(2)	(3)	(4)	(5)
SDI	2.084***	2.104***	2.138***	2.291***	2.048***
	(0.647)	(0.635)	(0.624)	(0.601)	(0.530)
SD of Crab Latitude	0.261	0.238			
	(0.249)	(0.242)			
Mean Crab Latitude	-0.223	-0.196	-0.141	-0.126	
	(0.157)	(0.154)	(0.141)	(0.139)	
Vessel Horsepower	-0.0001				
	(0.002)				
Vessel Length	0.003	0.004	0.017		
	(0.027)	(0.025)	(0.021)		
Constant	5.015	3.791	1.240	1.315	-3.487***
	(6.076)	(5.968)	(5.311)	(5.265)	(0.376)
Observations	322	344	344	344	344
Log Likelihood	-79.393	-80.787	-81.267	-81.623	-82.055
Akaike Inf. Crit.	170.787	171.575	170.535	169.245	168.109
Note:			*p<0.1**p<0.05***p<0.01		

Table A8: Model Coefficients (2-year averages, 2013/14-2014/15)

	Dependent variable:				
	treatment				
	(1)	(2)	(3)	(4)	(5)
SDI	2.450***	2.387***	2.397***	2.533***	2.285***
	(0.703)	(0.665)	(0.647)	(0.631)	(0.552)
SD of Crab Latitude	0.307	0.275	0.255		
	(0.244)	(0.219)	(0.203)		
Mean Crab Latitude	-0.217	-0.214	-0.188	-0.122	
	(0.156)	(0.156)	(0.154)	(0.140)	
Vessel Horsepower	-0.0002	-0.0004			
	(0.002)	(0.002)			
Vessel Length	-0.008				
	(0.028)				
Constant	4.943	4.563	3.416	0.937	-3.694***
	(6.057)	(5.924)	(5.805)	(5.305)	(0.410)
Observations	322	322	344	344	344
Log Likelihood	-78.169	-78.211	-79.521	-80.291	-80.687
Akaike Inf. Crit.	168.338	166.423	167.043	166.581	165.373
Note:			*p<0.1**p<0.05***p<0.01		

Table A9: Model Coefficients (3-year averages, 2011/12-2013/14)

	Dependent variable:						
	treatment						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SDI	3.008***	3.012***	3.041***	2.625***	2.691***	3.080***	2.699***
	(0.770)	(0.725)	(0.719)	(0.650)	(0.646)	(0.709)	(0.612)
SD of Crab Latitude	0.138	0.140		-0.026	0.007		
	(0.260)	(0.239)		(0.210)	(0.196)		
Mean Crab Latitude	-0.251	-0.251	-0.209			-0.174	
	(0.164)	(0.164)	(0.145)			(0.141)	
Vessel Horsepower	0.0003	0.0003	0.001	0.0004			
	(0.002)	(0.002)	(0.001)	(0.002)			
Vessel Length	0.0004						
	(0.028)						
Constant	5.516	5.526	3.909	-3.986***	-4.013***	2.589	-4.012***
	(6.222)	(6.181)	(5.433)	(0.564)	(0.465)	(5.316)	(0.464)
Observations	322	322	322	322	344	344	344
Log Likelihood	-76.583	-76.583	-76.750	-77.842	-78.981	-78.186	-78.981
Akaike Inf. Crit.	165.166	163.166	161.500	163.684	163.961	162.372	161.963
Note:					*p<0.1**p<0.05***p<0.01		

Table A10: Model Coefficients (5-year averages, 2010/11-2014/15)

	Dependent variable:				
	treatment				
	(1)	(2)	(3)	(4)	(5)
SDI	3.394***	3.397***	3.416***	3.100***	3.282***
	(0.800)	(0.776)	(0.768)	(0.712)	(0.681)
SD of Crab Latitude	0.322	0.323	0.332	0.157	
	(0.243)	(0.238)	(0.226)	(0.191)	
Mean Crab Latitude	-0.261	-0.261*	-0.239		
	(0.160)	(0.158)	(0.157)		
Vessel Horsepower	-0.0001	-0.0001			
	(0.002)	(0.002)			
Vessel Length	0.0005				
	(0.026)				
Constant	5.695	5.691	4.754	-4.307***	-4.269***
	(5.957)	(5.952)	(5.905)	(0.497)	(0.495)
Observations	322	322	344	344	344
Log Likelihood	-73.411	-73.411	-74.654	-75.910	-76.233
Akaike Inf. Crit.	158.821	156.822	157.309	157.819	156.467
Note:			*p<0.1**p<0.05***p<0.01		