Potential Impacts of Re-Opening the Trawl Rockfish Conservation Area off the Coasts of Oregon and California

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Abstract

Marine protected areas and closed areas are a common tool in ecosystem-based management. The Rockfish Conservation Area (RCA) was a closure set in place in 2002 to address the overfished status of several rockfish species in the West Coast groundfish fishery after it was declared an economic disaster. The RCA reopened in January of 2020 off the Oregon and California Coasts, in response to the rebuilt status of all but one previously overfished stock. To understand the response of fishers to this reopening, Vessel Monitoring System (VMS) data was used to describe the spatial and temporal patterns of vessels in the first quarter of the reopening. Simultaneously, ocean productivity through Pacific Decadal Oscillation (PDO) index was analyzed to describe long-term, low-frequency ocean processes on fishing spatial distributions. Given the complexities of various social, economic and environmental influences on fishing behavior and markets, a shift in management from species specific management to ecosystem-based management has been encouraged in marine fisheries management. Likewise, the analysis showed that while vessels used the reopened RCA, the overall distribution of concentrated fishing behavior could not alone be described by the reopening.

Introduction

Marine protected areas (MPAs) and area closures are conservation tools often used in ecosystem-based management (EBM) that protect habitat from destructive human activities and overexploitation, (Hilborn & Ovando, 2014; Field et.al, 2006). Bottom-trawling is a non-selective fishing method, common in multispecies fisheries (Hixon & Tissot, 2007) and is the primary gear type used in the West Coast groundfish fishery (NWFSC, 2020). Fish stocks, such as rockfish (*Sebastes spp*.) which are not likely to travel for prolonged periods of time or areas outside closure borders may benefit from the protection MPAs give by defining areas off limits to bottom-trawling (Wallace & Gertseva, 2017; Hilborn & Ovando, 2014). Resident organisms and habitats within a MPA may experience a release from the human behavior the MPA was designed to prohibit, allowing populations to rebound (Keller et.al, 2014). MPAs take many forms and address different human behaviors, yet determining success may be difficult to quantify (Hilborn et. al, 2004; Gallacher et.al, 2016) Different dimensions, whether ecological, social, or economic, have different criteria of success (Steiner et. al, 2018; Errend et.al, 2018). In fact, some stakeholders may not consider a MPA successful unless social and economic benefits are demonstrated in addition to ecological ones (Li et. al, 2020; Shester et.al, 2020; Yates et.al, 2019).

After several decades of unsustainable catch rates, West Coast rockfish stocks were declared overfished and the groundfish fishery was an economic disaster (NOAA, 2000). The rockfish conservation area (RCA), created in 2002, was designed to reduce the incidental catch of overfished rockfish species: Darkblotched rockfish (*Sebastes crameri*), Canary rockfish (*Sebastes pinniger*), and Bocaccio (*Sebastes paucispinis*) (Wallace & Gertseva, 2017; Mason et.al, 2012). The RCA extended from the Mexican Border to the Canadian Border of the United States with a shoreward boundary at the 183 m isobath, extending seaward to the 366 isobath (NOAA, 2021), and followed the single species protection mindset. Rockfish are characterized by their general high site fidelity (Hannah & Rankin, 2011), long-lived life histories (Love et.al, 2002; Conrath & Knoth, 2013) late maturity (Berkeley et al.,2004) and increase in larval quality and annual fecundity associated with an increase in female age and size (Hixon et.al, 2014). These traits are often associated with vulnerability associated with excessive exploitation and may experience a shift in fisheries towards younger and smaller age at maturity (Wallace & Gertseva, 2017;Kuparinen & Hutchings, 2012; De Roos et.al, 2006), yet meet the criteria often associated with ecological benefits forecasted from a closed area. These life history traits may be an adaptation for low frequency environmental variability.

In the West Coast groundfish fishery (here-after groundfish fishery), management measures were designed to reduce bycatch of depleted species, such as the depth-based area closure of the rockfish conservation area, with additional management measures later incorporated to protect essential fish habitat (Bjorkland et.al, 2015; Bellman & Heppell, 2007). In combination with these area closures, other management measures such as changes in trawl footrope size (Bellman et. al, 2005), Vessel Monitoring System (VMS), and trip limits were introduced (Warlick et.al, 2018). In 2011, the fishery adopted a catch shares management structure, further aiding in the rebuilding of many rockfish species in the following years (Pfeiffer et.al, 2018). As a consequence of the successful rebuilding of overfished stocks and the implementation of other management measures, the RCA reopened to bottom contact gear on 1 January 2020 along the California and Oregon coasts (PFMC, 2020). The RCA along the Washington coast remained in place (PFMC, 2020). This reopening has been regarded as a great conservation success (Shester et. al, 2020), but given the differing dimensions of measurement between social, economic and ecological successes, and the uniqueness of closures reopening, it is important to understand fishing responses to reopened areas.

Many studies describe fishing behavior changes often associated with area closures. For instance, Murawski and colleagues (2005) showed that New England fishers increased their fishing activity along the edges of a closed area. Fishers will display characteristics of fishing the line (Murawski et al., 2005), where they fish the edges of the area closure. In contrast, near a MPA in the Indian Ocean, Sultan (2020) concludes that while fishers do “fish the line” to some extent, factors such as catch variability, distance to fishing grounds, and the potential for physical risk also influenced the response of fishers to marine protected areas. These examples explore fishing changes when a closure is put in place. This study aims to understand changes when a closure is lifted. Specifically, we asked: 1) did fishers use these previously off-limits areas in 2020 and to what extent, and 2) how did bottom-trawl vessel behavior in 2020 compare to behavior in the previous five years? Because large-scale oceanographic processes influence food web structure and groundfish productivity (Mantua & Hare, 2002; Newman et. al, 2016; Peterson et.al, 2016), we also asked if any changes in fishing and transit behavior that occurred in 2020 could be related to Pacific Decadal Oscillation (PDO).

Methods

Vessel Participation

We examined the behavior of 25 bottom-trawl fishing vessels by recreating vessel tracks through mapping of Vessel Monitoring System (VMS) data from 2015-2020. These vessels conducted a total of 607 bottom-trawl trips in the first quarter of 2015-2020. Trips varied from a high of 149 trips in 2015 to a low of 51 trips in 2019 (Table 1). These trips yield total landings of 25,017 metric tons (mt) over the study period, with a peak of 5,991 mt in 2015 and a low of 3,036 mt in 2020. To ensure VMS data confidentiality, trips were aggregated coastwide.

Table 1: Number of vessels, trips and associated landings included in this study. Vessels had a declared bottom-trawl code, and participated in at least one trip during the first quarter of the year. Values are aggregated coastwide for Quarter 1 of each year.

	Vessels	Trips	Coastwide Landings in mt
2015	23	149	5990.602
2016	19	101	4614.393
2017	22	88	4711.304
2018	18	111	3187.209
2019	17	51	3876.754
2020	16	107	3036.33

Use of the Rockfish Conservation Area by Fishing Vessels

To assess the use of RCA areas opened in 2020, we used VMS data from 2015-2020. VMS data are increasingly used to describe spatial patterns in fishing behavior (e.g., Bez et.al, 2011; Lee et. al, 2010) and can provide fishing information when logbook data may not be readily available (Hintzen et. al, 2012). By comparing 2020, the year the RCA opened, to the previous five years, we aimed to assess the degree to which patterns exhibited in 2020 differ from a typical pattern expressed over the previous five years (cf., Underwood 1992). The emerging COVID-19 pandemic was a major disrupting force for U.S. fisheries beginning in the second quarter of 2020 (Link et al. 2020, Haas et al. 2021) and certainly affected fishing and seafood markets (Smith et al. 2020, White et al. 2021). Therefore, we opted to focus on the January-March (i.e., the first quarter) pre-pandemic time period to eliminate any potential confounding effects associated with COVID-19.

Vessels participating in the groundfish fishery must have VMS which is actively transmitting once a vessel declares its intentions to fish (50 CFR§ 660.14). Our analysis focused on bottom-trawling vessels with a VMS declaration code of 230 which participated in the fishery in the first quarter of 2015-2020.

Using VMS data, we defined a fishing trip if it met the following criteria: 1) the vessel left from a harbor to the ocean, 2) while in the ocean, the vessel moved at variable speeds and headings, and 3) the vessel returned to harbor. VMS does not display what behavior a fishing vessel is engaging in (Eastwood et.al, 2007), therefore, we used vessel speed as a proxy for potential behaviors of vessels (Mills et al 2007, Lee et al. 2010). Following Murawski and colleagues (2005) we considered speeds greater than 6.5km/h as probable transiting behavior. Similarly, speeds less than or equal to 6.5km/h were characterized as probable fishing behavior (NWFSC, 2020; Lomeli et.al, 2018). Typical fishing trips by trawlers range between two and seven days in this region (NWFSC, 2020). Consequently, we limited our analysis to trips that were longer than 15 hours and shorter than 240 hours.

Fishing trips with large gaps in transmission times were eliminated from consideration. Gaps in transmission can occur when there is a loss of power or a defective VMS unit. For our analyses, we opted to eliminate fishing trips with gaps that exceeded 5.6 hours (2 standard deviations above the mean VMS transmission interval) from consideration.

Spatial patterns of fishing behavior

To determine the degree to which the reopened regions of the RCA were used by fishing vessels, we identified probable fishing behavior (speeds of less than 6.5km/h) that occurred within the RCA boundaries. We examined the occurrence of probable fishing within the RCA each year using the simple features ("sf") package in R (Pebesma E., 2018). RCA boundaries were altered to match NOAA regulations (NOAA, 2021), as boundaries altered slightly between years. We created density maps describing where slow transmissions (<6.5 km/h) occurred to get a better visual understanding of where probable fishing behavior was more likely to take place relative to the shoreline and the RCA boundary. All trips were aggregated for each of the six years. We used the density plot function "stat_density2d" from the "ggplot2" package in R programming to create a 2D kernel density estimate of the fishing points.

Temporal patterns of fishing behavior

We tested the hypothesis that mean fishing time and distance, as well as transiting time and distance, did not differ among years using analysis of variance (ANOVA). Tukey's HSD pairwise comparisons were used to assess year-to-year differences in fishing and transiting distance and time.

Confounding effects of ocean productivity on fishing behavior

To assess the degree to which fishing behavior in 2020 may have been affected by ocean productivity in addition to the opening of the RCA, we asked if changes in fishing behavior were associated with annual shifts in the Pacific Decadal Oscillation (PDO). The PDO is a periodic pattern of ocean climate variability centered over the mid-latitude Pacific basin that affects primary and secondary production throughout the California Current (Mantua & Hare 2002), and has been used extensively as a proxy for ocean productivity in this region (e.g. Peterson et al. 2014). We thus conducted an analysis of covariance (ANCOVA) to investigate the hypothesis that fishing time and distance and transit time and distance did not differ among years (main effect) or with Pacific Decadal Oscillation (PDO) index (covariate).

Results

Spatial patterns of fishing

In Oregon and California waters from 2015 through 2020, fishing vessels spent an average of 0.91% (SD 1.77%) of the time vessels were potentially fishing (i.e., moving at speeds < 6.5 km/hr) within boundaries of the RCA (Table 2). In 2020, the year the RCA reopened, 4.5% of the time vessels that were potentially fishing fell within former boundaries of the RCA. This was more than 20-fold greater than the average 0.19% that occurred in 2015-2019 before the RCA was reopened. By contrast, in Washington waters where the RCA remained closed, fishing vessels spent an average of 0.30% (SD 0.34%) of the time they were potentially fishing within the RCA in 2020. However, we did not observe an increase in the time vessels could potentially fish within the RCA boundaries in 2020 (Table 2).

Table 2: The number of vessels, trips and probable fishing behavior (speed < 6.5 km/hr) that occurred within RCA boundaries in the first quarter of 2015-2020. Because the RCA opened in 2020 in California and Oregon but remained closed in Washington, data for Washington are shown separately.

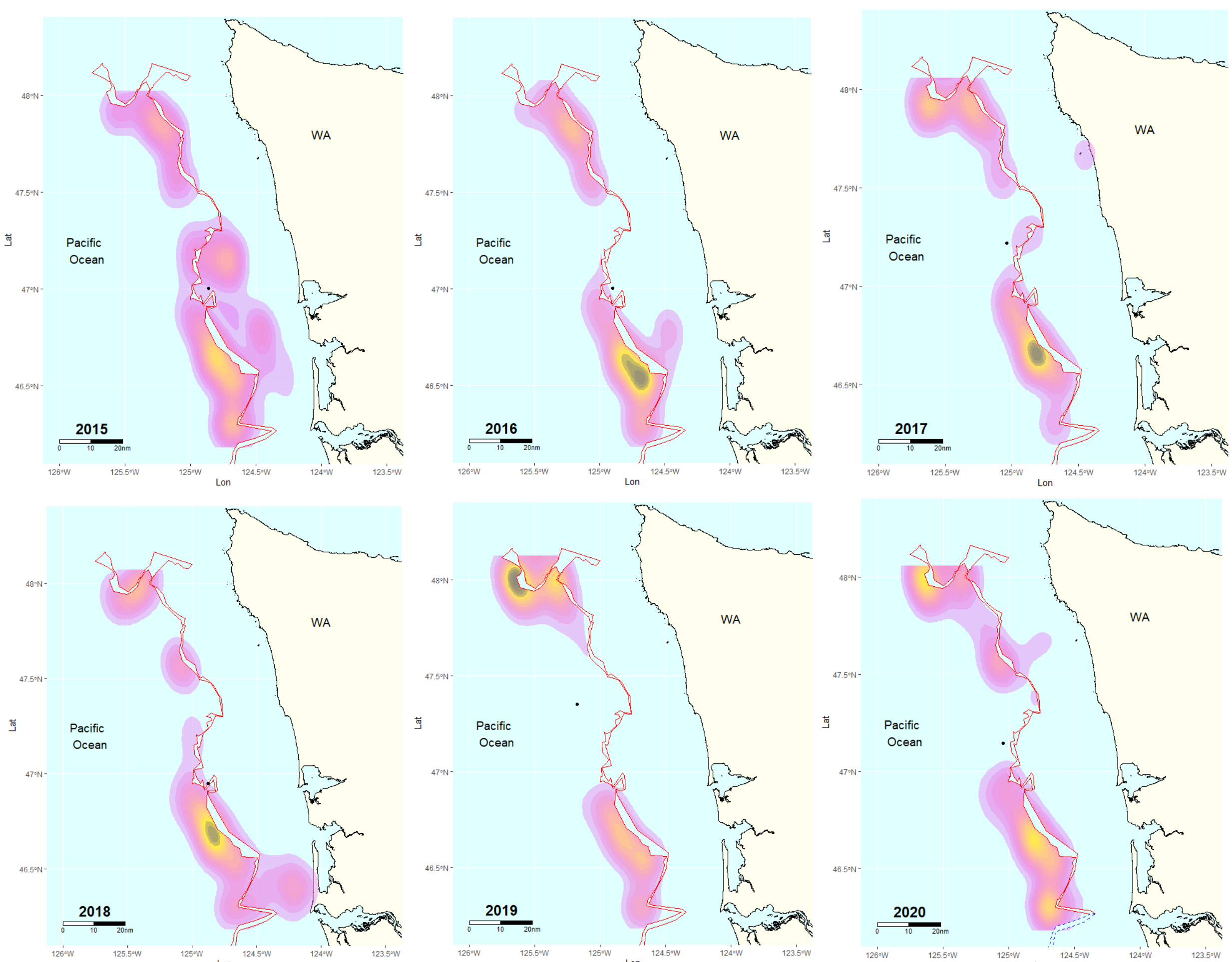
	Vessels	Trips	Probable Fishing Transmissions in WA RCA	Probable Fishing Transmissions in OR/CA RCA	Total Slow Transmissions	Hours in WA RCA	Hours in OR/CA RCA	Percent Fishing within WA RCA	Percent Fishing within OR/CA RCA
2015	9	14	6	9	5838.967	4.32	12.37	0.074%	0.212%
2016	7	12	4	11	3953.017	4.02	10.00	0.102%	0.253%
2017	5	10	6	5	3401.067	6.00	2.78	0.176%	0.082%
2018	6	10	11	6	3618.9	10.38	6.02	0.287%	0.166%
2019	8	11	18	4	1704.017	16.67	3.95	0.978%	0.232%
2020	8	26	5	133	2924.033	5.37	132.18	0.184%	4.521%

Represented in Figure 1a, the fishing activity off the Washington coast remained very similar in the six years analyzed. We can consider the activity occurring off of the Washington coast as a "control group" as the RCA remained closed to trawl fishing in 2020.

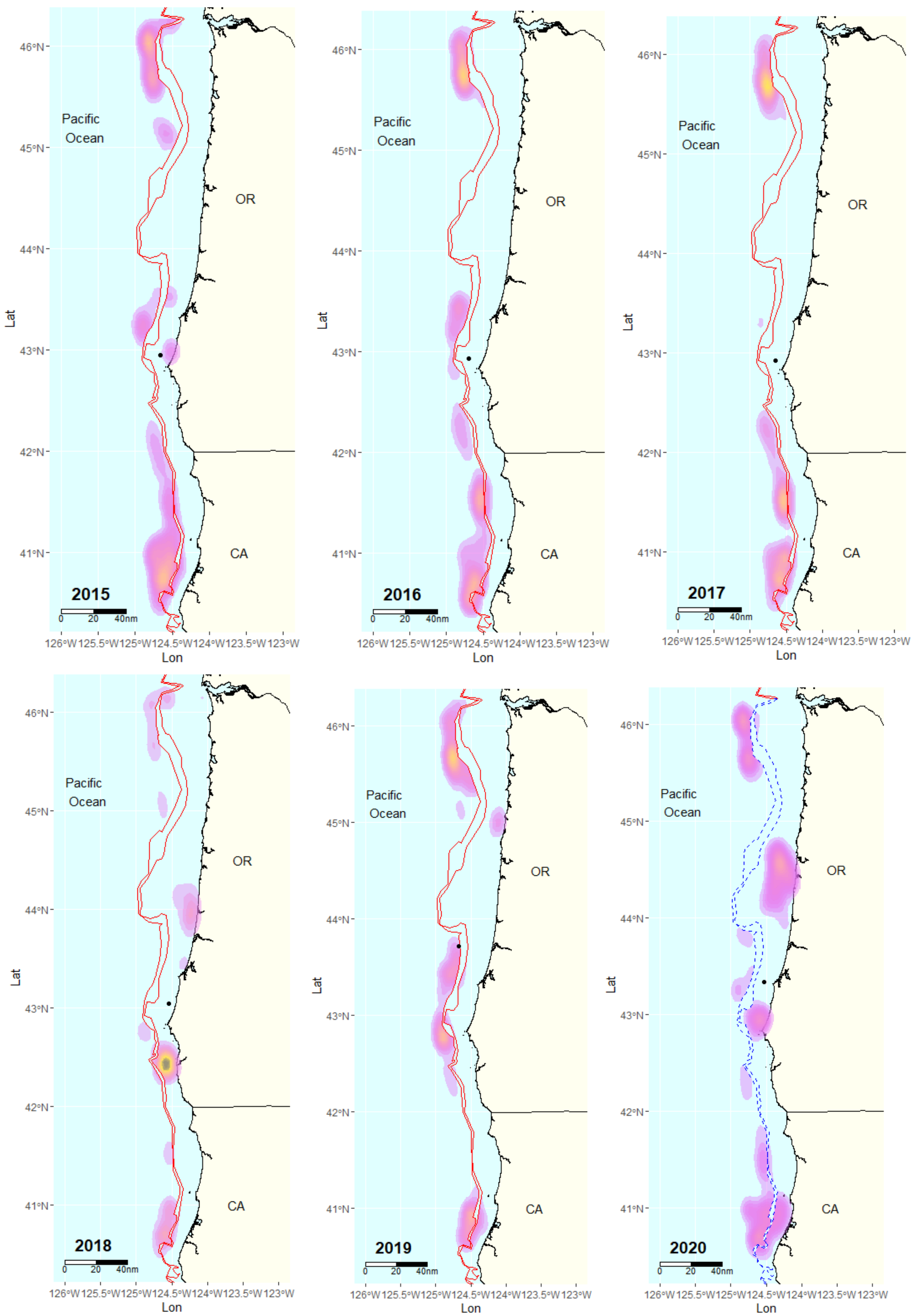
Further South, Figure 1b shows fishing behavior from the Columbia River to Cape Mendocino where the RCA reopened in 2020. In 2020, there is a noticeable shoreward shift in fishing density. Activity was primarily occurring on the seaward side of the RCA in the first five years observed, but it appears to have moved towards the shore in 2020. As we move further south along the coast between Cape Mendocino and Point Sur in Figure 1c, we see fishing activity occur in similar areas over the years, however in later years, the activity dissipates from the San Francisco Bay area and is more concentrated further north.

Figure 1: Density plots of probable fishing behavior coastwide from 2015-2020. The RCA did not re-open off the coast of Washington in 2020. The red line indicates the RCA boundary, with the blue dotted line representing the former RCA boundary in 2020. The black dot describes the mean fishing point of all transmissions plotted for that year.

a) Washington Coast Density Plots



b) Oregon Coast through Cape Mendocino Density Plots



2015
Pacific
Ocean
OR
CA
46°N
45°N
44°N
43°N
42°N
41°N
Lat
0
20
40nm
126°W 125.5°W 125°W 124.5°W 124°W 123.5°W 123°W
Lon
2016
Pacific
Ocean
OR
CA
2017
Pacific
Ocean
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CA
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Pacific
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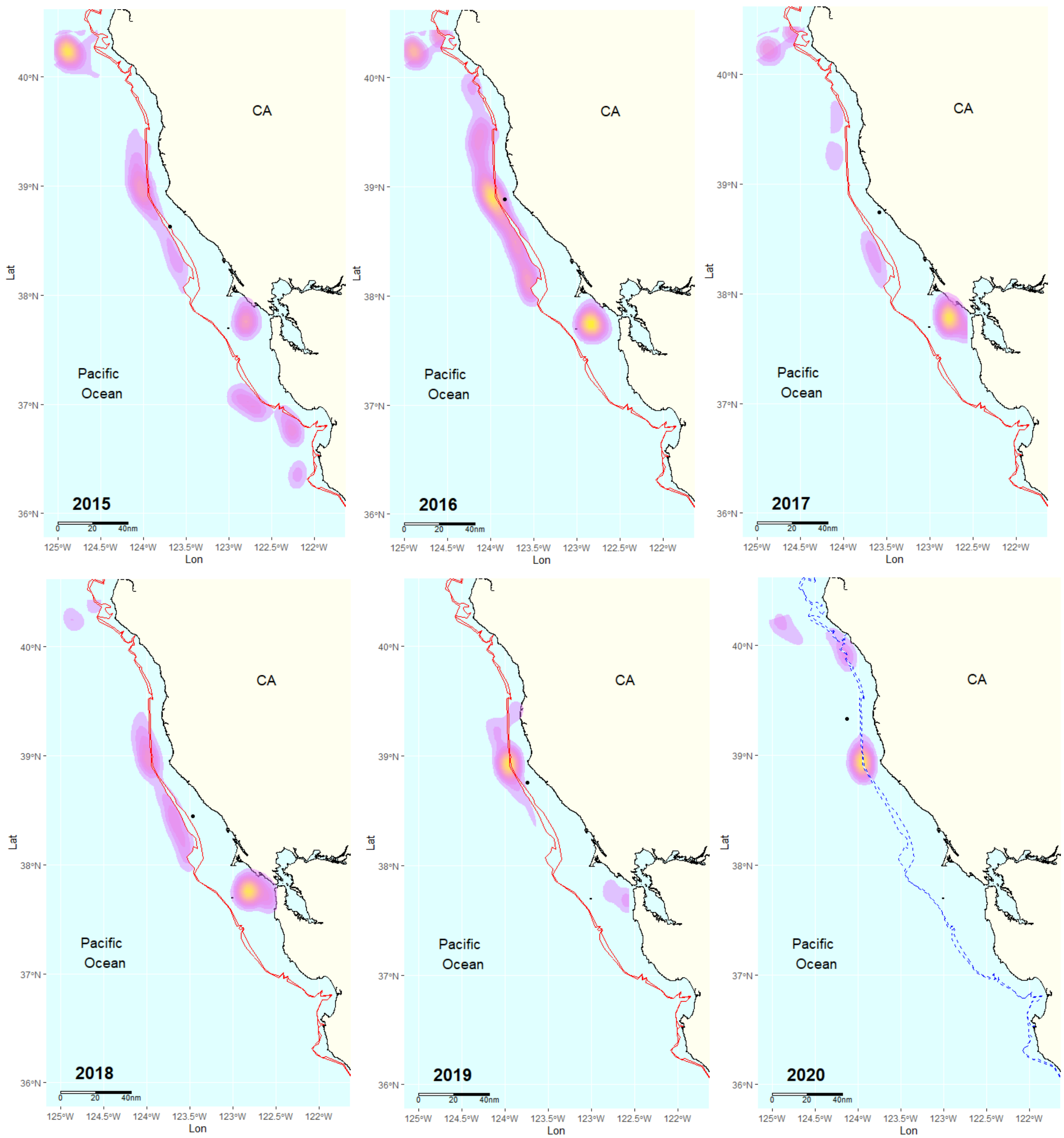
c) California Coast from Cape Mendocino to Pt. Sur Density Plots



Temporal patterns of fishing behavior

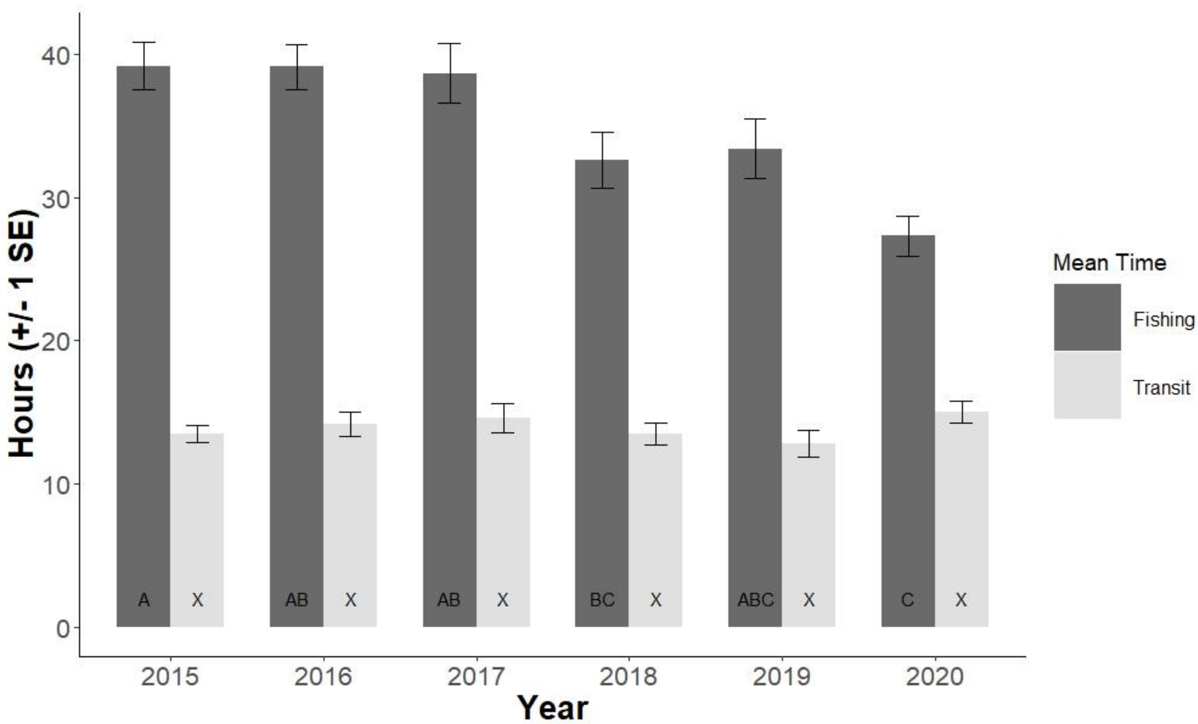
We did not detect a difference among years in the average time vessels transited (i.e. vessel speed > 6/5 km/hr) between fishing sites (Figure 2a; F = 0.889; df = 5; P = 0.488). In contrast, the average time vessels fished varied among years (Figure 2a; F = 7.619; df = 5; P < 0.001). While fishing time in 2020 was lower than fishing time in 2015-2017 (Tukey's HSD; P <0.001), we were unable to detect a difference in fishing time between 2020 and 2019 or 2018 (Tukey's HSD; P > 0.25).

Similarly, when we examined the distance transited by fishing vessels, we did not detect a difference among years (Figure 2b; F = 0.592; df = 5; P = 0.706). The average distance vessels fished did vary among years (Figure 2b; F = 10.57; df = 5; P < 0.001), and, as with fishing time, mean distance fished in 2020 was different than 2015-2017 (Tukey's HSD; P < 0.001) but not 2018 or 2019 (Tukey's HSD; P > 0.14).

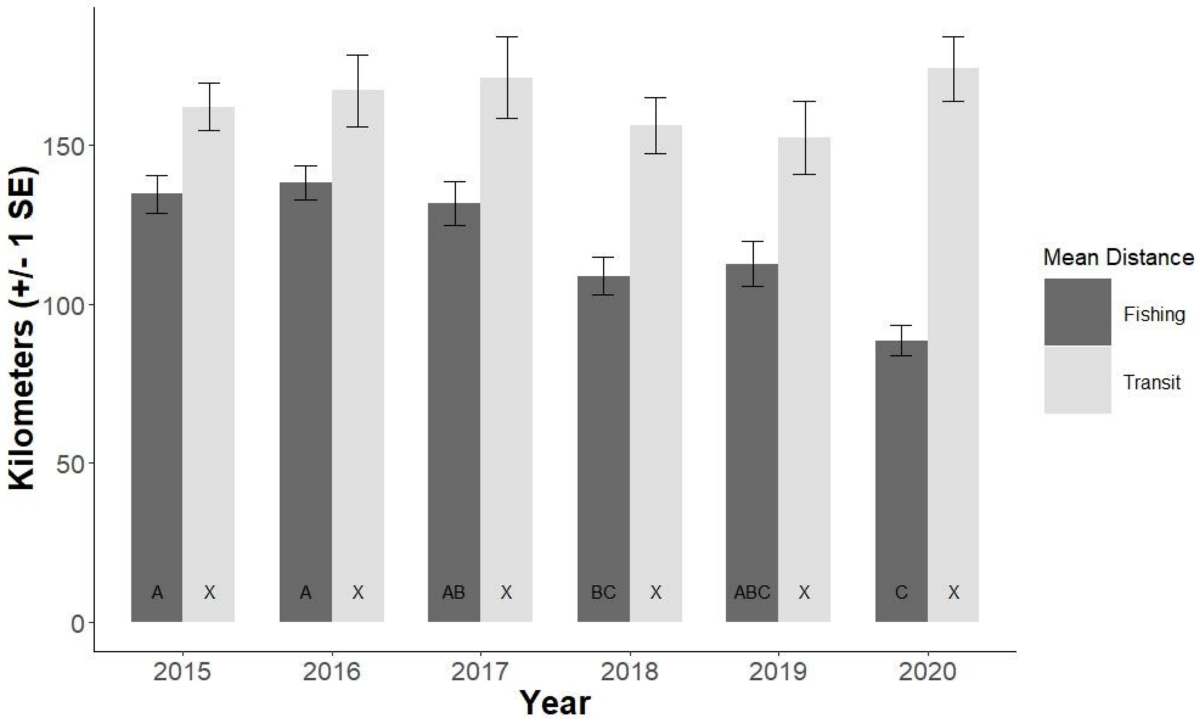
The proportion of each trip spent fishing was lower in 2020 than other years for both time (Figure 2c; F = 8.06; df = 5; P < 0.001) and distance (Figure 2c; F = 8.546; df = 5; P < 0.001). On average, vessels spent 71.2% of their time fishing per trip, however, in 2020 this declined to 62.8%. Importantly, when we removed trips in which vessels could have been fishing within the RCA boundary, the results remained the same—the proportion of time fishing was lower in 2020 than other years (F = 7.111; df = 5 ; P < 0.001). The consistency of the results that included or excluded trips in the RCA suggests this pattern is unlikely to be solely the result of the RCA reopening.

Figure 2: Mean fishing time and distance (+/- 1 SE) in the first quarter of 2015-2020. Letters within bars show means that are not significantly different in post hoc Tukey's HSD tests.

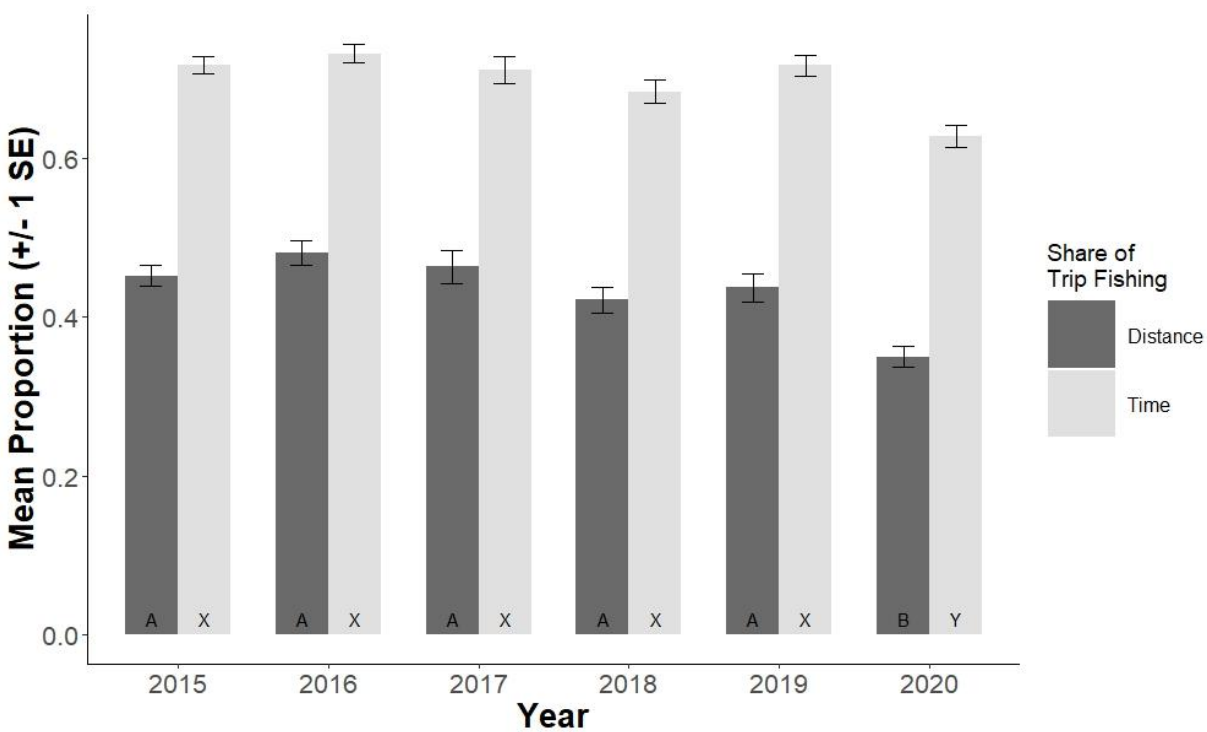
a) Mean Time by Action



b) Mean Distance by Action



c) ANOVA: Share of Trip Spent Fishing by Metric

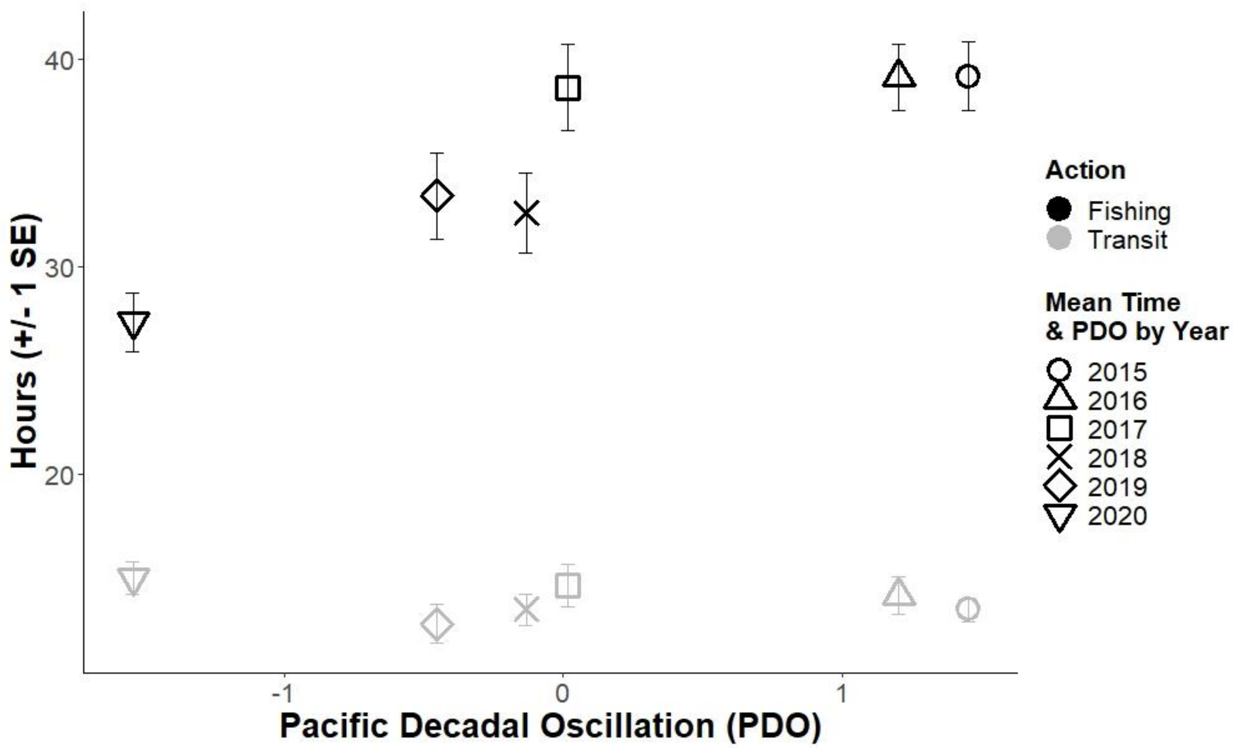


Confounding effects of ocean productivity on fishing behavior

We next explored the degree to which variability in ocean productivity could have influenced the patterns of fishing behavior observed, shown in Figure 3. Analysis of covariance revealed that, after accounting for interannual differences in fishing behavior, fishing time and distance were correlated with the PDO, indicating that fishing occurred in years with high ocean productivity (i.e., when the PDO was in a cool phase and thus the PDO index was negative; Table 3). The pattern of reduced fishing time and distance persisted when we repeated the analysis with fishing trips that occurred within the RCA boundaries removed from the analysis. We did not observe a significant association between transit distance or time and the PDO.

Figure 3: Mean fishing time and distance (+/- 1 SE) in the first quarter of 2015-2020 as a function of PDO for the first quarter of 2015-2020.

a)



b)

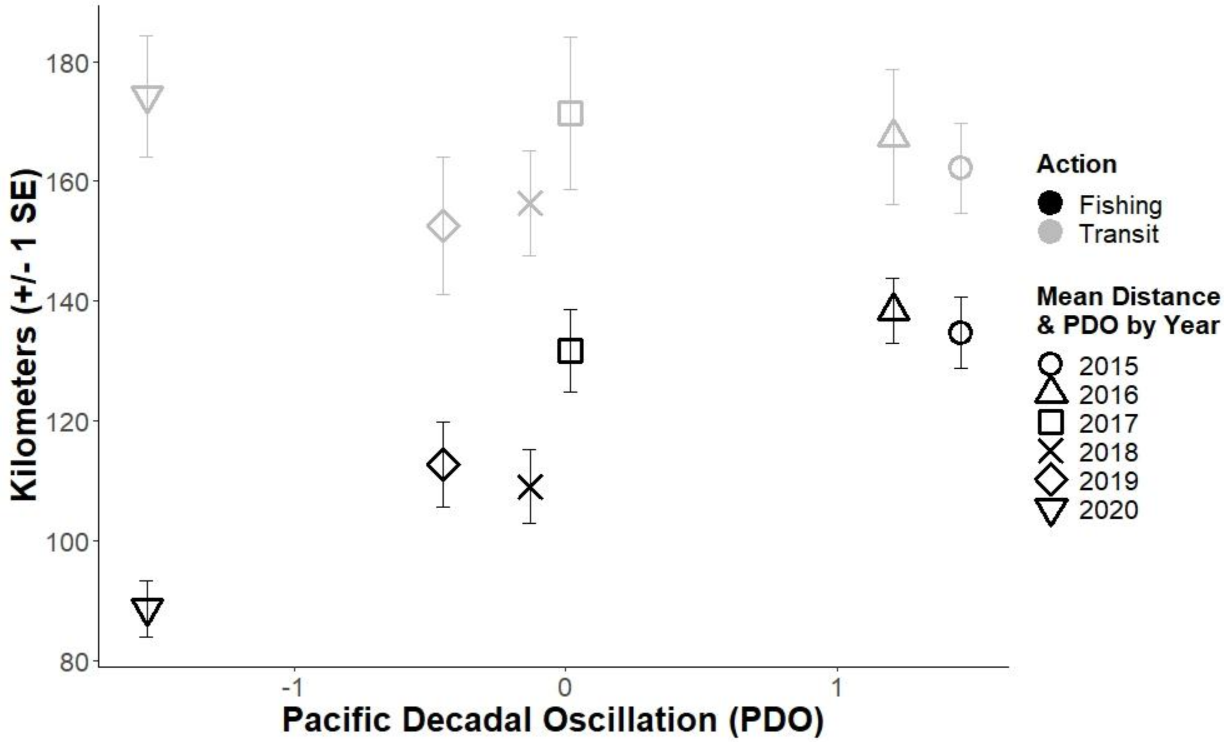


Table 3: Results of analysis of covariance investigating effects of year (main effect) and PDO (covariate) on fishing time and distance.

Measurements	All Trips			RCA Trips Removed		
Fishing Time	**Df**	**F-value**	**P-value**	**Df**	**F-value**	**P-value**
PDO	1	27.368	<0.001*	1	25.566	<0.001*
Year	5	2.716	0.019*	5	2.335	0.041*
PDO:Year	5	2.064	0.068	5	1.854	0.101
Transit Time	**Df**	**F-value**	**P-value**	**Df**	**F-value**	**P-value**
PDO	1	1.421	0.234	1	1.861	0.173
Year	5	0.756	0.582	5	1.004	0.415
PDO:Year	5	1.702	0.132	5	2.184	0.055
Fishing Distance	**Df**	**F-value**	**P-value**	**Df**	**F-value**	**P-value**
PDO	1	40.380	<0.001*	1	39.724	<0.001*
Year	5	2.984	0.011*	5	2.701	0.020*
PDO:Year	5	2.578	0.025*	5	2.032	0.073
Transit Distance	**Df**	**F-value**	**P-value**	**Df**	**F-value**	**P-value**
PDO	1	0.450	0.503	1	0.445	0.505
Year	5	0.638	0.671	5	0.839	0.522
PDO:Year	5	1.991	0.078	5	2.545	0.027*

Discussion

This study examined bottom-trawling behavior in response to the reopening of the rockfish conservation area off the coasts of Oregon and California. Through mapping of VMS coordinates, we described fishing behavior off the entire West Coast of the U.S. in the first quarter, January-March, of 2020 compared to the same time period in the five years leading up to the reopening. We found that fishing behavior in Quarter 1 2020 was different from Quarter 1 of the prior 5 years, but this difference could not solely be attributed to the reopening of the RCA. While this is only one case of a closure reopening to harvest, there are many factors that should be considered in the greater scope of ecosystem-based management.

As can be seen in Figure 1, fishing behavior moved shoreward off the Oregon and California coasts. The RCA remained in effect off the coast of Washington. Neither PDO nor the reopening of the RCA described the observed increase in shoreward fishing effort in 2020 that was observed off the coast of Oregon and California. Interestingly, this shoreward shift was not observed in Washington waters in 2020. This analysis involved data from Quarter 1, of each year, and given the shift of PDO from positive to negative, the COVID 19 pandemic, and complex interactions with other fisheries, further monitoring and analysis of other quarters may shed light upon how these systems play together.

First, the beginning of our analysis coincided with a harmful algal bloom that delayed the dungeness crab fishery in 2015-2016 and resulted in the California dungeness crab fishery never opening due to high levels of domoic acid in the crabs (Ritzman et. al, 2016). Revenue from individual fisheries may vary annually due to natural processes and market pressures. Diversifying across multiple fisheries can reduce associated financial risk to fishers (Kasperski & Holland, 2012). Along the same note, in 2018, an exempted fisheries permit was issued for vessels to participate in a novel midwater rockfish fishery (PFMC, 2020) which may have contributed to the observed decrease in bottom-trawl vessel participation, decrease in trips, and decrease in landings trend that was observed over the time period of our analysis.

Second, researchers contributing to the growing body of literature focused around ecosystem-based management suggest moving away from a focus on single species or stock management measures, and incorporating large scale oceanographic processes and spatial data centered around fishing behavior, should be further studied to describe fish recruitment and distribution (Francis et.al, 2011, Levin et al, 2018; Fu et.al, 2012; Field & Francis; 2006). Fish assemblages and seafloor ecosystems are not uniformly distributed along the seafloor (Cope & Punt, 2011). Indeed, rather than creating a mosaic of surpluses and depletions within a range of a stock, it is more important to control the total amount of fishing to ensure successful management of a stock (Ralston & O'Farrell, 2008). Likewise, considering humans as an integral part of the ecosystem is required in ecosystem-based management (Levin et.al, 2009). Within the California Current ecosystem, humans and environmental drivers are frequently being considered together, rather than separately (Dereynier, 2012; Field& Francis; 2006, Harvey et al, 2018) The densest areas of fishing behavior in our analysis of 2020 data were shoreward of the RCA, not within the reopened RCA boundaries. When extracting the trips that had utilized the RCA, there was still a noticeable change in the spatial distribution of vessels, most notably towards the shore. When comparing the same behavioral metrics that were used to describe fishing responses to the RCA as a function of Pacific Decadal Oscillation, vessel movement still displayed the same trends.

While we cannot say for certain whether or not the RCA was successful, the stocks it was designed to protect were rebuilt ahead of schedule. There was a high level of compliance in stakeholders. When considering the success of a MPA, one must understand the goals of the MPA in the first place. For the RCA, it was designed as a temporary, species-specific closure to bottom contact gear. Low frequency oceanographic processes may be associated with this shift shoreward in fishing activity observed off the coasts of Oregon and California. In the context of ecosystem-based management, many different ocean factors and management measures must be considered. MPA success relies on economic improvement, social buy-in, and measurable ecological benefits. As was the case with the rockfish conservation area, overfished stocks were rebuilt, and the goal of the RCA was met from a management perspective. When removing the protection, both habitat and biomass that a MPA provides, it is important to understand fishing behavior in response. This study looked at the first quarter that fishers were able to access the reopened area. In order to truly understand the ramifications of reopening a MPA, further monitoring would provide more information. Likewise, comparing fishing behavior as a function of PDO is a novel process, but might help inform the spatial influences on fishing behavior in addition to human management processes, as it has been indicated that fish assemblages and turnover vary based on depth (Anderson et. al, 2013). Likewise, while MPAs and area closures may provide protection from human influences, MPAs are more likely to be successful when coupled with other management measures (Gaines et.al, 2018), and success of MPAs and rebuilding efforts may be more successful when large oceanographic factors are included (Holt & Punt, 2009).

Increased incorporation of ecosystem-based fisheries management, a growing body of knowledge contributing to better fisheries policies, and a high compliance within fishery stakeholder groups are all processes that are important and should be considered by managers and stakeholders alike. When contemplating the drivers to be considered in ecosystem-based management, an interdisciplinary framework incorporating Integrated Ecosystem Approaches (IEA) is becoming more necessary to understand the complex interplay between natural drivers and human interactions (Levin et.al, 2009). In the integrated socio-ecological system of the California Current Ecosystem, ocean circulation, sea surface temperature and upwelling patterns are at the base representing bottom up drivers, along with human interactions that affect the habitat and biodiversity, as human behavior is also associated with ocean dynamics (Levin et al, 2016). In order to incorporate human activities into ecosystem-based management, economic success, and a variety of management strategies alongside MPAs, is necessary (Melnychuk et.al, 2013). Minimizing MPAs may also minimize the socio-economic costs associated with them (Li et.al, 2020).

Data Availability: Confidential Vessel Monitoring System data may be acquired by direct request from the NOAA Fisheries, West Coast Region, Sustainable Fisheries Division, subject to a nondisclosure agreement. Aggregated, nonconfidential data to construct metrics data used as input for the graphs and figures, as well as the R code are available by request to the authors.

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