Displacement of fishing effort by Large Scale Marine Protected Areas

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Abstract

Large-scale Marine Protected Areas (LSMPAs) have seen a significant increase over the last years. Fishing effort is effectively eliminated within these protected areas upon implementation. The benefits of reducing effort have been largely studied, and include increases in abundance, biomass, and diversity within the bounded regions. These no-take zones may produce spillover effects, which provide fish for outside areas. However, the economic and ecological implications of displacing fishing effort are not yet fully understood. Novel data products that track fishing effort at the vessel-level allow us to identify changes in fleet- and vessel-level behavior upon the implementation of protected areas, as well as how these redistribute. This papers evaluates the implications of implementing LSMPA, by evaluating changes in fishing hours, showing that vessels in the effected region reduce fishing effort after the implementation of PIPA. Our results are robust to a set of specifications. We also track the relative spatial allocation of fishing events thorugh time, and identify that areas closer to PIPA show an increase in relative fishing hourse due to the displacement of PIPA-fishing vessels. Our results not only provide an impact evaluation of the effect of LSMPAs on fishing activity, but provide insights into vessel redistribution dynamics, which may have ecological and economic implications.

Introduction

This work identifies the behavioral changes of fishing vessels due to the implementation of PIPA. Not only can we identify temporal changes in fishing patterns (*i.e.* time and distance), but also spatial patterns. Our vessel-level tracks allow us to see where PIPA-fishing vessels go after the closure, providing empirical insights about the redistribution of fishing effort after the implementaion of a MPA.

Methods

This section is divided into two main parts. First, we provide a general description of AIS data and the process of identification of vessel-level events done by Global Fishing Watch[1]. Alongside, we describe the subset of data that we use for these analyses. When relevant, we also point out possible shortcommings in the data, or factors that must be considered in the later analyses. Then we move on to explain our identification strategy, and the main analyses that we undertake.

Data

AIS data

Automatic Identification Systems are on-board devices intended to provide at-sea saftey and prevent ship collisions by broadcasting vessel locations to surrounding vessels. These broadcasted positions can be recorded by satellites and land-based antenas. GFW uses a neural network to infer vessel characteristics and whether each broadcasted position represents a fishing event, thus allowing us to estimate near real-time fishing events globally since 2012 [Kroodsma et al., 2018]. The recent addition of satellites that can receive AIS signals causes an apparent increase in the number of broadcasted AIS messages (*i.e.* points) and therefore fishing hours. The variability in AIS data and ocean conditions require that temporal trends be taken into account. We do that by incorporating a series of controls, which are defined in the following section.

PIPA data

Our data contain over 45 million individual AIS messages for 371 purse seiners and longliners. A total of 233 vessels have fished within PIPA waters; 217 did so at least once before 2015. However, not all vessels continued to fish elsewhere after PIPA implementation: 34 vessels have no recorded AIS messages after 2015[2], leaving us with 183 vessels that fished inside

[1] Global Fishing Watch: globalfishingwatch.org

[2] The 0 missing vessels might have exited the fishery, been decomissioned or sold (therefore changing their AIS and mmsi), or turned off their AIS transmiters. In either case, we are not able to observe these.

PIPA before its implementation, and continued to fish elsewhere afterward. Vessels that fished within PIPA before implementation might stop fishing afterwards, therefore not being observable in the post-treatment period. New vessels might have also entered the fishery after PIPA closure, and were likely not exposed to the policy intervention in the pre-treatment period. Therefore, we define our treatment and control groups as follows.

The treatment group contains all vessels (n = 183) that fished within PIPA at least once before the closure, and that continued to fish elsewhere afterwards. Vessels in the control group meet al three of the following conditions: i) Vessels never fished within PIPA waters, ii) vessels belong to other PNA countries, and iii) vessels have fished in surrounding areas (*i.e.* PNA-countries' EEZ) before and after PIPA closure. For each vessel meeting these characteristics, we calculate their total monthly fishing hours. Figure 1 provides a visual representation of the vessel-level streams of fishing events that make up each group through time. Tables 1 and 2 show the number of vessels following a BACI design, and fishing hours, respectively. Tables show data grouped by gear (longlines, purse seines), group (treated, control), and period (before, after). The relative change in fishing hours (After / Before) is also shown.

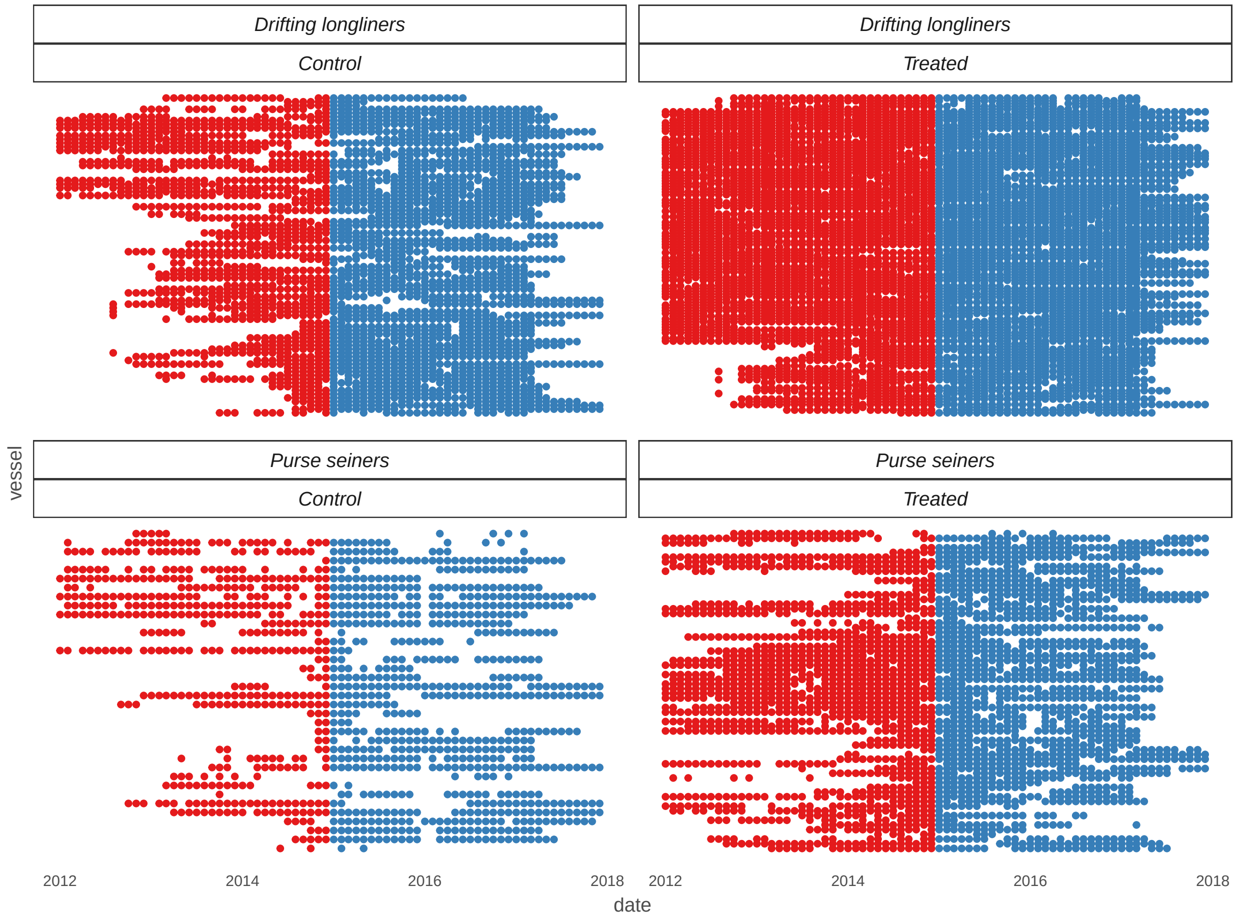

Figure 1: Stream of fishing events by vessels through time. Each line represents a vessel, with dots indicating months with fishing activity and colors indicating the pre and post periods. Pannels separating between gear and treated or control groups.

Table 1: Number of fishing vessels (identified by mmsi) by gear and treatment group.

Gear	Treatment	n
drifting_longlines	FALSE	85
drifting_longlines	TRUE	115
purse_seines	FALSE	36
purse_seines	TRUE	68

Table 2: Mean fishing hours and relative change by gear and treatment group.

Gear	Treatment	Before	After	Change (A / B)
drifting_longlines	FALSE	474.47780	462.5491	0.9748593
drifting_longlines	TRUE	544.61935	522.8392	0.9600085
purse_seines	FALSE	59.49026	154.5776	2.5983673
purse_seines	TRUE	52.91534	131.5452	2.4859561

Analysis

The first analysis focuses on identifying the response of fishing vessels to PIPA closure. Our variables of interests are fishing effort, indicated by total fishing hours per month, and distance traveled (Km) on every fishing trip. We compare fishing hours[3] before and after the implementation of PIPA using a Difference-in-Differences approach, where we track the variable of interest for vessels that used to fish inside PIPA and vessels that never fished inside PIPA, before and after PIPA implementation. Our specification is the following:

$$y_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Treat_i + \beta_3 Post_t \times Treat_i + \mu_1 Y_t + \mu_2 Y_t^2 + \phi_t + \gamma_i + \epsilon_{i,t}$$

Where $y_{i,t}$ is the variable of interest for vessel i in time period t. A dummy variable $Post_i$ takes the value of 0 for all dates prior to PIPA implementation and a value of 1 por all dates including and following PIPA implementation. $Treat_i$ is a dummy variable indicating whether a vessel belongs to the control ($Treat_i = 0$) or treatment ($Treat_i = 1$) group. α is the standard intercept, β_1 captures the *ex post* change, β_2 captures the difference between treated and control groups, and β_3 is our parameter of interest: de DiD estimate capturing the treatment effect. Finally, μ_1 and μ_2 are coefficients for a second order polynomial for years (Y_t)[4], while ϕ_t and γ_i represent month-, and flag-level dummies that account for seasonality or country-level management interventions.

Our second part of the analyses focuses on the redistribution of fishing effort. In other words, identifying where do vessels that used to fish inside PIPA go after its establishment. We calculate the monthly relative distribution of fishing hours by all treated vessels across all fished EEZs and the high seas. These trends are shown in Figures 3 and **??**, and the relative change is presented in Table 3. EEZs that had sproadic fishing events were pooled into a group of "others", leaving us with a total of n = 12 and n = 10 spatially defined regions (*i.e.* EEZs, High Seas, "other EEZs") for purse seiners and longliners, respectively.

To evaluate this change in effort allocation, we regress our variable of interest, fishing hours, on the interaction between a dummy variable indicating the policy intervention and a dummy variable for countries, to obtain the by-country change in proportional allocation of fishing effort:

[3] And soon, distance

[4] An earlier specification included years as a dummy variable. Such results are included in the appendx.

$$y_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Country_i + \beta 3 Post_t \times Country_i + \epsilon_{i,t}$$

Our variable of interest, $y_{i,t}$ represents the proportion of fishing hours that country i receives at time t. *Post* also represents a policy dummy that takes the value of 0 for all dates before implementation of PIPA, and 1 otherwise. *Country* is a dummy variable for countries, interpreted as individual EEZs, the high seas, and a group of "other EEZs". Our parameter of interest is β_3, which captures the country-level change in proportional fishing effort.

All regression coefficients were estimatedd via ordinary least squares, and heteroskedastic-robust standard errors were calculated. All analyses were performed in R version 3.5.1) [R Core Team, 2018]. Raw data and code used in this work are available on github.

Table 3:

country	Longliners	Purse seiners
PIPA	-11.48	-8.54
KIR	1.28	2.76
HS	0.00	0.00
COK	0.00	0.34
FSM	0.00	0.55
MHL	NA	-0.55
NRU	0.00	0.16
PNG	0.00	-10.02
SLB	-8.48	2.13
TKL	NA	0.19
TUV	7.23	1.47
others	22.55	11.51

Results

Our data suggest that purseiners and longliners have different responses to the implementation of a Large-Scale Marine Protected Area. Fig. 2 shows that mean fishing hours for purse seiners have an abrupt increase, just before January 1st, 2015. This trend is observed for both treated and control groups. Longliners, however, show a more stable trend. The number of mmsi codes increases through time. This can largely be explained by the addition of more satellites, which increase detectability of vessels. As expected, total fishing hours follow a similar trend to that of mmsi numbers.

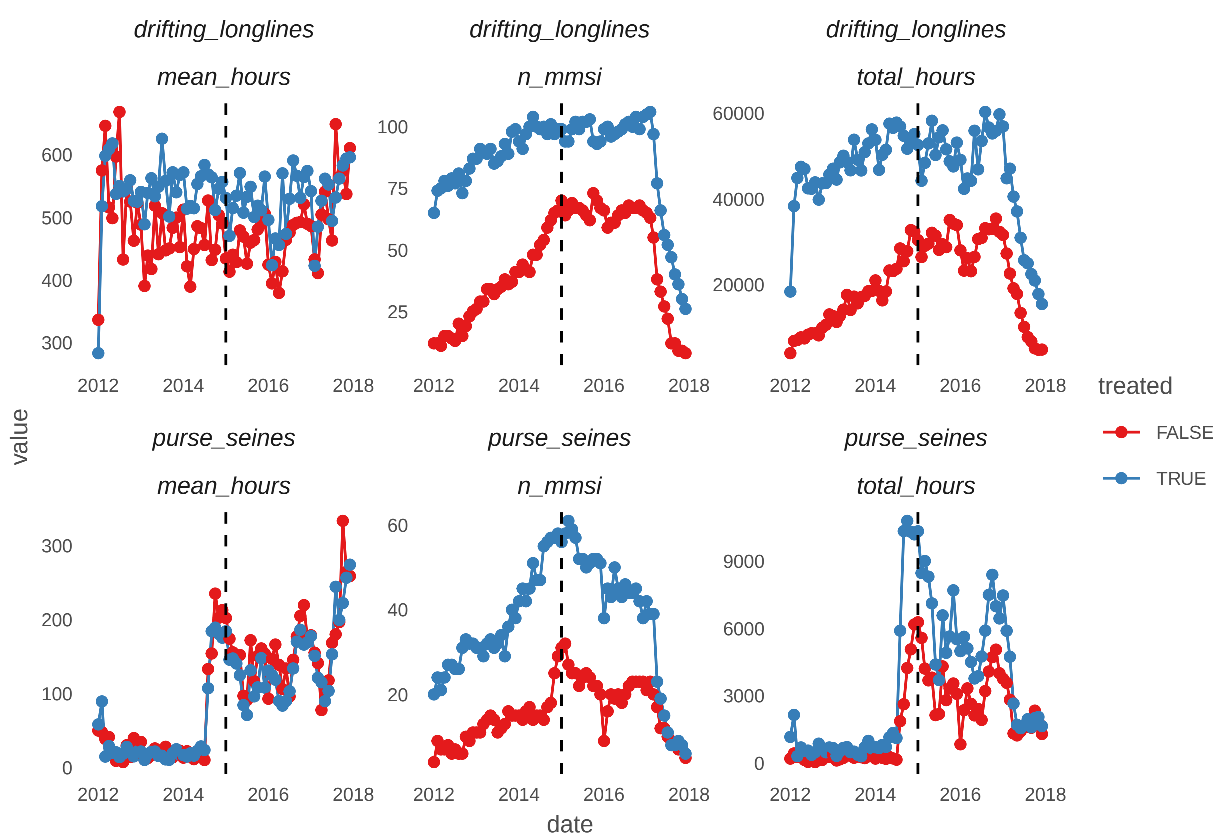

Figure 2: Fishing hours and number of vessels by month for all vessels. Vertical dashed line indicates PIPA closure.

Our DiD anaylsis shows that treated purse seiners reduce their fishing effort after PIPA implementation in the order of 16 hours per month. This result is robust and significant ($p < 0.05$) for all model specifications, with the effect varying between $\beta_3 = -16.457$ and $\beta_3 = -18.709$. Model specifications that include the year polynomial show lower values for the β_1 coefficient associated to the $Post_t$ policy dummy, and show positive and negative values for μ_1 and μ_2, the linear and cuadratic terms, respectively. These effectively represent the patterns observed in Figure {fig:all_vessels}.

Longliners show a similar pattern of effort reduction. However, the magnitude of the β_3 coefficient is smaller (ranging from $\beta_3 = -9.851$ to $\beta_3 = -14.850$) and not significant across all model specifications. This, along with higher standard error values suggest that longliners have a smaller and more variable response to the implementation of LSMPAs.

Regressions coefficients for each gear type are shown in Tables 4 and 8. Column (1) presents the DiD regression with no fixed effects, column (2) includes month fixed effects, column (3) includes month and the second degree polynomial for years, and column (4) includes all of the above and country-level fixed effects.

Table 4: Fishing hours from GFW for purse seiners (n = 106; 38 control, 68 treatment). Asterisks indicate significance levels. Numbers in parenthesis represent heteroskedastic-robust standard errors.

	Dependent variable:			
	hours			
	(1)	(2)	(3)	(4)
post	95.087***	99.232***	38.349***	41.920***
	(5.877)	(5.453)	(7.423)	(8.214)
treated	−6.575	−5.597	−3.811	6.541
	(4.985)	(4.564)	(4.247)	(5.195)
year			12,828.900***	16,665.590***
			(2,451.444)	(3,717.658)
year2			−3.178***	−4.131***
			(0.609)	(0.923)
post:treated	−16.457**	−16.739***	−17.304***	−18.709***
	(6.856)	(6.460)	(6.254)	(6.787)
Constant	59.490***	65.485***	−12,946,334.000***	−16,807,078.000***
	(4.422)	(6.132)	(2,473,372.000)	(3,759,572.000)
Month FE	No	Yes	Yes	Yes
Flag FE	No	No	No	Yes
Observations	3,867	3,867	3,867	3,481
R^2	0.171	0.243	0.281	0.299
Note:				*p<0.1; **p<0.05; ***p<0.01

Recall that to evaluate the redistribution of fishing effort we only track fishing vessels that belong to the treated group. In this case, we calculate the prportion of fishing effort allocated

Table 5: Fishing hours from GFW for longliners (n = 203; 88 control, 115 treatment). Asterisks indicate significance levels. Numbers in parenthesis represent heteroskedastic-robust standard errors.

	Dependent variable:			
	hours			
	(1)	(2)	(3)	(4)
post	−11.929	−6.968	−15.550	−6.761
	(7.969)	(7.975)	(10.181)	(11.289)
treated	70.142***	72.314***	71.985***	14.026*
	(7.200)	(7.200)	(7.279)	(7.988)
year			−6,673.971*	21,188.090***
			(3,606.793)	(5,631.642)
year2			1.657*	−5.259***
			(0.894)	(1.398)
post:treated	−9.851	−12.290	−12.779	−14.850
	(9.294)	(9.262)	(9.334)	(9.563)
Constant	474.478***	449.960***	6,719,355.000*	−21,341,371.000***
	(6.328)	(9.440)	(3,633,994.000)	(5,644,837.000)
Month FE	No	Yes	Yes	Yes
Flag FE	No	No	No	Yes
Observations	9,460	9,460	9,460	8,269
R^2	0.027	0.041	0.042	0.094
Note:				*p<0.1; **p<0.05; ***p<0.01

every month to each spatially explicit region outlined by EEZs and the high seas. For purse seiners, these represent 9 main EEZs, PIPA, the high seas, and a group of other EEZs. Figure 3 shows the monthly relative fishing hours that each region received by all 183 treated vessels. The top-left pannel shows the change in fishing effort inside PIPA, including the preemtive fishing and immediate reduction previously reported [McDermott et al., 2018].

The change in the relative allocation fishing effort by purse seiners increases in eight of the 12 regions after PIPA implementation 6. The largest increase is observed for the I-Kiribati EEZ, with an average increase of 0.11 ($p < 0.001$). In other words, the redistribution of treated vessels caused a 10% increase in the *relative* allocation of fishing effort within I-Kiribati waters. The only decrease is observed for Papua New Guinea, but the coefficient is not significant. Figure 5 provides a spatial representation of these changes. It is evident that the increase in relative fishing effort is greater for for regions closer to PIPA.

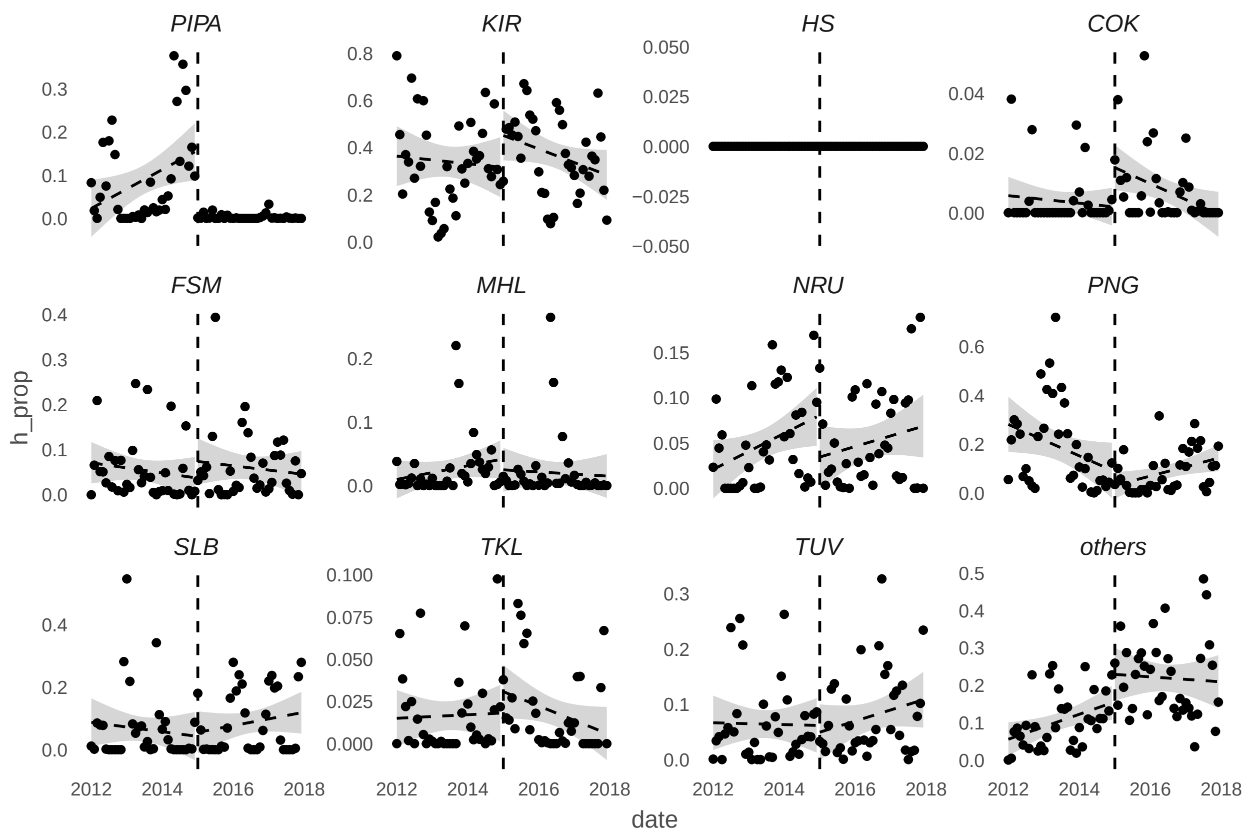

Figure 3:

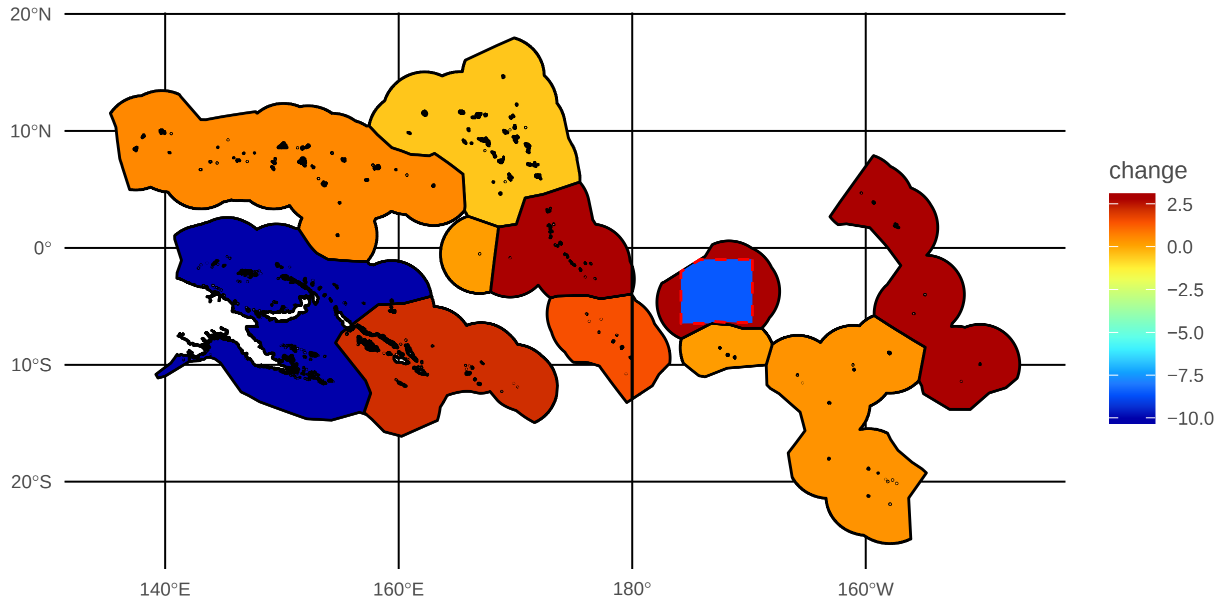

Figure 4:

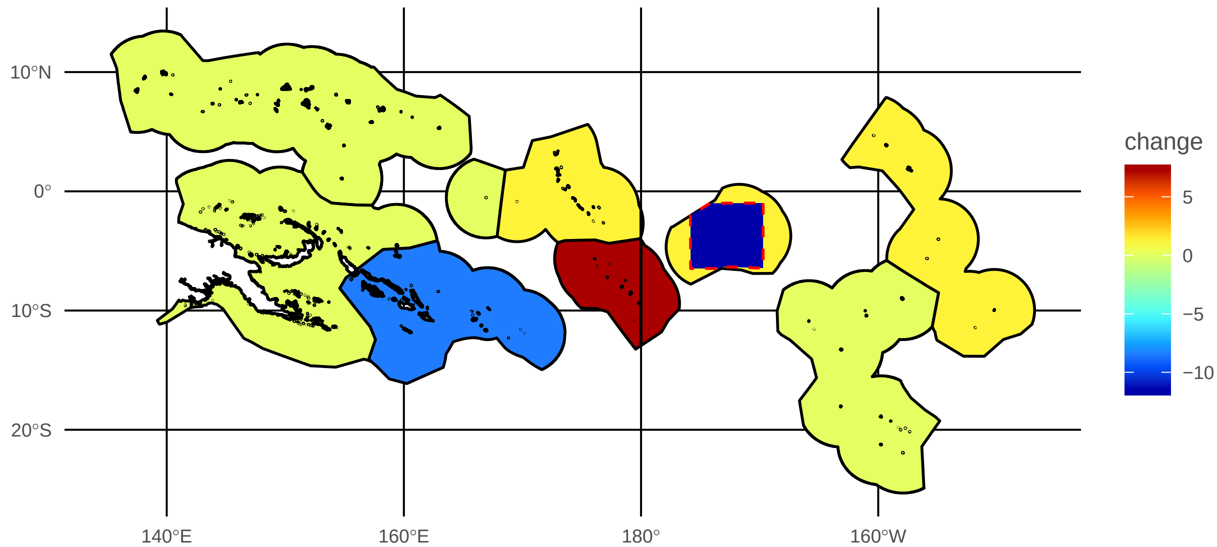

Figure 5:

Discusion

Our findings provide interesting insights into the effect that LSMPAs can have on vessel behavior and the redistribution of fishing effort. These collection of results shows that the implementation of PIPA caused treated vessels to redeuce their fishing hours, and that this effect is greater for purse seiners. Even though treated vessels fish less, their relative allocation of fishing hours increased for all other fishing grouds. This fidnings does not imply that there is more fishing effort, but rather that each region receives a greater portion of the post-PIPA fishing effort (which is lower than pre-PIPA). In this section we discuss the implications of vessel-level reductions in fishing effort and the increase in relative allocation of the remaining effort through space. We also provide plausible explanations as to why purse seiners seem to be more reactive to the spatial closure.

Previous studies on insular environments suggest that vessels move to distant places, which might be translated as increased costs [Stevenson et al., 2013]. Nevertheless, this study does not use counterfactuals that could help account for system- or fleet-level changes that

Table 6: Change in the relative allocation of fishing hours by purse seiners for each region. Asterisks indicate significance levels. Numbers in parenthesis represent heteroskedastic-robust standard errors.

	Dependent variable:
	h_prop
post	−0.085*** (0.018)
countryKIR	0.251*** (0.036)
countryHS	−0.089*** (0.018)
countryCOK	−0.085*** (0.018)
countryFSM	−0.034 (0.021)
countryMHL	−0.063*** (0.019)
countryNRU	−0.039** (0.020)
countryPNG	0.098*** (0.034)
countrySLB	−0.023 (0.026)
countryTKL	−0.072*** (0.018)
countryTUV	−0.024 (0.021)
countryothers	0.016 (0.021)
post:countryKIR	0.113** (0.045)
post:countryHS	0.085*** (0.018)
post:countryCOK	0.089*** (0.018)
post:countryFSM	0.091*** (0.025)
post:countryMHL	0.080*** (0.021)
post:countryNRU	0.087*** (0.021)
post:countryPNG	−0.015 (0.037)
post:countrySLB	0.107*** (0.031)
post:countryTKL	0.087*** (0.019)
post:countryTUV	0.100*** (0.025)
post:countryothers	0.201*** (0.028)
Constant	0.089*** (0.018)
Month FE	No
Observations	864
R^2	0.557
Note:	*p<0.1; **p<0.05; ***p<0.01

occur through time. Others have used similar satellite-tracking systems to show that fishing effort accumulates near the edges ospatial closures, yielding greater catches [Murawski et al., 2005]. Yet, these vessel tracks do not cover the pre-reserve period, making it difficult identify the contribution of spatial closures to the observed spatial distribution of fishing vessels. Recent work by Elahi et al. [2018] identified that total fishing effort in a focal region where a short-term MPA was implemented showed little change, likely indicating that fishers redistributed fishing effort to compensate for the reduction in available space. Our data is assambled in a similar way, with fishing positions before and after the implementation of PIPA and vessels grouped into treated and control groups. Our BACI design, along with our difference-in-differences analysis allows us to make causal inferences about the effect that large scale marine protected areas have on fishing effort.

The different responses observed between purse seiners and longliners might have two possible explanations. It is likely that PIPA did not contain habitat that longliners would consider optimal. Therefore, the sporadic fishing events that occurred there are of little importance to the fleet, and it is unlikely that the implementation of PIPA has an effect on them. Alternatively, the differences may be due to the nature of each fishing gear. Purse seiners are often constrained by seafloor and termocline depth, and often operate in more restricted areas [Kroodsma et al., 2018]. Tuna purse seiners are known to have greater proportion of null sets (*i.e.* where the purse seine is effectively casted arround tuna, but no catch is obtained) during El Niño years, where the termocline deepens in the Eastern Pacific [Dreyfus-Leon, 2015]. On the other hand, longliners may be more flexible as to where they can deploy their longlines. Ortuño-Crespo et al. [2018] evaluated the ecological niche of the pelagic longline fleet, and suggest that the fleet may be underutilizing the ocean, meaning that they can easily redistribute elsewhere.

References

Appendix

Table 7: Fishing hours from GFW for purse seiners (n = 106; 38 control, 68 treatment). Asterisks indicate significance levels. Numbers in parenthesis represent heteroskedastic-robuste standard errors.

	Dependent variable:			
	hours			
	(1)	(2)	(3)	(4)
post	95.087***	99.232***	146.372***	119.222***
	(5.877)	(5.453)	(6.926)	(6.717)
treated	−6.575	−5.597	−6.050	2.925
	(4.985)	(4.564)	(4.095)	(5.052)
post:treated	−16.457**	−16.739***	−14.748**	−16.231**
	(6.856)	(6.460)	(6.152)	(6.692)
Constant	59.490***	65.485***	36.643***	53.138***
	(4.422)	(6.132)	(6.462)	(10.394)
Month FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Flag FE	No	No	No	Yes
Observations	3,867	3,867	3,867	3,481
R^2	0.171	0.243	0.301	0.320
Note:		*p<0.1; **p<0.05; ***p<0.01		

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Table 8: Fishing hours from GFW for longliners (n = 203; 88 control, 115 treatment).. Asterisks indicate significance levels. Numbers in parenthesis represent heteroskedastic-robuste standard errors.

	Dependent variable:			
	hours			
	(1)	(2)	(3)	(4)
post	−11.929	−6.968	8.201	17.751*
	(7.969)	(7.975)	(11.119)	(10.388)
treated	70.142***	72.314***	72.243***	13.875*
	(7.200)	(7.200)	(7.283)	(7.992)
post:treated	−9.851	−12.290	−13.287	−14.750
	(9.294)	(9.262)	(9.344)	(9.569)
Constant	474.478***	449.960***	449.666***	429.919***
	(6.328)	(9.440)	(11.122)	(27.606)
Month FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Flag FE	No	No	No	Yes
Observations	9,460	9,460	9,460	8,269
R^2	0.027	0.041	0.042	0.094
Note:				*p<0.1; **p<0.05; ***p<0.01

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