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.

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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[1]. 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. It is therefore important to be cautious when comparing temporal trends. The variability in AIS data and dynamic 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

The GFW data contain 233 purse seiners and longliners that have fished within PIPA waters. From these, only 217 did so at least once before 2015, but only 183 continued to fish after 2015[2]. 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 that fished within PIPA at least once before the closure, and that continued to fish elsewhere afterwards. The control group has vessels that never fished within PIPA waters, belong to other PNA countries, and have fished in surrounding areas (*i.e.* PNA-countries' EEZ) before and after PIPA closure. Figure 1 provides a visual representation of the vessel-level that make up each of group through time.

Tables 1, 2, and 3 show the number of vessels, 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 (After / Before) is also shown. Table 1 shows information for all fishing vessels in the dataset, while Tables 2 and 3 show information for vessels that meet the BACI design (i.e. excludes vessels that only appear at one point in time).

[1] Global Fishing Watch

[2] The 34 missing vessels might have exited the fishery, been decomissioned or sold (therefore chaning their AIS and mmsi), or turned off their AIS transmiters. On either case, we are not able to observe these.

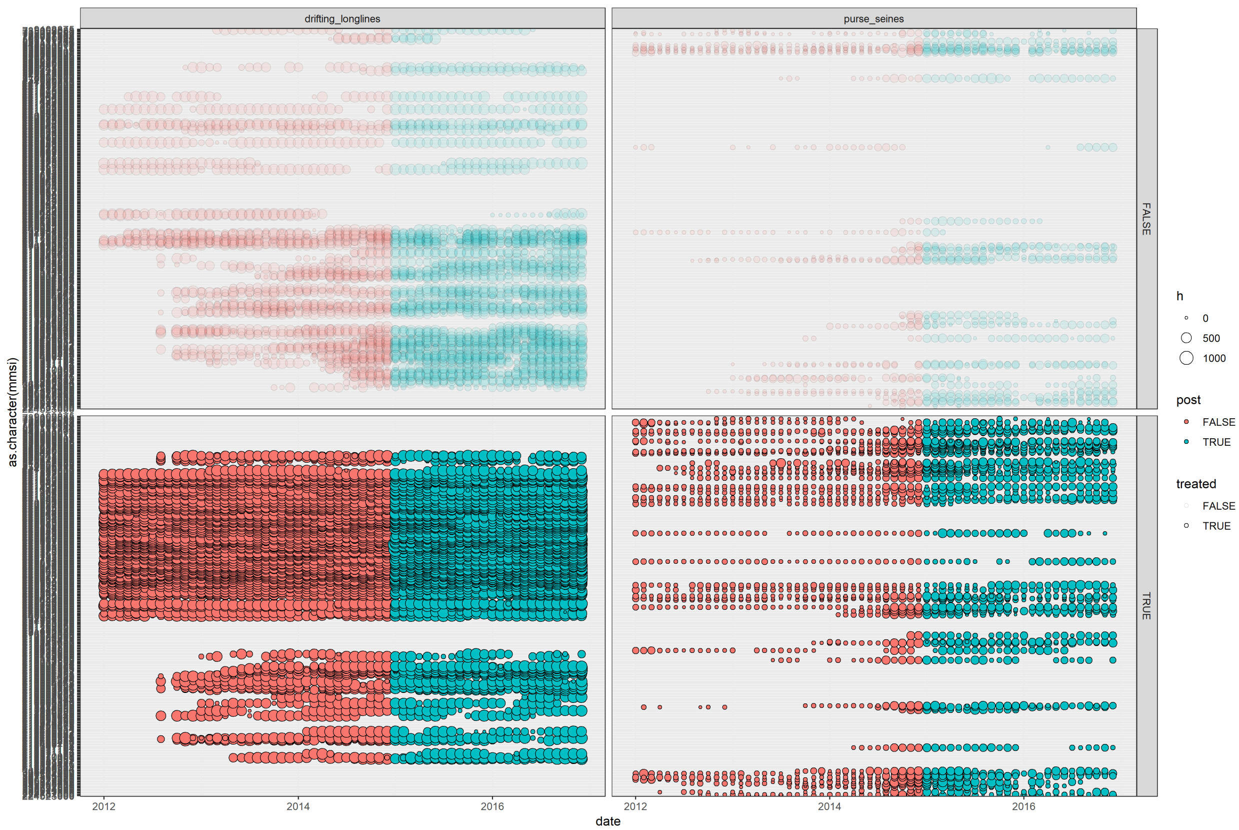


Figure 1: Stream of fishing events by vessels (stacked on the y-axis due to space) through time (x-axis). Each dot represent a vessel-month, with colors indicating the pre and post periods, and pannels separating between gear and treated or control groups.

Table 1: Number of fishing vessels (identified by mmsi) for each gear before and after PIPA implementation.

Gear	Treatment	Before	After	Change (A / B)
drifting_longlines	FALSE	105	218	2.0761905
drifting_longlines	TRUE	139	118	0.8489209
purse_seines	FALSE	49	89	1.8163265
purse_seines	TRUE	78	81	1.0384615

Table 2: Number of fishing vessels (identified by mmsi) for each gear before and after PIPA implementation.

Gear	Treatment	Before	After	Change (A / B)
drifting_longlines	FALSE	88	88	1
drifting_longlines	TRUE	115	115	1
purse_seines	FALSE	38	38	1
purse_seines	TRUE	68	68	1

Table 3: Mean fishing hours for each gear before and after

Gear	Treatment	Before	After	Change (A / B)
drifting_longlines	FALSE	481.42502	473.5823	0.9837094
drifting_longlines	TRUE	548.22580	524.8121	0.9572919
purse_seines	FALSE	66.50483	172.3775	2.5919548
purse_seines	TRUE	56.87322	146.2015	2.5706563

Analysis

Change in behavior

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:

$$y_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Treat_i + \beta_3 Post_t \times Treat_i + \mu_t + \phi_t + \gamma_i + \epsilon_{i,t}$$

Where y_{ijkl} 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_t, ϕ_t, and γ_i represent month-, year-, and flag-level dummies that account for seasonality or country-level management interventions.

[3] And soon, distance

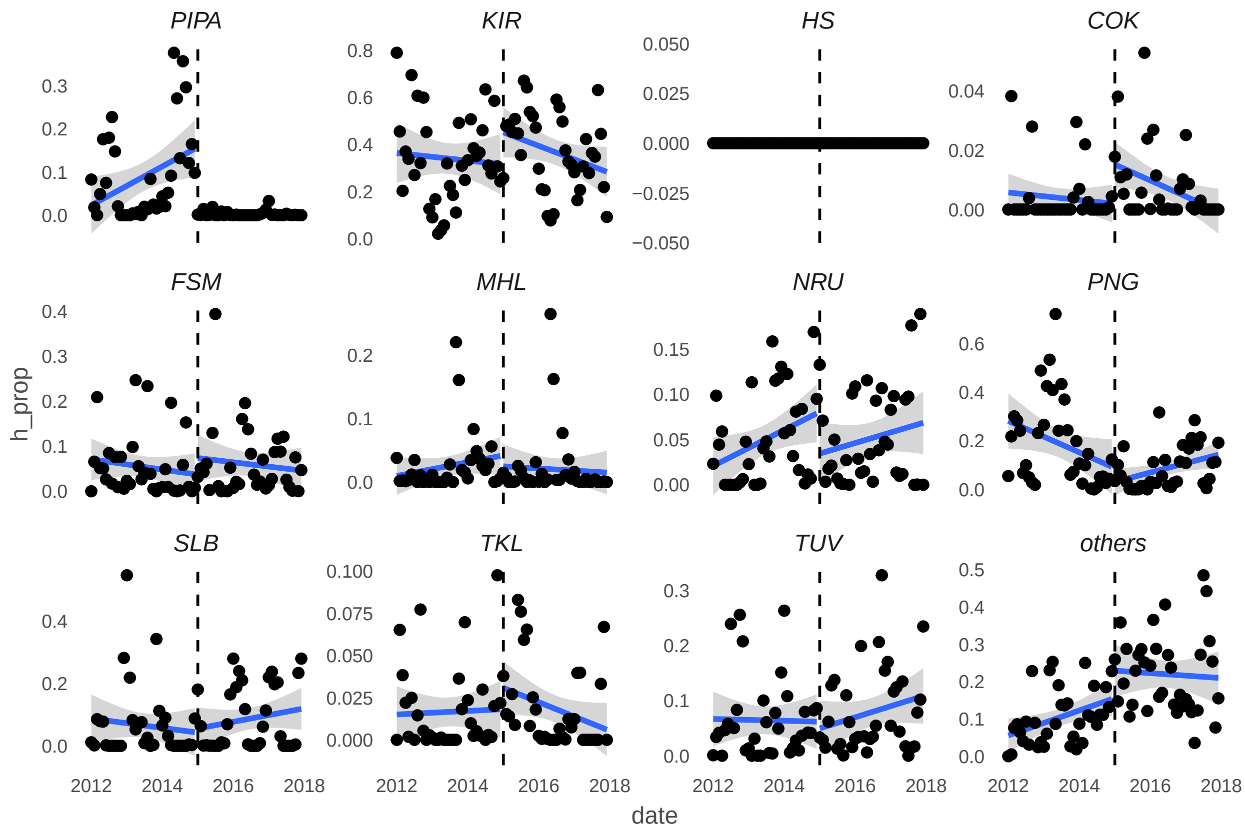


Figure 2:

Vessel displacement and redistribution

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 Figure 2. EEZs that had sproadic fishing events were pooled into a group of "others", leaving us with a total of n = 12 spatially defined regions (*i.e.* EEZs, High Seas, "other EEZs"). Figure **??** shows the yearly average of the relative spatial allocation of fishing efforts; this is the spatial representation of 2 averaged by year.

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:

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

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.

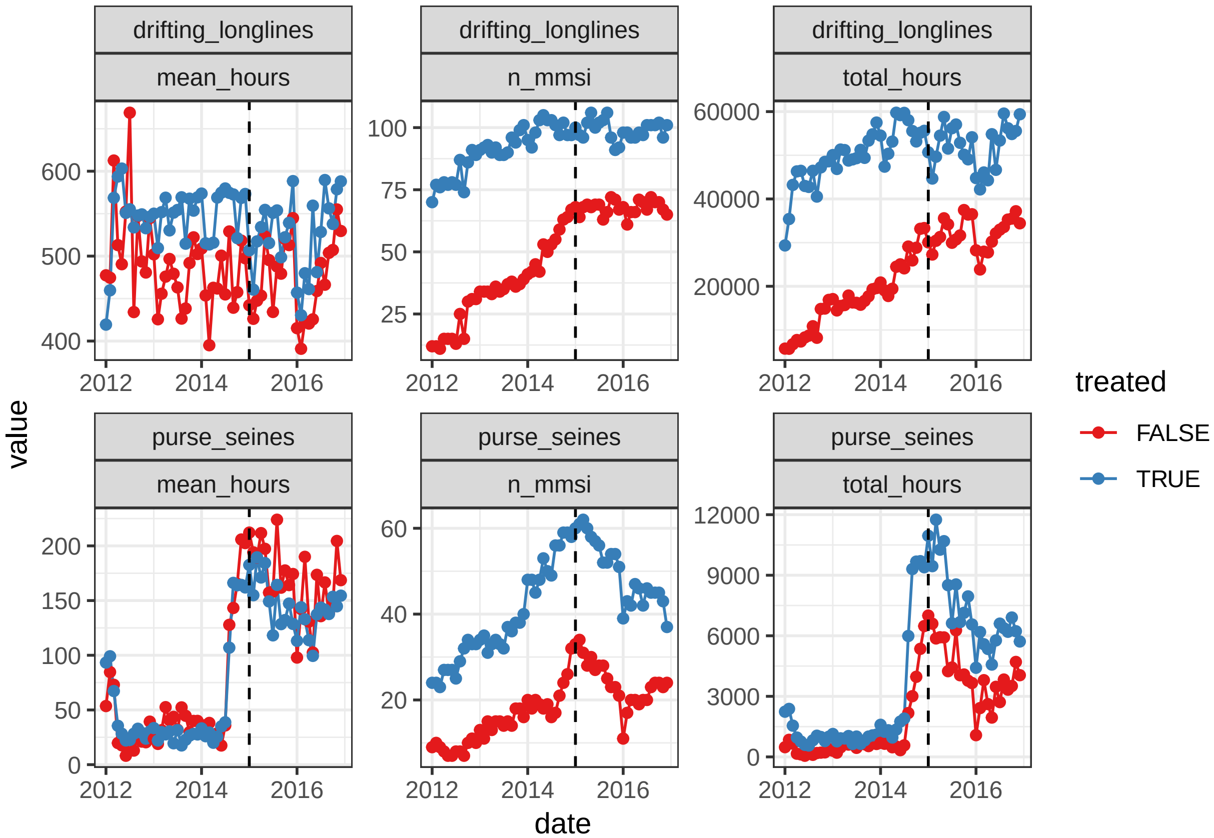


Figure 3: Fishing hours and number of vessels by month for all vessels. Vertical dashed line indicates PIPA closure.

Results

Fig. 3 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 largel be explained by the addition of more satellits, which increasedetectability of vessels. As expected total fishing hours follow a similar trend to that of mmsi numbers. Results of the regressions for each gear type are shown in Tables 4 and 5. Column (1) presents the DiD regression with no fixed effects, column (2) includes month fixed effects, column (3) includes month and year fixed effects, and column (4) includes month, year, and flag fixed effects. Figures 4 and 5 represent the same coefficient estimates.

Change in behavior

Purse seiners

Table 4: 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	105.873***	107.859***	113.466***	102.890***
	(5.532)	(5.364)	(5.887)	(6.076)
treated	−9.632**	−8.924**	−8.334**	−3.076
	(4.257)	(4.023)	(3.725)	(4.540)
post:treated	−16.544**	−16.889***	−17.235***	−11.150*
	(6.481)	(6.358)	(6.126)	(6.162)
Constant	66.505***	61.758***	40.085***	61.569***
	(3.780)	(5.352)	(5.699)	(9.753)
Month FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Flag FE	No	No	No	Yes
Observations	3,692	3,692	3,692	3,692
R^2	0.238	0.262	0.312	0.339
Note:			*p<0.1; **p<0.05; ***p<0.01	

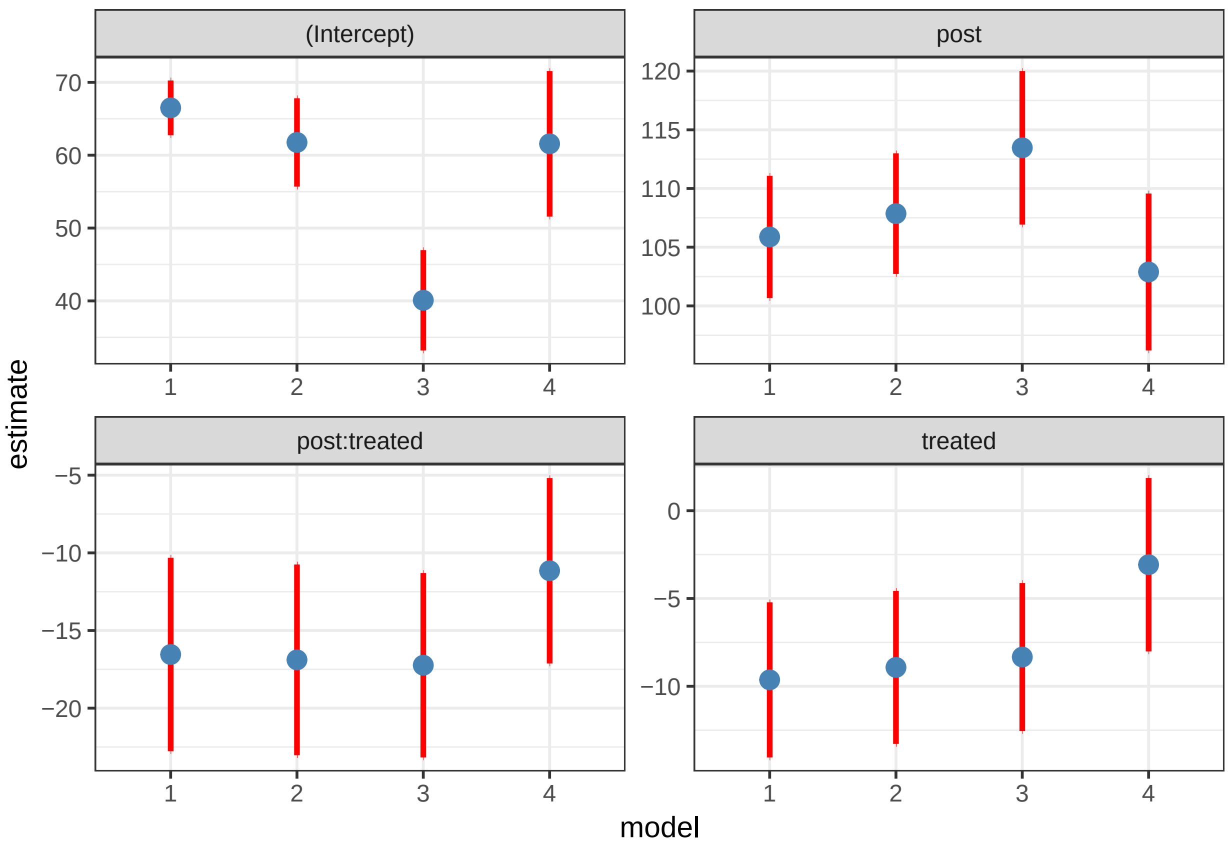


Figure 4: Coefficient estimates for each model. Top pannel indicates variable, x-axis represents model specification, and y-axis coefficient estimate.

Longliners

Table 5: 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	−7.843	−4.894	−7.580	24.708***
	(7.514)	(7.480)	(9.336)	(9.315)
treated	66.801***	69.434***	69.959***	18.878***
	(6.541)	(6.549)	(6.603)	(7.257)
post:treated	−15.571*	−17.806**	−18.340**	−25.775***
	(8.958)	(8.899)	(8.936)	(8.743)
Constant	481.425***	450.475***	447.866***	430.947***
	(5.733)	(9.239)	(10.280)	(24.476)
Month FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Flag FE	No	No	No	Yes
Observations	8,558	8,558	8,558	8,558
R^2	0.026	0.044	0.044	0.107
Note:			*p<0.1; **p<0.05; ***p<0.01	

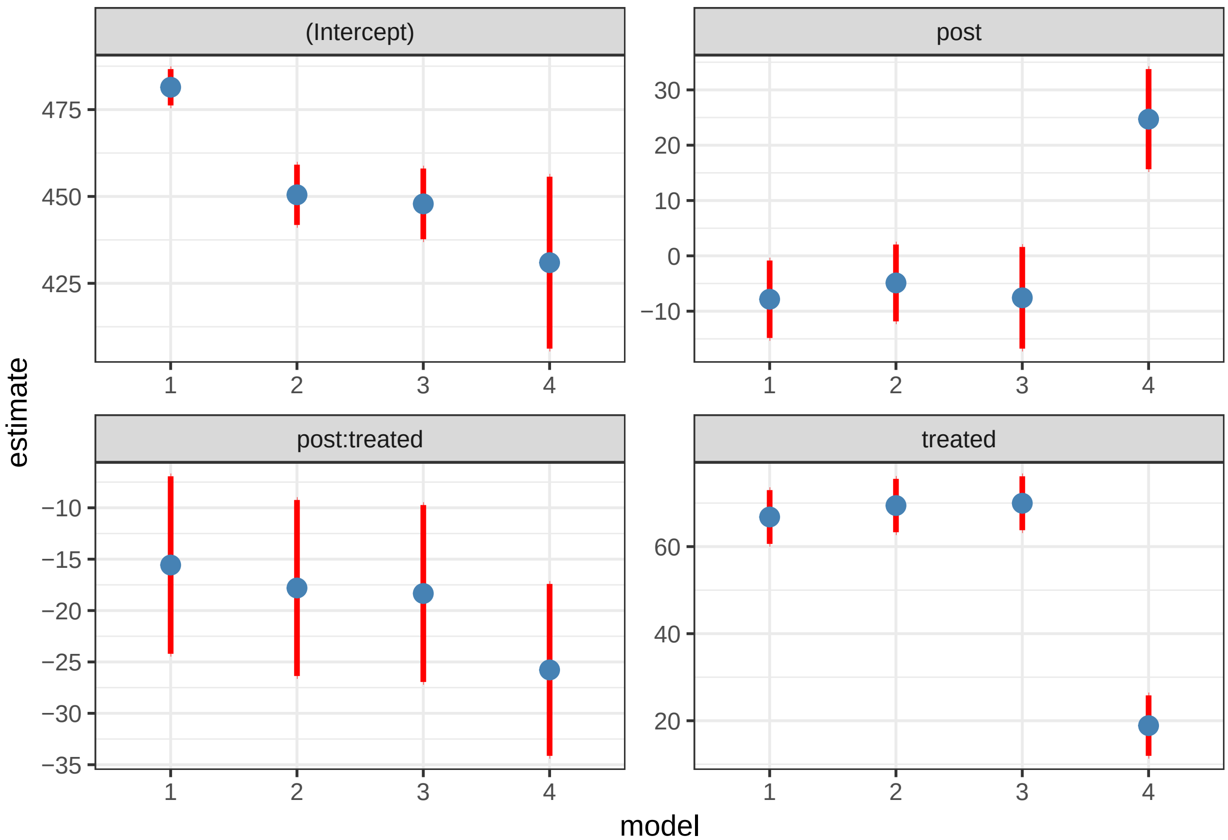
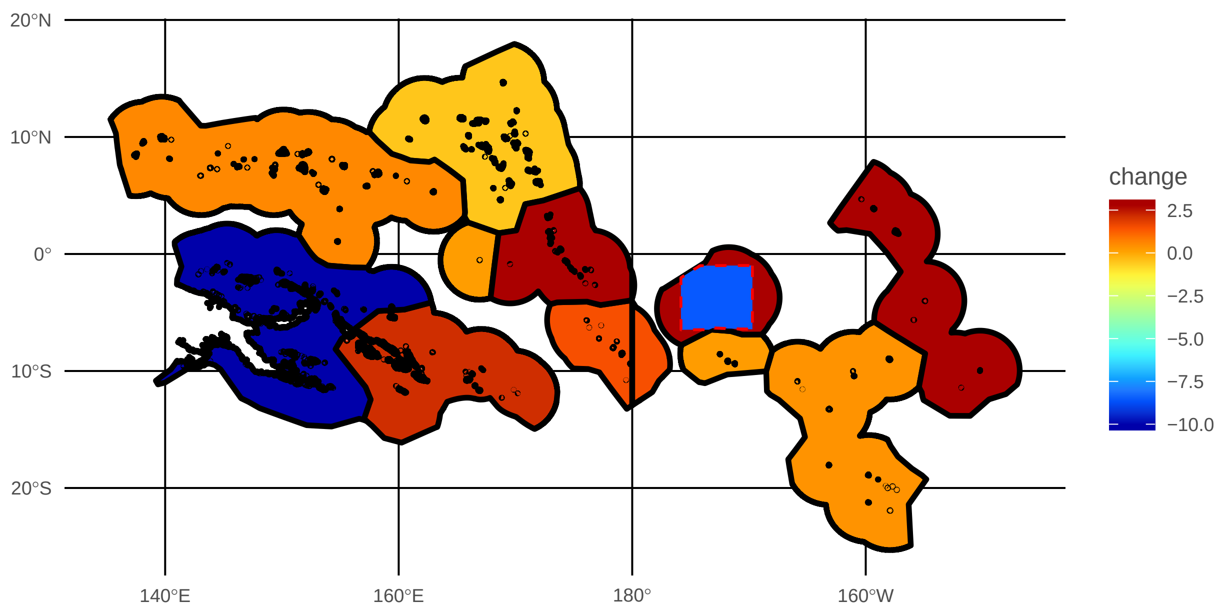


Figure 5: Coefficient estimates for each model. Top pannel indicates variable, x-axis represents model specification, and y-axis coefficient estimate.

Effort displacement and redistribution



References

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