Large-Scale Marine Protected Areas in the World's Largest Tuna Fishery

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The Parties to the Nauru Agreement (PNA) is a system for managing the world's largest skipjack tuna fishery, covering an area of 14.6 million km^2 in the Pacific Ocean. In 2015, PNA member Kiribati implemented one of the world's largest conservation areas: The Phoenix Island Protected Area (PIPA, 397,447 km^2). We use identification of fishing activity via Automatic Identification Systems and causal inference techniques to evaluate the behavioral changes and spatial redistribution of tuna purse seiners due to the implementation of a PIPA. Our work provides three main findings: 1) we observe a crowding effect for the first months after implementation, 2) vessels fish with similar intensity after the implementation, 3) vessels that fished inside the protected area redistribute to adjacent waters, including the high seas, and 4) the redistribution of vessels results in a reduction of 2500 vessel-days in Kiribati, which represents a loss of 30 million USD. We use our results to inform predictions of the impacts of a proposed LSMPA in Palau (a PNA member) and estimate potential losses to range from \$2.5 to \$11 million annually. As countries continue to implement LSMPAs as a way to reach ocean protection targets, managers should consider how fishing effort will change in space and time to ensure that fishing effort is not just displaced elsewhere.

Marine Spatial Planning | Fisheries | Marine Conservation

1. Introduction

Humans are increasingly utilizing the oceans. Multiple ocean uses such as off-shore aquaculture, conservation, energy harvesting, deep-sea mining, and fisheries are likely to compete for space. As we move forward with blue growth, we must understand the potential effects of activities displacing each other and etablish causal links between past management interventions and their outcomes (1).

Global international goals aim to protect 10% of the ocean environment by 2020. In an effort to meet this target, there has been a rapid increase in MPA coverage (2, 3), largely driven by a small number of Large-Scale Marine Protected Areas (LSMPAs), some of which ocurr in the world's largest fishing grounds for tuna. While today a small number of LSMPAs make up at least 80% of the managed areas in the ocean (4), very little is known about their human dimensions and implication for fisheries (5). One issue of particular importance is that of the displacement or redistribution of fishing effort, which may influence the outcomes of a spatial closure (6).

LSMPAs were initially assumed to have little social implications due to their general remoteness. However, there have been calls to incorporate the human dimensions into LSMPA management and evaluation (5, 7). Most research incorporating these dimensions has focused on governance and enforcement of LSMPAs (8, 9), but they are yet to be the focus of economic analyses (5). For example, the anticipation of LSMPAs may lead to preemptive overfishing, which will likely erodes or delay the expected benefits of an intervention (10).

One of the most notable Large-Scale Marine Protected Areas recently implemented is the Phoenix Island Protected Area (PIPA) in Kiribati. The area implemented in January 1st of 2015 has an extension of 397,447 km^2 and represents was implemented within an area that produces 50% of the World's tuna. Tuna purse seine fisheries in the region are collectively managed under a Vessel-day scheme (VDS) by nine countries commonly refered to as the Parties to the Nauru Agreement (PNA). Members include the Federated States of Micronesia, Kiribati, the Marshall Islands, Nauru, Palau, Papua New Guinea, the Solomon Islands, and Tuvalu. Tokelau joined the PNA group in 2012 and started selling access rights in 2013. The Nauru Agreement regulates access of foreign vessels (*i.e.* those from non-PNA countries). Holding 80% (14.6 million km^2) of historical skipjack tuna purse seine grounds within their Exclusive Economic Zones (EEZ), PNA countries have achieved greater bargaining power when providing fishing access to foreign fleets (11). The revenue from access fees represents up to 50% of government revenue from some of this countries. While no studies have assessed the immplications of PIPA, other PNA members have

Significance Statement

Authors must submit a 120-word maximum statement about the significance of their research paper written at a level understandable to an undergraduate educated scientist outside their field of speciality. The primary goal of the Significance Statement is to explain the relevance of the work in broad context to a broad readership. The Significance Statement appears in the paper itself and is required for all research papers.

All authors contributed equally to this work

The authors declare that they have no conflicts of interest

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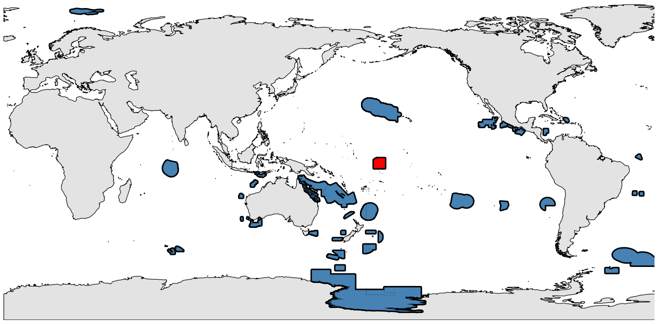

Fig. 1. Large Scale Marine Protected Areas. The map shows all areas larger than 30,000 Km^2. The Phoenix Island Protected Area is shown in red.

pledged the implementation of LSMPAs by 2020.

Here we evaluate the behavioral responses and spatial redistribution of the industrial tuna purse seine fleet resulting from the implementation of the Phoenix Islands Protected Area, and quantify its economic ramifications and impacts to Kiribati. We use the same data to hypothesize what might be the impacts of the proposed Palau National Marine Sanctuary. These are two of the largest protected areas on the planet and both are controled by PNA countries, where the largest tuna fisheries ocurr.

We use identification of fishing activity via Automatic Identification Systems (AIS) to track 313 tuna purse seine vessels that fished in PNA waters. We continuously observe 92 vessels for the 2012 - 2018 period. Of these, 64 vessels fished within PIPA at least once prior to its implementation. The remaining 28 vessels never fished in PIPA these waters. We refer to these groups as treated and control groups.

2. Results

A. Crowding effect. We first inspect the crowding effects that may arise due to the net reduction in fishing area. We produced rasters of monthly fishing effort for our treatment and control groups, and calculated two indices of spatial overlap: 1) the number of cells that had fishing activity from treated and control vessels for each month and 2) the correlation of presence/absence of fishing events between both groups over one month. We find that the two fleets significantly interact more with each other after the implementation of PIPA (Table **??** Fig. 2). The number of vessels with presence from both fleets and spatial correlations increase by a factor of four and three, respectively. This increase in crowding is likely to increase the encounter rates within vessels, and reduce the efficienvy of fishing opperations, resulting in a nusicance to vessels. This would cause vessels to leave curent fishing grounds, which might explain the pattern we observe of an increase and subsequent decrease back to pre-implementation levels.

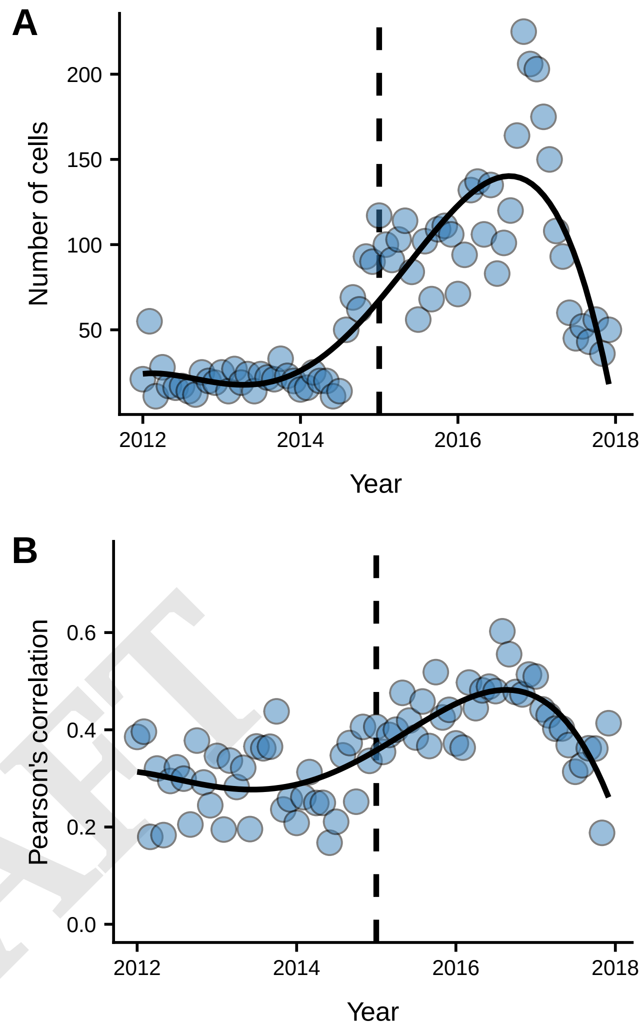

Fig. 2. Number of cells that had treated and control vessels (A) and spatial correlation in the presence-absence of treated and control vessels per cell (B). The solid lines represent the 4[th] degree polynomial fit reported in **??**

B. Behavioral changes. The behavioral responses that vessels can have to a spatial closure may occurr in different ways. For example, displacement to new fishing grounds may represent a cost as fishers search the ocean to identify the most suitable fishing places. This may result in increased fuel and labor costs. For every vessel we calculate in eight key measures that could capture responses to spatial closures: daily fishing hours, daily non-fishing at-sea hours, the proportion of fishing to non-fishing hours at sea, daily distance traveled, daily mean distance from shore of fishing events (km), daily mean distance from port of fishing events (km), as well as monthly hours spent in PNA waters and Kiribati waters (Fig. S2). We leverage our BACI design and implement a log-linear difference-in-differences analyses to evaluate how these measures change for treated vessels after implementation of PIPA, relative to the trends observed for control vessels.

We find no evidence of treated vessels fishing for mor hours after PIPA implementation, and a slight increase of

1% more time at sea ($p < 0.05$; Table S2). Treated vesseks traveled 20% less, with fishing events ocurring 23.8% closer to shore and 5% closer to port. These changes in distance from shore and port ar elikely caused by redistribution, as we observe that treated vessels fish 58% and 45% less in PNA and Kiribati waters, compared to the trend observed for control vessels ($p < 0.01$). The fact that vessel fishing hours did not decrease but that their time spent in PNA and Kiribati waters decreases suggests that these vessels have re-distributed elsewhere.

C. Economic impacts. The crowding effect combined with the reduction of hours spent in Kiribati and PNA waters overall suggests that treated vessels have redistributed elsewhere, meaning that they no longer buy access fees from PNA countries. To quantify the potential impacts of this leakage, we estimate the total annual vessel-days received by all PNA countries (Fig. S3). In this case we look at all 313 vessels, but continue to group them as treated and control vessels, as well as other vessels that we do not observe continuously or came into the fishery after the implementation of PIPA. We term this last group as "others". We find that the treated vessels spent 2,310 less days in PNA waters when comparing 2015 and 2016, while control and other vessels increased their activities in PNA waters by 5,489 and 4,447 days for the same period, respectively (Figs. S3A and 3). The 2,310 vessel-day reduction by treated vessels between 2015 and 2017 corresponds to $27.7 million USD at an average price of $12,000 USD per vessel-day. Looking at the total anual vessel-days allocated by all vessels to all countries, we see that the largest reductions ocurr for Kiribati, while Papua New Guinea exhibits a proportional increase (Fig. S4). Furthermore, in 2017 treated vessels exhibit the lowest vessel-day allcoation to PNA waters at just 10,026 vessel-days. This is 2,526 vessel-days lower ($30.3 million USD) than pre-implementation levels of 2012 - 2013 (mean ± sd of 12,552.46 ± 1,396.46; we exclude 2014 due to the blue paradox effect (10)).

We compliment our analysis of change in vessel-days by looking at country-level data. Specifically, we use data compiled by the Pacific Islands Forum Fisheries Agency (FFA*) where annual revenues from license fees are reported for each country (2008 - 2016; Fig. 4). We find that by 2016, Kiribati's revenue decreased from $148.8 million USD in 2015 to $118.3 million USD in 2016, representing a change in 30.5 million USD. We use a local polynomial regression fit to obtain a trend line for the total (*i.e.* summing across countries) revenues between 2008 and 2015, and extrapolate the trend to obtain an expected value for 2016. Our model suggests that revenue should be in the order of $463.5 million USD, but we observe only $423.5 million, suggesting that potential losses to the entire PNA are in the order of $40 million USD.

*https://www.ffa.int/node/2050

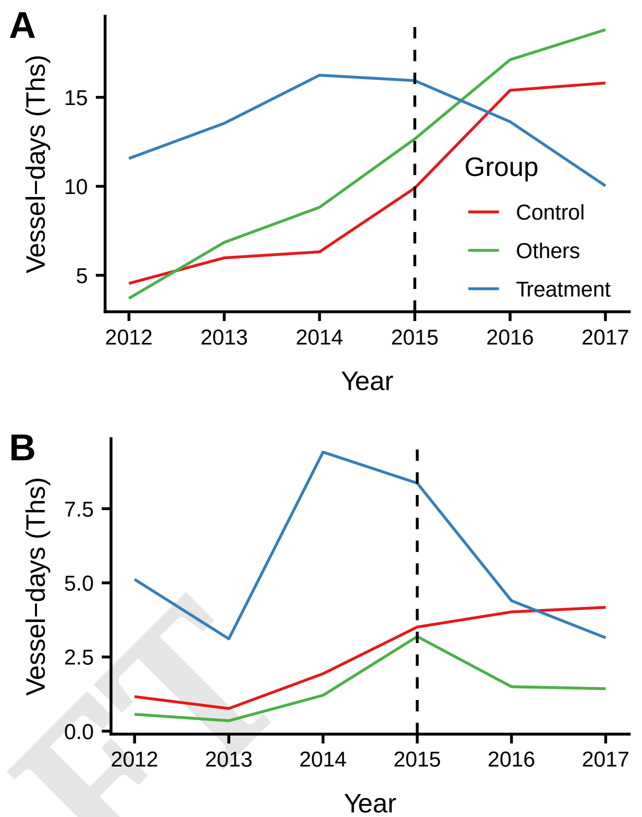

Fig. 3. Vessel days spent inside A) PNA waters and B) Kiribati waters by group of vessels.

Catches for each country's EEZ for the 1997 - 2016 period were also obtained from the FFA (Fig. S6). Catches in Kiribati waters decreased from 24,051 to 12,894 tonnes between 2015 and 2016 (46.3% decrease). Similar decreases were observed for The Federal States of Micronesia (60.9%), Papua New Guinea (43.4%) and the Solomon Islands (58.5%). In contrast, Tokelau (due south of Kiribati) showed a 22.3% increase in catches over the same period.

D. Potential Revenue Loss for Palau. On October 28, 2015, the President of Palau, H.E. Tommy E. Remengesau Jr., signed into law the Palau National Marine Sanctuary (PNMS) Act. Starting in December 2020, this Act will close 500,000 km^2 to commercial fishing activities, creating the 14th largest protected area in the world. The sanctuary will fully protect about 80 percent of the nation's EEZ. To prepare for full enactment of the PNMS, the act stipulates a "winding down" period, in which baseline vessel days (i.e., the number of vessel days used in 2014) were reduced by 20% in 2016; and an additional 10% from baseline in each subsequent year until full enactment in 2020. This appears to be occurring for the longline VDS, but it is uncertain whether this is being followed for the purse seine VDS, because purse seine VDS can be transferred for use in other EEZs. There has

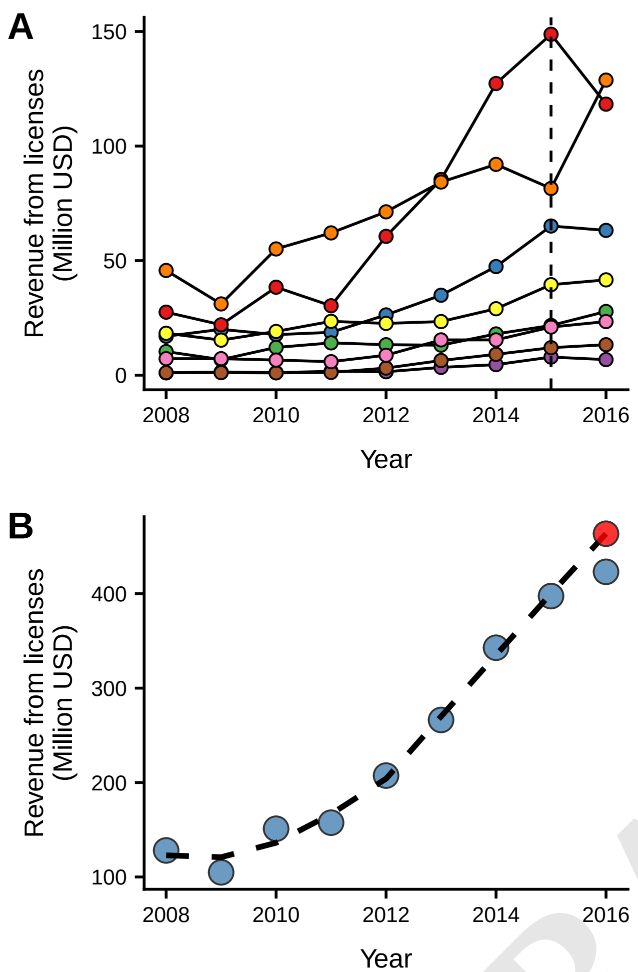

Fig. 4. Financial indicators for PNA countries. A) Revenue from fishing licenses fees, B) Total annual revenues for all 9 PNA countries with dashed line showing the local polynomial regression fit to the 2008 - 2015 data and the red dot representing the prediction from this regression. Vertical dashed line in both plots denotes implementation of PIPA.

been no official statement on what will happen to Palau's VDS upon full implementation of the PNMS. However, there is a sense that Palau will be able to keep its allotment come 2020 (Hanich, pers. comm.). In the 2015 Micronesian Presidents Summit, a letter was drafted by heads of state, calling on PNA members to be supportive of Palau as they moved forward with the PNMS Act (12). Further, other PNA members have not been penalized for other protected area closures (e.g., PIPA) (Hanich, pers. comm.).

Table 1 presents estimates of the potential revenue losses following full enactment of the PNMS under four different scenarios. In Scenario 1, Palau is able to keep its current allotment of purse seine vessel days (700) and is able to sell them for a similar price to what it is currently selling them to the US for ($12,500/day). In Scenario 2, Palau is able to keep its current allotment of purse seine vessel days (700) to transfer to other parties at the current benchmark price ($8,000/day). Scenario 2 is likely if Palau retains its current PAE, but the US no longer purchases days. It should be noted that if PAE continues to be calculated based on effort and biomass, and if Palau continues to be allocated vessel days, its PAE will decrease as effort in its EEZ reaches zero. In Scenario 3 and 4, Palau loses all of its PS vessel days, at $8,000/day and $12,500/day, respectively. In all scenarios, all longline vessel day and export tax revenues are lost. Longline vessel day loss is calculated using an average value of $200 for 10,500 days. Export tax loss is calculated given the average tax revenue from 2012-2014 ($482,236 from (13)).

Table 1. Estimated revenue losses under different scenarios of PNMS (in USD)

Scenario	PS VDS	LL VDS	Export tax	Total revenue loss
1	0	-2,100,000	-482,236	-2,582,236
2	-3,150,000	-2,100,000	-482,236	-5,732,236
3	-5,600,000	-2,100,000	-482,236	-8,182,236
4	-8,750,000	-2,100,000	-482,236	-11,332,236

3. Discussion

Our findings provide insights into the effect that LSMPAs can have on vessel behavior and the redistribution of fishing effort. These results show that the implementation of PIPA had little effect on the total fishing effort exerted by purse seiners. However, regions adjacent to PIPA show an increase in the relative amount of fishing effort, suggesting that effort is simply displaced to nearby areas. This does not imply that there is more fishing effort exerted by treated vessels, but rather that each region receives a greater portion of the post-PIPA fishing effort of these same vessels, which is lower than pre-PIPA levels. Additionally, we show that post-PIPA there is a concentration of effort leading to crowding. 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 protected areas around Pacific islands suggest that vessels move to distant places, which might be translated as increased costs (14). Others have used similar satellite-tracking systems to show that fishing effort accumulates near the edges of spatial closures, yielding greater catches over time (15). But these vessel tracks do not cover the pre-reserve period, making it difficult to identify the contribution of spatial closures to the observed spatial distribution of fishing vessels. Recent work by (16) 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, which is assembled in a similar way, allows us to make similar inferences about the unobserved change in aggregate fishing effort and its spatial redistribution.

The role of the institutions at play is evident. Vessels that fished inside PIPA before the implementation were likely fishing in Kiribati waters under a VDS license. Upon implementation, some vessels redistribute to other areas of the Kiribati EEZ and the adjacent high seas for the year immediately after the closure. As stated before, it is reasonable for a vessel holding a license to fish in Kiribati waters to simply reallocate their effort to other parts of that EEZ. However, the shift to the high seas may not follow the same logic. Instead, it is possible that vessels that redistribute to the high seas were operating in Kiribati illegally, and decide to reallocate in the high seas to continue fishing without a license. Or they are now not willing to pay Kiribati to fish in the remaining open areas.

A major shortcoming of our analysis is that we do not observe catches or revenues, which ultimately are the factors that guide the decision making process of profit-maximizing agents. Therefore, it is difficult to know whether the small change in fishing hours represents a positive or negative impact. An additional factor that we are yet to test is the change in non-fishing hours spent at sea. It is plausible that fishing hours remain constant, but vessels have to increase search time. Upon being relocated, fishers may not identify the best fishing grounds as easily as before, and therefore invest a greater proportion of their time searching for their catch. Further analysis of temporal trends in non-fishing hours, as well as distance traveled should provide us with insights as to why fishers reduced fishing hours. However, the widespread footprint of the treated fleet may suggest that they are well acquainted with the region (see Figure S8), and it's unlikely that they would need to invest much time to identify new fishing grounds.

Our work suggests that the implementation of LSMPAs has little impact on total fishing effort. We also show that fishing effort is redistributed to areas close by, and that this leads to a potentially negative crowding effect. A growing body of literature suggests that closing the high seas to all fishing could increase fishery yields and profitability of fisheries, with negligible costs to food security (17–20). Such management interventions should consider how fishing effort will change in space and through time, and the ecological implications of this redistribution to ensure that fishing effort is not just displaced elsewhere, leading to overfishing in adjacent waters. While LSMPAs can provide a wide range of benefits, their implementation must be accompained with traditional fisheries management to maximize effectiveness.

4. Conclusions

5. References

1. Burgess MG, Clemence M, McDermott GR, Costello C, Gaines SD (2018) Five rules for pragmatic blue growth. *Marine Policy* 87:331–339.
2. Wood LJ, Fish L, Laughren J, Pauly D (2008) Assessing progress towards global marine protection targets: shortfalls in information and action. *Oryx* 42(03).
3. Sala E, et al. (2018) Assessing real progress towards effective ocean protection. *Marine Policy* 91(2):11–13.
4. Toonen RJ, et al. (2013) One size does not fit all: the emerging frontier in large-scale marine conservation. *Mar Pollut Bull* 77(1-2):7–10.
5. Gray NJ, et al. (2017) Human dimensions of large-scale marine protected areas: Advancing research and practice. *Coastal Management* pp. 1–9.
6. Smith MD, Wilen JE (2003) Economic impacts of marine reserves: the importance of spatial behavior. *Journal of Environmental Economics and Management* 46(2):183–206.
7. Agardy T, di Sciara GN, Christie P (2011) Mind the gap: Addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Marine Policy* 35(2):226–232.
8. Alger J, Dauvergne P (2017) The global norm of large marine protected areas: Explaining variable adoption and implementation. *Env. Pol. Gov.* 27(4):298–310.
9. Christie P, et al. (2017) Why people matter in ocean governance: Incorporating human dimensions into large-scale marine protected areas. *Marine Policy* 84:273–284.
10. McDermott GR, Meng KC, McDonald GG, Costello CJ (2018) The blue paradox: Preemptive overfishing in marine reserves. *Proc Natl Acad Sci USA.*
11. Havice E (2010) The structure of tuna access agreements in the western and central pacific ocean: Lessons for vessel day scheme planning. *Marine Policy* 34(5):979–987.
12. Senase JRT (2015) Micronesian presidents call on pna to support palau sanctuary. *Island Times.* Palau.
13. Gillett R (2016) *Fisheries in the economies of the Pacific island countries and territories.* (Pacific Community), 2nd edition.
14. Stevenson TC, Tissot BN, Walsh WJ (2013) Socioeconomic consequences of fishing displacement from marine protected areas in hawaii. *Biological Conservation* 160:50–58.
15. Murawski S, Wigley S, Fogarty M, Rago P, Mountain D (2005) Effort distribution and catch patterns adjacent to temperate MPAs. *ICES Journal of Marine Science.*
16. Elahi R, et al. (2018) Leveraging vessel traffic data and a temporary fishing closure to inform marine management. *Front Ecol Environ.*
17. White C, Costello C (2014) Close the high seas to fishing? *PLoS Biol* 12(3):e1001826.
18. Sumaila UR, et al. (2015) Winners and losers in a world where the high seas is closed to fishing. *Sci Rep* 5(1):8481.
19. Sala E, et al. (2018) The economics of fishing the high seas. *Sci Adv* 4(6):eaat2504.
20. Schiller L, Bailey M, Jacquet J, Sala E (2018) High seas fisheries play a negligible role in addressing global food security. *Sci Adv* 4(8):eaat8351.
21. Kroodsma DA, et al. (2018) Tracking the global footprint of fisheries. *Science* 359(6378):904–908.
22. R Core Team (2018) *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, Vienna, Austria).
23. De Santo EM (2013) Missing marine protected area (MPA) targets: How the push for quantity over quality undermines sustainability and social justice. *J Environ Manage* 124:137–146.
24. Kaplan DM, Chassot E, Gruss A, Fonteneau A (2010) Pelagic MPAs: the devil is in the details. *Trends Ecol Evol (Amst)* 25(2):62–3; author reply 63.
25. Game ET, et al. (2009) Pelagic protected areas: the missing dimension in ocean conservation. *Trends Ecol Evol (Amst)* 24(7):360–369.
26. Maxwell SM, et al. (2015) Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. *Marine Policy* 58:42–50.
27. Singleton RL, Roberts CM (2014) The contribution of very large marine protected areas to marine conservation: giant leaps or smoke and mirrors? *Mar Pollut Bull* 87(1-2):7–10.
28. Hilborn R, Micheli F, De Leo GA (2006) Integrating marine protected areas with catch regulation. *Can. J. Fish. Aquat. Sci.* 63(3):642–649.
29. Cabral RB, Gaines SD, Johnson BA, Bell TW, White C (2017) Drivers of redistribution of fishing and non-fishing effort after the implementation of a marine protected area network. *Ecol Appl* 27(2):416–428.
30. Havice E (2013) Rights-based management in the western and central pacific ocean tuna fishery: Economic and environmental change under the vessel day scheme. *Marine Policy* 42:259–267.
31. Hagrannsoknir (2014) Review of the purse seine vessel day scheme, (PNA Office, available at: www.pnatuna.com/sites/ default/files/Independentofreport.
32. PNA (2016) Palau arrangement for the management of the western pacific fishery as amended.
33. Yeeting AD, Weikard HP, Bailey M, Ram-Bidesi V, Bush SR (2018) Stabilising cooperation through pragmatic tolerance: the case of the parties to the nauru agreement (pna) tuna fishery. *Regional Environmental Change* 18(3):885–897.
34. PNA (2014) Minimum benchmark fee for a fishing day under the vessel day scheme.
35. Arnason R (2014) Review of the pna purse seine vessel day scheme, (Parties to the Nauru Agreement Office, PO Box 3992, Majuro, Marshall Islands 96960), Technical report.
36. FAO (2018) *The state of world fisheries and aquaculture 2018: meeting the sustainable development goals*, The state of world fisheries and aquaculture. (UN).
37. Aqorau T, Bergin A (1997) Ocean governance in the western pacific purse seine fishery - palau arrangement. *Marine Policy* 21(2):173–186.
38. PNA (2018) Parties to the nauru agreement.
39. McCauley DJ, et al. (2016) Ending hide and seek at sea. *Science* 351(6278):1148–1150.
40. Chapman L (2000) Development options and constraints including infrastructure and training needs within the tuna fishing industry and support services in vanuatu, (Fisheries Development Section, Secretariat of the Pacific Community, Noumea), Technical report.
41. Tewid S (2013) Performance audit report on managing sustainable fisheries (tuna), (Office of the Public Auditor, Republic of Palau), Technical report.
42. Pojas R (2018) Palau sells pna fishing days to philippine company. *Island Times.* Palau.
43. Skirtun M, Hare S (2017) Review of the biological and economic impacts of the proposed marine sanctuary in palau, (Forum Fisheries Agency, Solomon Islands), Technical report.

6. Appendix

7. Supplementary tables and figures

Table S1. Coefficient estimates for a third-polinomial fit to the measures of crowding. The first column shows coefficients for the number of cells with treated and control vessels during the same month. The second column shows coefficients for the spatial correlation for presence / absence of treated and control vessels. The explanatory variable is the number of months before implementation of PIPA. Numbers in parentheses are heteroskedastic-robust standard errors.

	(1)	(2)
Constant	67.152*** (5.727)	0.357*** (0.014)
Months	4.592*** (0.422)	0.008*** (0.001)
Months ^{2}	0.062* (0.033)	0.0001 (0.0001)
Months ^{3}	$-$0.004*** (0.0005)	$-$0.00001*** (0.00000)
Months ^{4}	$-$0.0001*** (0.00003)	$-$0.00000* (0.00000)
Month FE	Yes	Yes
Flag FE	Yes	Yes
Observations	72	72
R^2	0.743	0.566
Note:		*p<0.1; **p<0.05; ***p<0.01

Table S2. Difference-in-differences estimates for our 10 variables of interest: 1) Daily fishing hours, 2) Daily non-fishing at-sea hours, 3) Daily proportion of fishing hours to total at-sea hours, 4) Daily distance traveled, 5) Daily mean distance from port for fishing events, 6) Daily mean distance from shore for fishing events, 7) Monthly fishing hours spent in Kiribati waters, 8) Monthly fishing hours spent in PNA waters. Numbers in parentheses are heteroskedastic-robust standard errors.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	1.875***	3.860***	0.198***	4.878***	7.199***	13.886***	2.497***	2.624***
	(0.038)	(0.007)	(0.009)	(0.045)	(0.026)	(0.028)	(0.281)	(0.255)
Post	0.654***	−0.243***	0.157***	−0.099***	0.336***	0.248***	1.537***	1.556***
	(0.026)	(0.008)	(0.007)	(0.036)	(0.016)	(0.017)	(0.154)	(0.119)
Treated	0.008	0.008	−0.007	0.275***	0.180***	−0.018	0.393***	0.244**
	(0.028)	(0.006)	(0.007)	(0.032)	(0.017)	(0.018)	(0.151)	(0.119)
Post × Treated	−0.020	0.033***	0.0002	−0.250***	−0.281***	−0.059***	−0.531***	−0.368***
	(0.030)	(0.009)	(0.007)	(0.040)	(0.019)	(0.019)	(0.175)	(0.135)
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flag FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25,073	74,600	25,073	73,265	25,073	25,073	1,460	2,056
R^2	0.141	0.075	0.151	0.011	0.163	0.293	0.198	0.282

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

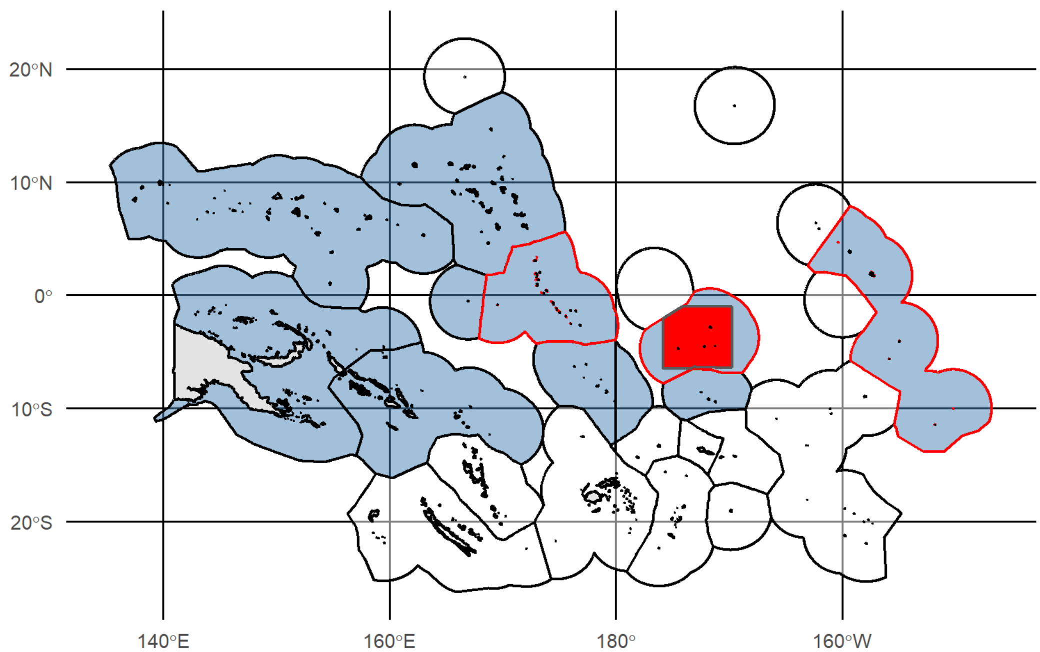

Fig. S1. Map of the Exclusive Economic Zones (EEZs) of the region of interest. Countries that belong to the PNA are shown in blue, while empty polygons indicates all others. A red line indicates the Kiribati EEZ, and a solid red polygon delineates PIPA.

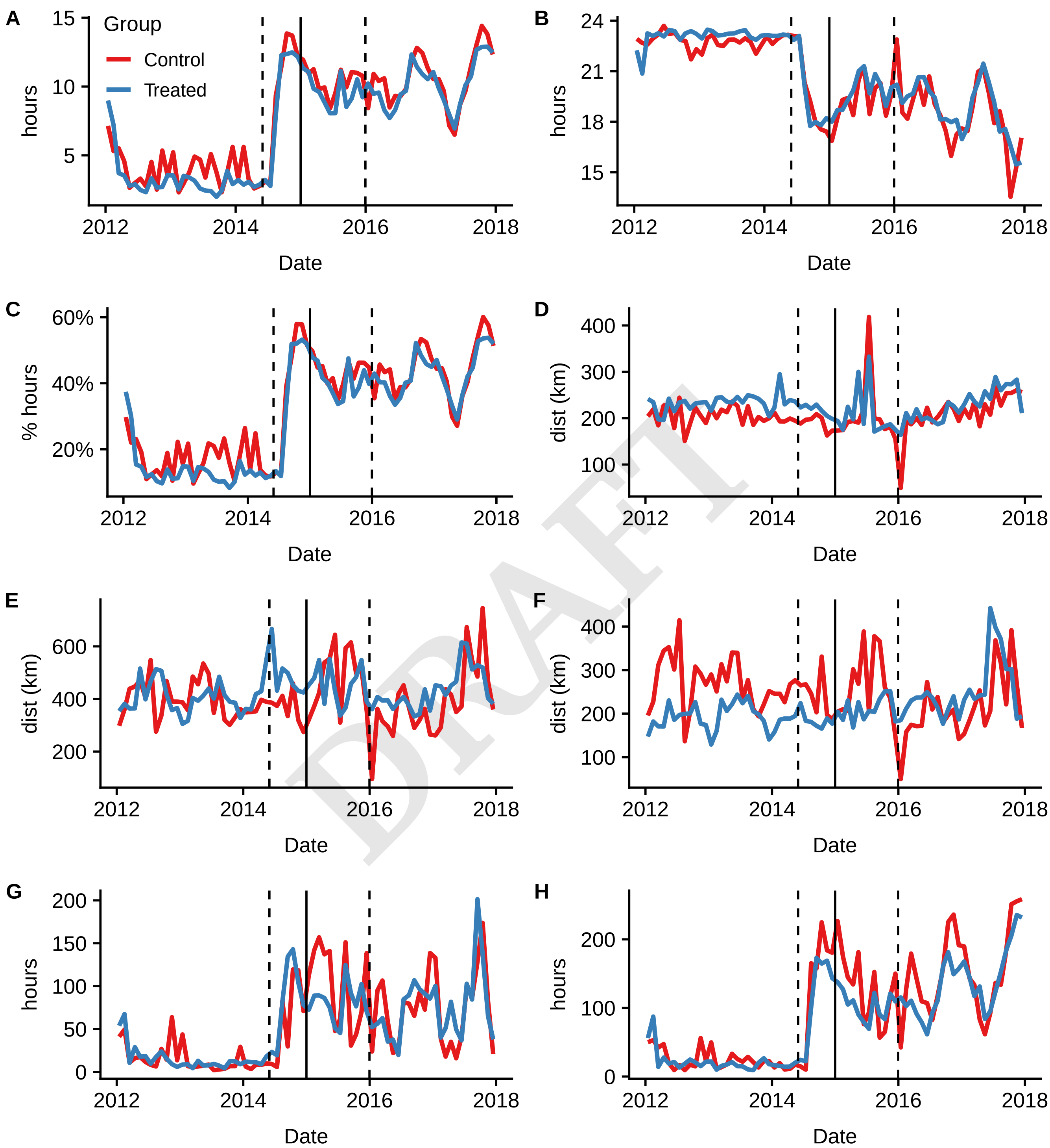

Fig. S2. Time series showing monthly averages for eight variables of interest: A) Fishing hours, B) Non-fishing hours at-sea, C) Proportion of fishing hours to total hours at-sea, D) Distance traveled, E) Mean distance from port for fishing evetns, F) Mean distance from shore for fishing events, I) Monthly hours spent in Kiribati waters, J) Proportion of fishing hours spent in PNA waters.

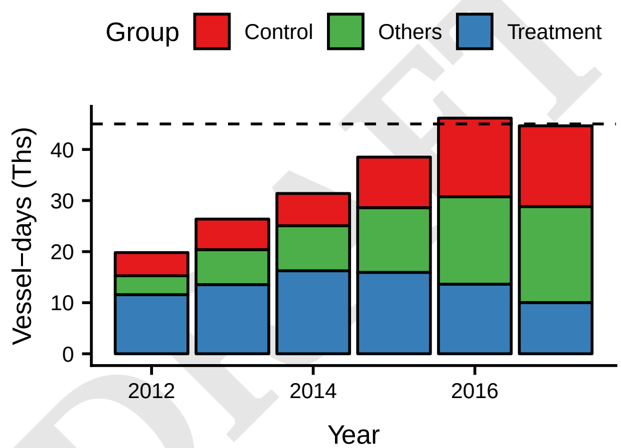

Fig. S3. Observed vessel-days for all countries by treated, control, and excluded vessels.

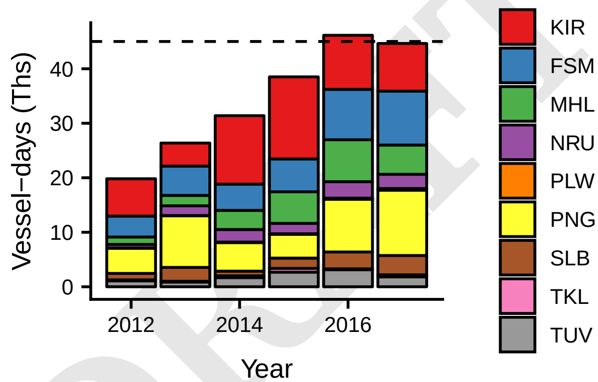

Fig. S4. Observed vessel days by country and year

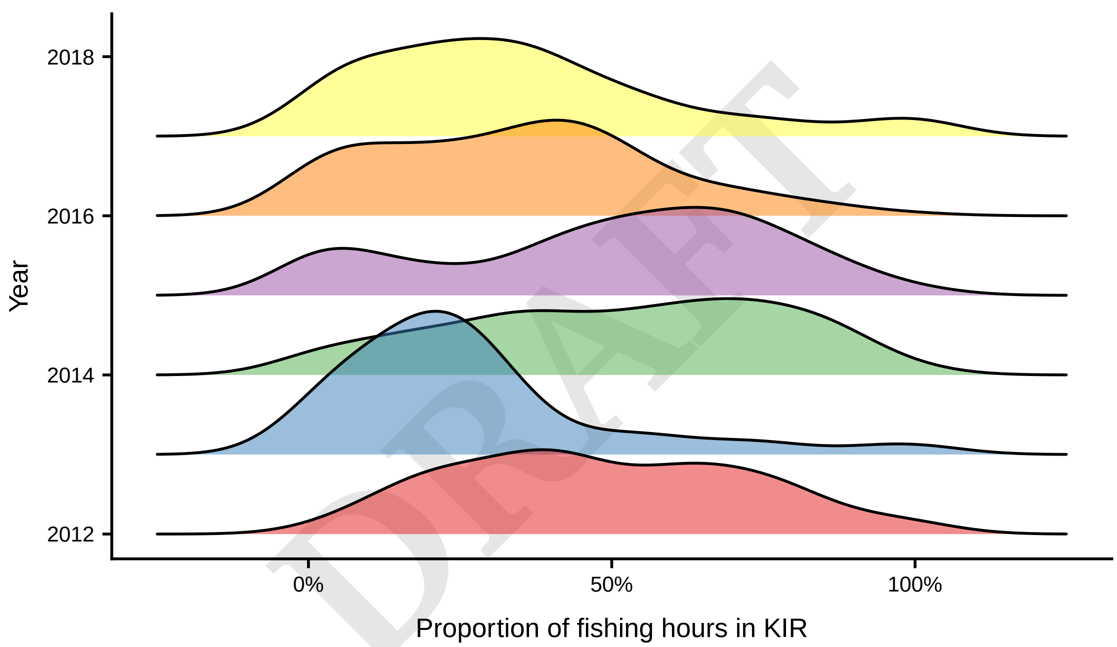

Fig. S5. Ridgeplot for the density of the % of total fishing hours that take place within Kiribati EEZ waters by year for treated vessels where the unit of observation is an individual vessel.

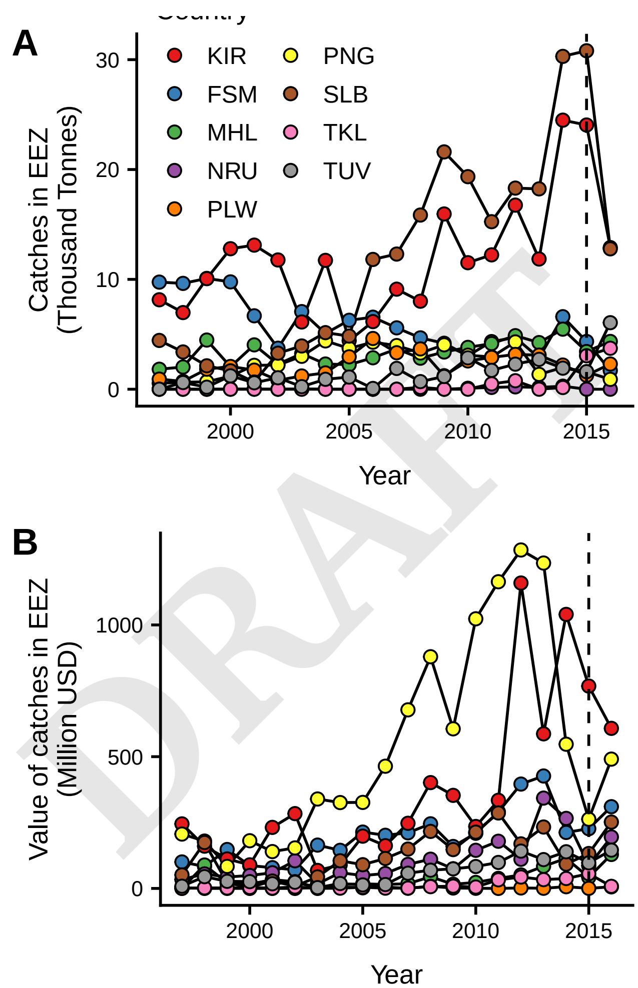

Fig. S6. Financial indicators for PNA countries. A) Annual catches by EEZ and, B) Annual value of catches by EEZ. Vertical dashed line in both plots denotes implementation of PIPA.

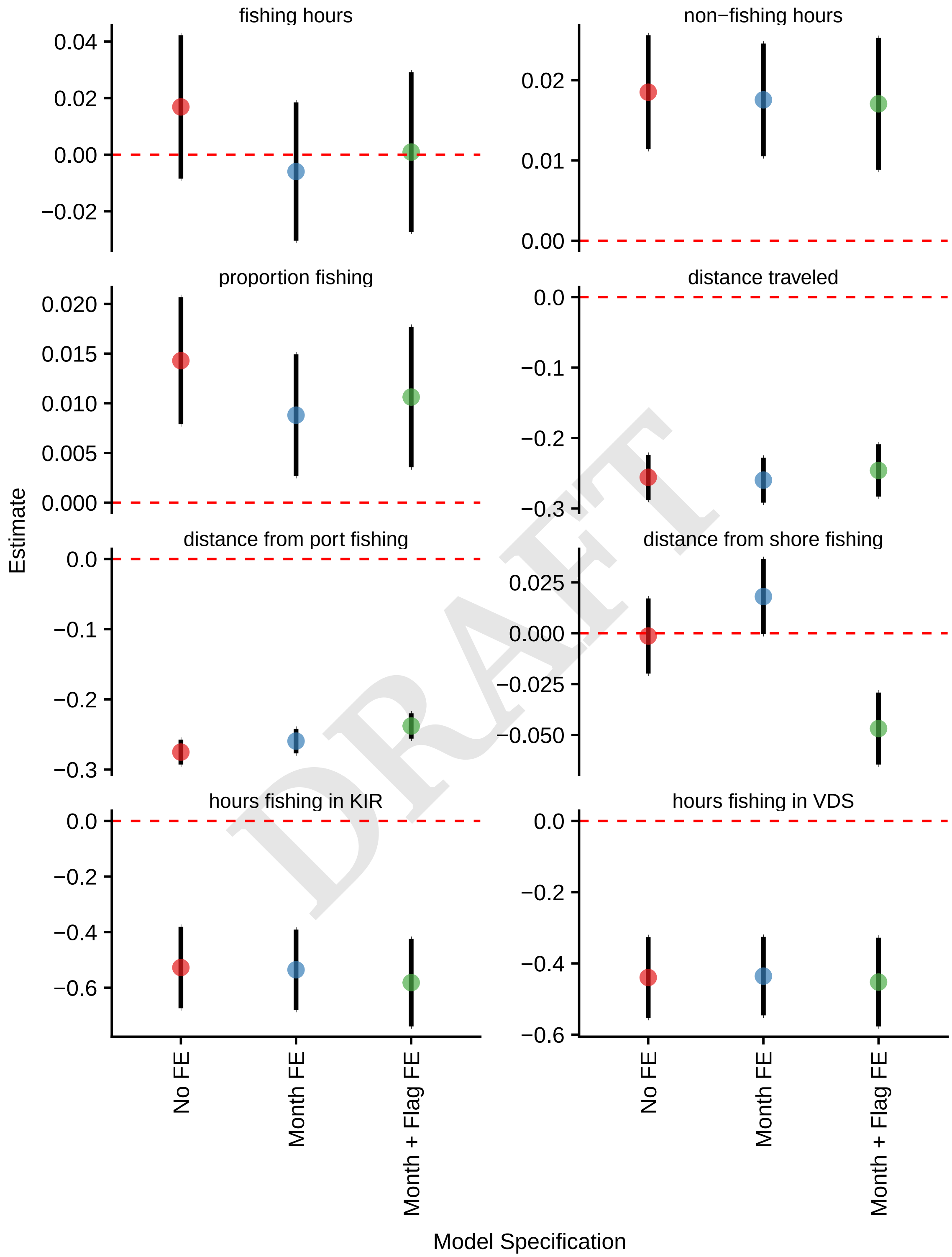

Fig. S7. Alternative difference-in-differences estimates for our variables of interest using different model specifications. Table S2 reports estimates for models with month and flag fixed effects (*i.e.* green dots).

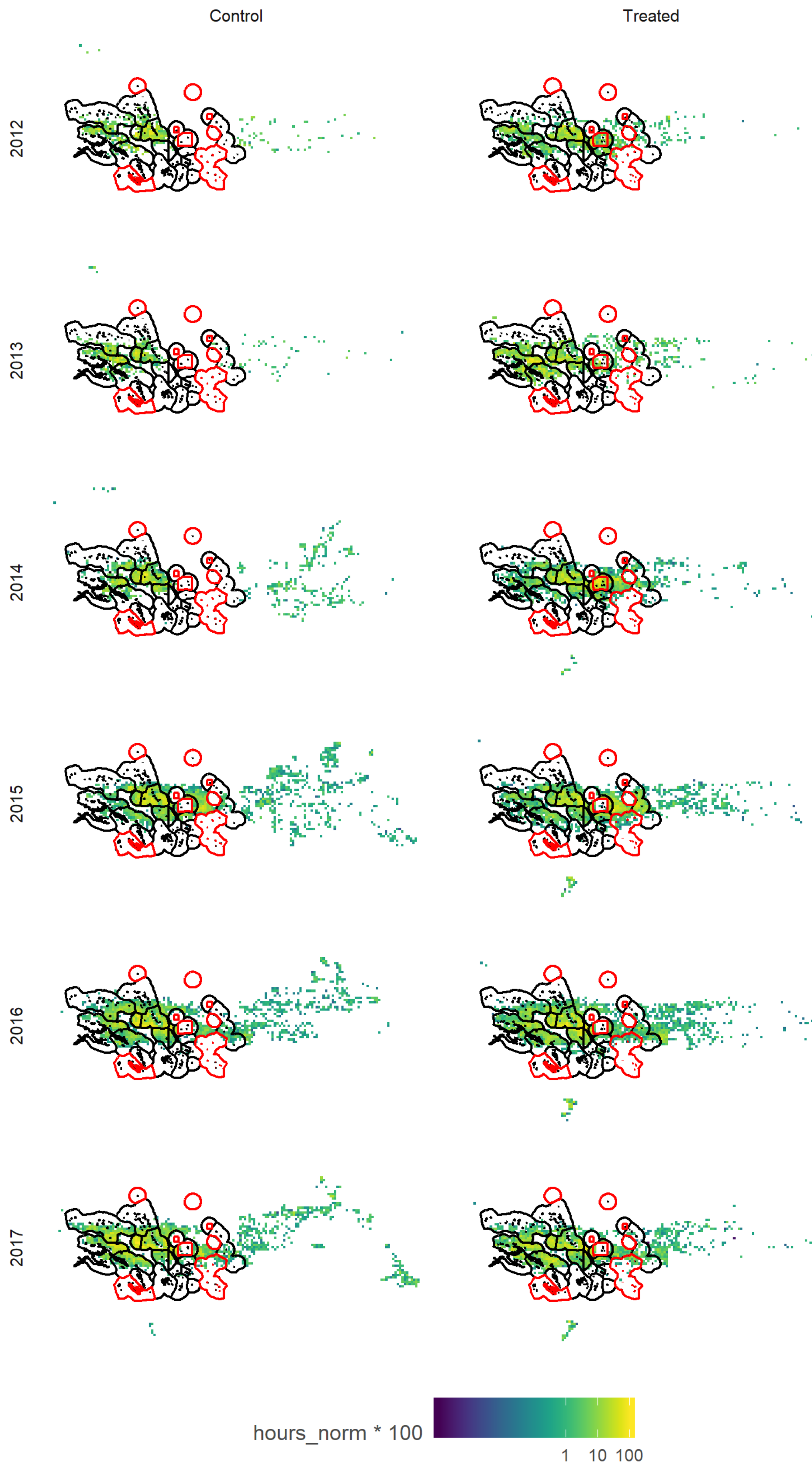

Fig. S8. Yearly spatial distribution of fishing effort by treated and control vessels. Color corresponds to % of total fishing effort in each panel. Red polygons show LSMPAs in the region.

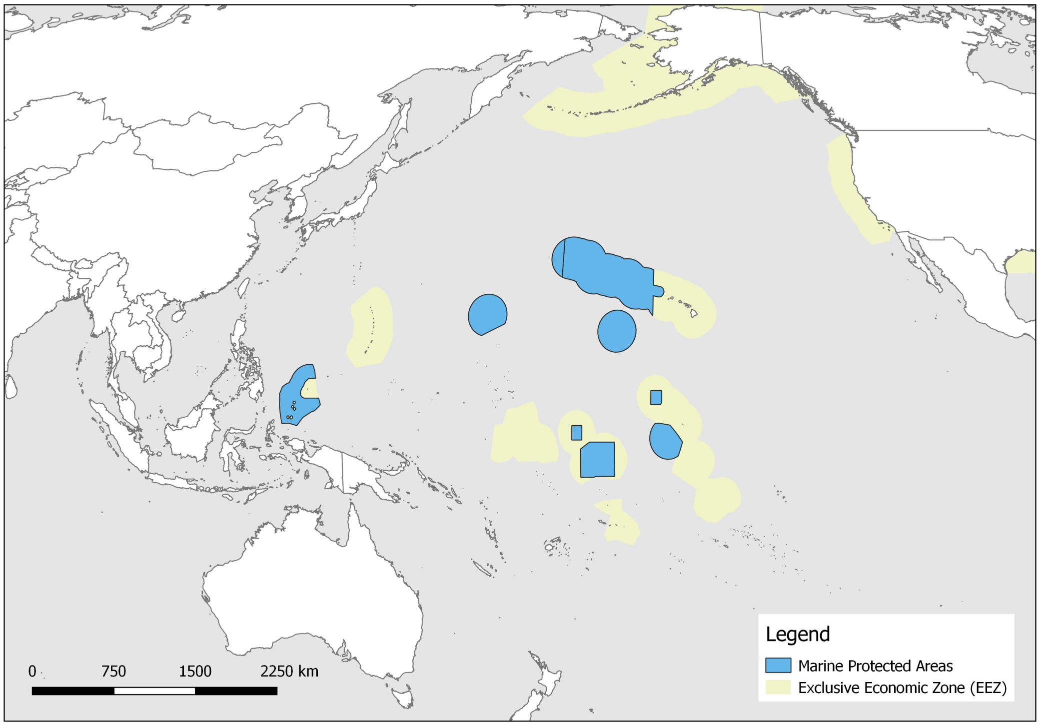

Fig. S9. Map of the Four Protected Areas

8. Palau National Marine Sanctuary 393

9. Alternative Controls

Table S3. Difference-in-differences estimates for our 10 variables of interest: 1) Daily fishing hours, 2) Daily non-fishing at-sea hours, 3) Daily proportion of fishing hours to total at-sea hours, 4) Daily distance traveled, 5) Daily mean distance from port, 6) Daily mean distance from shore, 7) Daily mean distance from port for fishing events, 8) Daily mean distance from shore for fishing events, 9) Monthly proportion of hours spent in Kiribati waters, 10) Monthly proportion of fishing hours spent in PNA waters. Numbers in parentheses are heteroskedastic-robust standard errors.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Constant	1.875***	3.860***	0.198***	4.878***	5.513***	10.647***	7.199***	13.886***	2.497***	2.624***
	(0.038)	(0.007)	(0.009)	(0.045)	(0.054)	(0.088)	(0.026)	(0.028)	(0.281)	(0.255)
Post	0.654***	−0.243***	0.157***	−0.099***	−0.077*	−0.201***	0.336***	0.248***	1.537***	1.556***
	(0.026)	(0.008)	(0.007)	(0.036)	(0.042)	(0.061)	(0.016)	(0.017)	(0.154)	(0.119)
Treated	0.008	0.008	−0.007	0.275***	0.059	0.087	0.180***	−0.018	0.393***	0.244**
	(0.028)	(0.006)	(0.007)	(0.032)	(0.037)	(0.055)	(0.017)	(0.018)	(0.151)	(0.119)
Post × Treated	−0.020	0.033***	0.0002	−0.250***	−0.248***	−0.267***	−0.281***	−0.059***	−0.531***	−0.368***
	(0.030)	(0.009)	(0.007)	(0.040)	(0.048)	(0.069)	(0.019)	(0.019)	(0.175)	(0.135)
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flag FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25,073	74,600	25,073	73,265	74,995	74,995	25,073	25,073	1,460	2,056
R^2	0.141	0.075	0.151	0.011	0.019	0.013	0.163	0.293	0.198	0.282

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

A. Excluding all Chinese vessels.

Table S4. Difference-in-differences estimates for our 10 variables of interest: 1) Daily fishing hours, 2) Daily non-fishing at-sea hours, 3) Daily proportion of fishing hours to total at-sea hours, 4) Daily distance traveled, 5) Daily mean distance from port, 6) Daily mean distance from shore, 7) Daily mean distance from port for fishing events, 8) Daily mean distance from shore for fishing events, 9) Monthly proportion of hours spent in Kiribati waters, 10) Monthly proportion of fishing hours spent in PNA waters. Numbers in parentheses are heteroskedastic-robust standard errors.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Constant	2.438***	3.602***	0.362***	4.575***	5.007***	11.149***	6.400***	12.771***	2.842***	3.659***
	(0.042)	(0.012)	(0.011)	(0.051)	(0.056)	(0.080)	(0.030)	(0.028)	(0.238)	(0.187)
Post	0.466***	−0.173***	0.095***	−0.174***	−0.636***	−0.771***	0.096***	0.006	1.794***	1.778***
	(0.037)	(0.010)	(0.010)	(0.048)	(0.051)	(0.076)	(0.025)	(0.024)	(0.197)	(0.164)
Treated	−0.142***	0.023***	−0.059***	0.450***	0.048	0.158**	0.077***	−0.164***	0.570***	0.443***
	(0.037)	(0.007)	(0.009)	(0.040)	(0.043)	(0.067)	(0.025)	(0.025)	(0.197)	(0.164)
Post × Treated	0.152***	−0.031***	0.061***	−0.236***	0.275***	0.253***	−0.072***	0.139***	−0.910***	−0.728***
	(0.040)	(0.011)	(0.010)	(0.052)	(0.056)	(0.082)	(0.027)	(0.026)	(0.216)	(0.177)
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flag FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,523	63,902	21,523	61,827	64,224	64,224	21,523	21,523	1,280	1,759
R^2	0.137	0.073	0.148	0.015	0.020	0.015	0.165	0.316	0.187	0.271

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

B. Excluding all PNA vessels.

Table S5. Difference-in-differences estimates for our 10 variables of interest: 1) Daily fishing hours, 2) Daily non-fishing at-sea hours, 3) Daily proportion of fishing hours to total at-sea hours, 4) Daily distance traveled, 5) Daily mean distance from port, 6) Daily mean distance from shore, 7) Daily mean distance from port for fishing events, 8) Daily mean distance from shore for fishing events, 9) Monthly proportion of hours spent in Kiribati waters, 10) Monthly proportion of fishing hours spent in PNA waters. Numbers in parentheses are heteroskedastic-robust standard errors.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Constant	2.343***	3.624***	0.327***	4.599***	4.860***	11.030***	6.176***	12.513***	3.246***	4.062***
	(0.035)	(0.010)	(0.009)	(0.045)	(0.052)	(0.071)	(0.025)	(0.023)	(0.208)	(0.160)
Post	0.599***	−0.211***	0.139***	−0.167***	−0.364***	−0.532***	0.338***	0.261***	1.477***	1.457***
	(0.027)	(0.008)	(0.007)	(0.034)	(0.042)	(0.059)	(0.017)	(0.018)	(0.148)	(0.122)
Treated	−0.065**	0.007	−0.025***	0.326***	0.040	0.099*	0.158***	−0.010	0.375**	0.116
	(0.029)	(0.006)	(0.007)	(0.031)	(0.037)	(0.054)	(0.019)	(0.019)	(0.150)	(0.126)
Post × Treated	0.017	0.003	0.015**	−0.187***	0.070	0.077	−0.274***	−0.072***	−0.562***	−0.353**
	(0.031)	(0.009)	(0.008)	(0.039)	(0.048)	(0.068)	(0.020)	(0.020)	(0.170)	(0.139)
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flag FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,152	73,259	24,152	73,001	73,668	73,668	24,152	24,152	1,420	1,998
R^2	0.143	0.075	0.154	0.014	0.021	0.015	0.157	0.291	0.174	0.246

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

C. Excluding all USA and TWN vessels.

10. Additional 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 fishing events performed by Global Fishing Watch.† Alongside, we describe the subset of data used in our analysis. We also point out possible shortcomings in the data, or factors that must be considered in the analysis. We then move on to explain our empirical strategy for the identification of behavioral changes and the redistribution of fishing effort.

A. Data. Automatic Identification Systems (AIS) are on-board devices that provide at-sea safety and prevent ship collisions by broadcasting vessel position, course, and activity to surrounding vessels. These broadcast messages can be received by satellites and land-based antennas. GFW then uses machine learning algorithms (convolutional neural networks) on the broadcast messages to infer what type of fishing is taking place and where it is taking place, thus allowing the estimation of near real-time fishing events globally (21).

The amount of data gathered by GFW is dependent on the number of antennas and satellites that can receive signals. The total satellite count increased from 3 to 6 on June 1st 2014 , and then from 6 to 10 on January 1st 2016. This causes an increase in the number of *received* AIS messages (*i.e.* points), and therefore an apparent increase in the number of vessels. The addition of new satellites affects all vessels in the same way.

Our analysis focuses on tune purse seine vessels, the most important fishery for PNA countries. We identify a total of 186 purse seiners that fished in PNA waters at least once before 2015. Vessels that entered the fishery after 2015 were not exposed to the policy intervention in the pre-treatment period and are therefore excluded from our analyses, leaving us with 125 vessels. We identify 90 vessels that have fished inside PIPA at least once since 2012; 72 did so before the announcement of the closure (*i.e.* 09/01/2014 *sensu* (10)). From these, we only observe before and after data for 64 tuna purse seiners. On the other hand, 45 vessels never fished inside PIPA during the 2012 - 2015 period, but we only observe befor and after data for 28 of these.

Therefore, our treatment group contains all purse seiners (n = 64) that fished within PIPA at least once before the announcement, and that continued to fish elsewhere after the January 2015 implementation. Vessels in the control group meet the following two conditions: i) never fished within PIPA waters from 2012-2015, and ii) vessels have fished in surrounding areas (*i.e.* PNA-countries' EEZ) before and after PIPA closure (n = 28). Together, these vessels represent more than 20 million georeferenced positions for which we know activity (fishing or not fishing).

We include three additional control groups as a robustness check. The first group contains only vessels that belong to PNA countries (n = 7). The second group excludes all Chinese vessels (n = 12). Our third control is made up of Japanese purse seiners that fish in the Pacific but have never fished inside PIPA (n = 27). Our main definition of treatment and control groups leaves us with 64 treated and 28 control vessels, which have just over 22 million observations with about 22% of these observations identified as fishing events by the neural network classification.

† Global Fishing Watch: globalfishingwatch.org

Table S6. Number of fishing vessels and mean daily fishing hours by group before and after PIPA implementation.

Group	n	Before	After	Change (A / B)
Control	28	7.15	10.68	1.49
Treatment	64	6.21	9.89	1.59

B. Analyses.

B.1. crowding effect. If the implementation of the reserve induces a crowding effect, we would expect to observe no trend before the implementation of the reserve. The implementation would lead to an increase in these measures, which, if vessels avoid crowding, should then come back down. We therefore expect to have three inflection points: 1) in the transition between no trend and initial crowding due to MPA implementation, 2) When the crowding has reached its maximum and starts to decrease, and 3) when the decrease levels off, pressumably to pre-MPA levels. For this reason, we fit a 4th degree polynomial to our monthly indices. We do so by centering our time series of crowding indices on the day of implementation. Our explanatory variable is therefore the number of months before or after the implementation. For example, since PIPA was implemented in January 1st of 2015, December of 2014 has a value of -1, and Feb of 2015 would receive a value of 1.

$$y_t = \alpha + \beta_1 month_t + \beta_2 month_t^2 + \beta_3 month_t^3 + \beta_4 month_t^4 + \epsilon_t$$

B.2. Behavioral changes. We then focus on identifying the response of vessels to the PIPA closure. We use daily fishing and non-fishing hours, daily proportion of fishing vs. non-fishing hours, daily distance traveled (km), distance from shore (km) and distance from home port(km) for fishing and non-fishing events, and proportion of total fishing hours allocated to Kiribati waters and PNA waters as our main outcomes of interest. We compare these outcomes before and after the implementation of PIPA using a Difference-in-Differences approach. Our main specification is the following:

$$log(y)_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Treat_i + \beta_3 Post_t \times Treat_i + \phi_t + \gamma_i + \epsilon_{i,t}$$

Where $log(y_{i,t})$ is the log-transformed outcome of interest for vessel i on day t. A dummy variable $Post_t$ takes the value of 0 for all dates prior to PIPA implementation and a value of 1 for all dates following PIPA implementation. $Treat_i$ is a dummy variable indicating whether a vessel belongs to the treatment ($Treat_i = 1$) or control ($Treat_i = 0$) group. α is the standard intercept term, $beta_1$ captures the temporal trend, $beta_2$ captures the initial difference between treated and control groups, and $beta_3$ is our parameter of interest: the Difference-in-Differences estimate capturing the treatment effect. Finally, phi_t and γ_i represent month and flag dummies that account for seasonality or country-level management interventions. We test for other more complex specifications that interact a quarterly dummy or year-month dummies with the treatment group and find qualitatively the same results[‡].

We discretize spatial units by creating a polygon for PIPA and distinct spatial units for each geographically separate EEZ of each country. Some vessels might shift from EEZs into the high seas, but we are interested in knowing *where* in the high seas, so we incorporate additional regions by using a 5-degree buffer of the high seas. The rest of the high seas are merged into a single spatial unit. For example, if we were to do this only for Kiribati, we would have 8 spatial units: PIPA, three EEZ units, three 1-degree buffers of high seas around each of the EEZ regions. around each EEZ, and the rest of the high seas. We clipped any overlapping high seas buffers to avoid duplication.

All regression coefficients were estimated via ordinary least squares, and heteroskedasticity-robust standard errors were calculated. All analyses were performed in R version 3.5.1 (22). Raw data and code used in this work are available on github.

[‡] I actually need more time to run these, but I don't think they'll change

11. Old Text

A. Large-Scale Marine Protected Areas. The cutoff at which an MPA is considered to be a LSMPA ranges from areas larger than 30,000 km^2 as defined by (23) or areas larger than 250,000 km^2, as defined by (4). Figure 1 shows LSMPAs that meet the latter condition, and are also fully no-take. LSMPAs are often implemented in the pelagic environment, where the dominant human activity is industrial fishing (5, 21). The early literature on LSMPAs focused on the inherent challenges and difficulties that come with a pelagic environment. (24) claimed that very large MPAs would result in excessive opportunity costs and that these would be difficult to enforce. (25) suggested that most of the challenges could be overcome with the incorporation of technology, in what then became known as Dynamic Ocean Management (26).[§]

Spatial closures of this magnitude are likely to induce changes in fishers' behavior. Theoretical models of fishing effort redistribution range from the simplistic assumption that effort inside the bounded region disappears, to spatially explicit models that reallocate fishing effort based on habitat characteristics, presence of other vessels, and expected returns (6, 28). However, these focus on the long term optimal equilibrium, and redistribution of fishing effort may not always be optimally distributed, especially over the first few years (14).

The empirical research that has been done in smaller sized MPAs suggests that resource users may show idiosyncratic responses. For example, (14) show that a network of MPAs displaced fishing effort farther away from ports, resulting in higher *perceived* costs, and increases in catch per unit effort. (29) analyze the redistribution of fishing and non-fishing vessels following the implementation of a network of MPAs in California, and find that dive boats follow a fishing-the-line pattern, while some fishing boats follow an ideal free distribution. More recently (16) used satellite tracking data to show that a temporal spatial closure caused trawlers to maintain effort but apply it more intensively elsewhere, particularly along the borders and closer to shore. The way in which fishers react to a spatial closure can have major implications for its outcome (6, 28), highlighting the need to understand how fishers react to the implementation of LSMPAs, how fishing effort changes, and how it is spatially redistributed. All these studies evaluate relatively small closures within Exclusive Economic Zones, where other regulations exist. This may not always be the case for LSMPAs, where often the entire EEZ is converted into a LSMPA, leaving fishers with the option of moving to the high seas or other countries' EEZs, with potentially very different fishing regulations.

B. Nauru agreement and the Phoenix Islands Protected Area. The cooperation that emerged under the Nauru Agreement allowed for subsequent agreements that strengthened fisheries management, like the Palau Agreement, which limited the number of purse seiners at 205 vessels from 1995-2007.[¶] However, the most notable regulation is the approach to manage fishing effort: a Vessel Day Scheme (VDS) implemented in 2007 (30). This effectively modified how fishing effort was managed, from total number of vessels (under the Palau Agreement) to total vessel-days. Under the purse seine VDS, a total number of annual vessel days for the entire fishery is agreed upon by the PNA parties. Each party's allowable effort (PAE) is then calculated based on historic effort and biomass within each party's EEZ. Sixty percent of the PAE is calculated based on EEZ effort over the last seven years and 40% of the PAE is calculated based on the 10-year average of each country's share of estimated skipjack and yellowfin biomass within its EEZ.[‖]. A minimum benchmark fee is set for purse seine vessel days which each party can transfer (*i.e.* sell to another PNA member) or sell to the highest bidder (*i.e.* sell to a fishing company). Vessel days can be transferred to fish in any PNA party's EEZ, without penalty to the transferred parties' allocations (32).[**] The mean value of a vessel day has steadily increased since 2007 (30). Although detailed records on sales or transfers of vessel days are not publicly available (30, 33), a minimum benchmark fee of $8,000/day was set from 2015 (34).

(33) summarize the PNA implementing arrangements as follows: "foreign vessels [are required] to be registered and licensed, report catches, maintain log books, allow observers on board and maintain transparency over their fishing activities." Further, vessels registered with the Vessel Day Scheme are required to have Automatic Location Communicators (ALC) or Mobile Transceiver Units (MTU) that transmit their locations at least once per hour while they are within the VDS Management Area (32). Every entire day that a vessel is within the VDS Management Area is counted as a vessel day used, unless the vessel reports a "no fishing day" (e.g., travel, maintenance, etc.) and periods of less than 24 hours are counted as partial days (32). As described in the Palau Arrangement, fishing days by vessels shorter than 50m (longer than 80m) count as 0.5 (1.5) vessel days. Countries are responsible for ensuring registered vessels comply with the implementing arrangements and that they stay within their PAE. Parties that exceed their PAE should reportedly be penalized by reductions to the following year's PAE (32). There are some criticisms of the PNA PS VDS claiming that there is a lack of monitoring, compliance, and transparency that could

[§] See (27), who provide an objective discussion of the pros and cons of LSMPAs.

[¶] See (11) for a detailed description of the Nauru, Palau, and Federal States of Micronesia agreements.

[‖] This is explained in more detail in Article 12.5 of the 2012 Amendment to the Palau Agreement and in (31)

[**] The process of transferring days between parties is described in Article 7 of the Management Scheme (32).

hinder the future success of the program (33, 35). While the effectiveness of this scheme has been debated in terms of meeting fishery management and conservation objectives, the licensing significantly contributes to the economy of these island nations (11).

The main tuna species caught in the region are skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*) and bigeye (*Thunnus obesus*). From these, the first two are amongst the top-10 species represented in global fisheries production statistics, with 2016 catches increasing relative to the 2005-2014 average (36). This region of the Pacific has historically accounted for a large portion of tuna catches (37). Today, the PNA controls close to 50% of global skipjack tuna production (38) and the combined area of all EEZs involved is 14.6 million km^2, larger than the land mass of the United States of America. A large portion of global skipjack catch derives from purse seine vessels licensed under the VDS. Fishing vessels from Australia, New Zealand, China, France, Korea, Japan, the Philippines, Taiwan, and the United States participate in the purse-seining VDS.

One of the most notable and recent management interventions in the region is the implementation of the Phoenix Islands Protected Area (PIPA) by the government of Kiribati. PIPA was first declared in 2006, and established in 2008 with only 4% of the area declared as no-take. On January 1st, 2015, the no-take area within PIPA was expanded to a total area of 397,447 km^2, roughly 1.5 times the size of Ecuador. Figure S1 shows a map of the PNA countries (excluding Palau) and the Phoenix Islands Protected Area.

The closure of such a large area in one of the most important fishing regions in the world provides a unique opportunity to evaluate the behavioral responses and redistribution of fishing effort by vessels that used to fish there. PIPA has been the focus of previous research showing that fishing effort is effectively reduced after implementation (10, 39). To this, we pose two questions: How did individual vessels respond to the sudden exclusion of such a big area? Where did all the vessels go? And what does this imply for revenues from selling VDS for both Kiribati and the PNA as a whole?

A spatial closure might cause fishers to modify their behavior as they adapt to a new state of the world. For example, some may have to travel further distances to find new fishing grounds, increasing their fuel costs. If fishers had developed experience for fishing in particular sites, being excluded might impose a learning cost on them, as they identify new fishing grounds. This might result in increased search times. However, if the area of knowledge of a vessel is significantly larger than that of the spatial closure, they might already know other places to fish. In the next sections we describe the data and methods used to answer these questions.

C. Palau.

C.1. Palau National Monument. On October 28, 2015, the President of Palau, H.E. Tommy E. Remengesau Jr., signed into law the Palau National Marine Sanctuary (PNMS) Act. Starting in December 2020, this Act will close 500,000 km^2 to commercial fishing activities, creating the 14th largest protected area in the world. The sanctuary will fully protect about 80 percent of the nation's EEZ. The remaining 20% of Palau's EEZ (close to the most heavily populated islands: Koror and Babeldaob) will become a Domestic Fishing Zone in which traditional and domestic fishing activities will be allowed to provide fish solely for the domestic market (*i.e.* exports of pelagic fish will be prohibited). Alongside these protections, the Palau National Marine Sanctuary (PNMS) Act will support a domestic pelagic fishery. In this section, we use our preceding analysis on the ex-post impacts of PIPA to attempt to make some *ex ante* predictions about the potential impacts of PNMS. We start by giving some background on the fishing that is currently taking place inside the future PNMS.

C.2. Background on Commercial Fishing in Palau. Foreign tuna fishing in Palau's EEZ began before WWI. Pole and line was the initial gear used to target skipjack tuna by Japanese vessels. Foreign fishing activities stopped during WWII and started again in the 1960s when Japanese fishers returned and the locally based Van Camp Seafood Company carried out fishing with boats crewed by Okinawans. The Japanese also began purse seine fishing in the 1960s and 1970s and limited longline fishing for yellowfin tuna developed during the same time. During the 1980s, longline fishers began to set their lines deeper, shifting their targets to bigeye tuna. During the 1980s, Korean and Taiwanese vessels also began longline fishing in Palauan waters for export to Japan (40). There are currently three transshipment companies operating in Palau.

Purse seine vessels target schools of skipjack tuna that are then canned. Compared to other EEZs in the Pacific, especially the PNA EEZs, Palau's EEZ is not known to be a preferred fishing ground for purse seining (Sisior, pers. comm.). This can be seen in Figure **??**. Currently all purse seine boats fishing in Palau's EEZ are Japanese and they do not land their catch in Palau (Table S7).

All longline vessels fishing in Palau's EEZ are foreign owned (Table S8). Japanese longline vessels do not land their catch in Palau. Locally-based, foreign-owned longline boats are mostly Taiwanese vessels that are contracted by one of the two main fishing companies (Palau International Traders Incorporated (PITI) and Kuniyoshi Fishing Company

Table S7. Japanese Purse Seine Fleet Statistics

Year	No. Vessels	Catch in metric tonnes (mt)
2012	36	not reported
2013	5	246
2014	21	453
2015	30	169
2016	30	130

Source: Annual Report to the Western and Central Pacific Fisheries Commussion. Palau. 2017

(KFC)). Ninety-five percent of the catch from PITI and KFC contracted boats is exported to Japan upon landing in Koror (the largest town in and former capital of Palau). Most of the discards are either sold or donated in Palau. A very small portion of the discards is frozen and transported to Taiwan when vessels return to their home ports.

Table S8. Longline Fleet Statistics

Year	Total Vessels	Flag	No. Vessels	Total catches (mt)
2012	77	Belize	2	not reported
		Taiwan	50	2080
		Japan	25	1148
2013	83	Belize	1	6
		Taiwan	54	1871
		Japan	28	1159
2014	71	Belize	1	not reported
		Taiwan	41	1356
		Japan	28	721
		Vanuatu	1	17
2015	51	Taiwan	30	970
		Japan	19	314
		Vanuatu	2	33
2016	57	China	3	40
		Taiwan	33	1828
		Japan	19	550
		Vanuatu	2	27

Source: Annual Report to the Western and Central Pacific Fisheries Commussion. Palau. 2017

C.3. Access fees and taxes. An agreement between Palau and four Japanese fishing associations[††] covered three methods of fishing (longline, purse seine, and pole and line) and allowed Japan to have up to 290 vessels in Palau waters with no limits on catch. Japan paid 4-5% of catch returns for this access, but there was no way to validate their catch (41). Between 2010 and 2014, Japan paid Palau between \$196,100- \$867,120 annually in access fees (13). Currently, these access fees have been replaced by the PNA vessel day scheme (described earlier).

There used to be a number of agreements between the Republic of Palau and foreign owned, local based companies, in particular PITI and KFC, to allow longline fishing (41). Vessels under these agreements were internationally-owned, locally-based vessels that paid for annual licenses based on the size of each vessel. These are the vessels shown in Table S8 (excluding the Japanese vessels). So, for example, there were 38 vessels as part of these agreements in 2016. Between 2010 and 2014, licensing fee revenue from these agreements was between \$219,000-\$284,600 per year (13). These access fees have also been replaced by a new longline-specific version of the VDS (described in more detail below).

There are two multilateral treaties that grant preferential access to Palau waters to US and Federated States of Micronesia (FSM) flagged purse seine boats: the US Multilateral Tuna Treaty and the Federated States of Micronesia Arrangement. The US Treaty was renegotiated in 2016 with stipulations on minimum vessel day fees. Very little purse seine fishing is conducted by FSM and US vessels in Palau's EEZ, but Palau still receives a portion of these treaty funds. These agreements have been described by some commentators as foreign aid, with little connection to underlying fish stocks (13).

The export tax for all commercial tuna and billfish, either fresh or frozen, is \$0.35/kg. Average annual revenue from export taxes was around \$500,000 from 2011-2014 (13). Other than the access fees and tax revenue, Palau

[††] This is a single agreement between Palau and four associations—1)Federation of Japan Tuna Fisheries Cooperative Associations, 2) National Offshore Tuna Fisheries Association of Japan, 3) Japan Far Seas Purse Seine Fishing Association, 4) Federation of North Pacific District Purse Seine Fisheries Cooperative Association of Japan (Performance Audit Report on Managing Sustainable Fisheries (Tuna) 2013).

receives little additional economic benefits from pelagic fisheries, especially considering that very few jobs are created by the fishery. Between 80 to 90 people are employed by offshore fisheries, and of these only around 20% are Palauans, earning wages that are only 50% of average wages in Palau (13).

C.4. Parties to the Nauru Agreement and the Vessel Day Scheme. In the case of Palau, the VDS is run by the Bureau of Marine Resources, within the Ministry of Natural Resources, Environment and Tourism. Palau's current purse seine VDS allotment is reportedly around 700 vessel days annually (Sisior, pers. comm., (42)), although historically this number has been lower (average of 580 days between 2008-2011 (41)). Palau sells most of its vessel days to the US for $12,500 per day (as negotiated in the US treaty), regardless of whether US vessels actually fish in Palau's EEZ. The remainder of Palau's purse seine vessel days are sold for between $9-10,000 each. When vessel days are purchased to transfer to another EEZ, Palau charges a transfer fee (approximately $500), for administration costs and future opportunity costs (since vessel day allotments are based partly on historical effort within the EEZ). Though records are confidential, it has been publicly reported that one PNA member party that Palau has transferred vessel days to is Papua New Guinea (41) and in 2018, vessel days were sold to a fishing company in the Philippines for the first time (42). In 2018, Palau brought in approximately $9 million USD in VDS revenue (Sisior pers. comm.).

The longline VDS (LL VDS) is in its infancy and has not yet been fully implemented at the PNA-scale, although several countries are now implementing it at the country-scale. Palau was the first party to implement the VDS for longline fishing in 2017. In 2014, longline boats fishing in Palau's EEZ fished 10,500 days (Sisior, pers. comm.). Since 2016, the number of allowed longline VDs has been a fraction of the 2014 days, reducing each year as stipulated in the PNMS Act. Palau sells its LL VD for $150-$250 (Sisior pers. comm.). Because the LL VDS is still new and has yet to be fully implemented by all parties, LL VD are not currently transferable between PNA member EEZs.

C.5. Plans for a domestic pelagic fishery. In the recent past, a single domestic pole and line vessel supplied Palau with an estimated 100mt of catch (13). The vessel ceased operations in recent years when the captain became ill and passed away, but there is talk that it is gearing up to start operations again under new leadership (Sisior, pers. comm.). Otherwise, there are no domestic vessels dedicated to full-time offshore fishing. A number of fishers occasionally troll offshore for tuna and other pelagics, but there are no official estimates of volumes. Local NGOs have sponsored short trainings on small-scale canning and proper techniques for processing high grade tuna to encourage existing fishers to devote more time to offshore fishing. There are several possible scenarios for a domestic fishery (including those featured in a feasibility report by FFA (43)), but there has yet to be any official action towards a particular scenario.