Supplementary Materials for: "Well-Designed Environmental Markets Enable Large-Scale Marine Conservation"

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1 Supplementary Materials

1.1 Model parameterization

We calibrate our model to loosely match the fishery dynamics observed for the VDS operated by the PNA. The table below contains the values used to parameterize the model.

Parameter	Value	Source
MSY	1.875600e+06	50th percentile from MSY in Table 8 of WCPFC Stock Assessment
B_{msy}	1.628000e+06	50th percentile from MSY in Table 8 of WCPFC Stock Assessment
K	6.876526e+06	50th percentile from MSY in Table 8 of WCPFC Stock Assessment
B_c/B_{msy}	0.51	50th percentile from MSY in Table 8 of WCPFC Stock Assessment
C_{now}	1.679444e+06	Catches from WCPFC Stock Assessment
B_{now}	3.507028e+06	Current Biomass (2012 - 2015 average)
r	0.57	From FishBase: Prior r = 0.57, 95 CL = 0.41 - 0.78
β	1.3	Standard
p	1100	Mean between Thailand and Japan values (Value of WCPFC-CA Tuna Fisheries 2017 Report)
q	3.420000e-05	Estimated so that efforts match catches given biomass and vessel-day prices
c	1800	Estimated to match cost and revenue structures
f	0.1	Biomass is equally distributed between countries

1.2 Empirical Analysis

1.2.1 Effort redistribution

We can compare the footprint of displaced and non-displaced vessels before and after the implementation of PIPA to better understand the effort redistribution. Non-displaced vessels serve as a control group that was not subject to a spatial closure but might have redistributed in response to changing environmental conditions, such as ENSO. The spatial redistribution patterns of displaced vessels relative to non-displaced vessels suggest that some relocated to other waters in Kiribati (*i.e.* Gilbert islands and Line islands), but also the Marshall Islands, Tuvalu, Nauru, and the high seas (Fig S5).

1.2.2 Data and code availability

Raw data and code used in this work are available on github.

2 Supplementary tables and figures

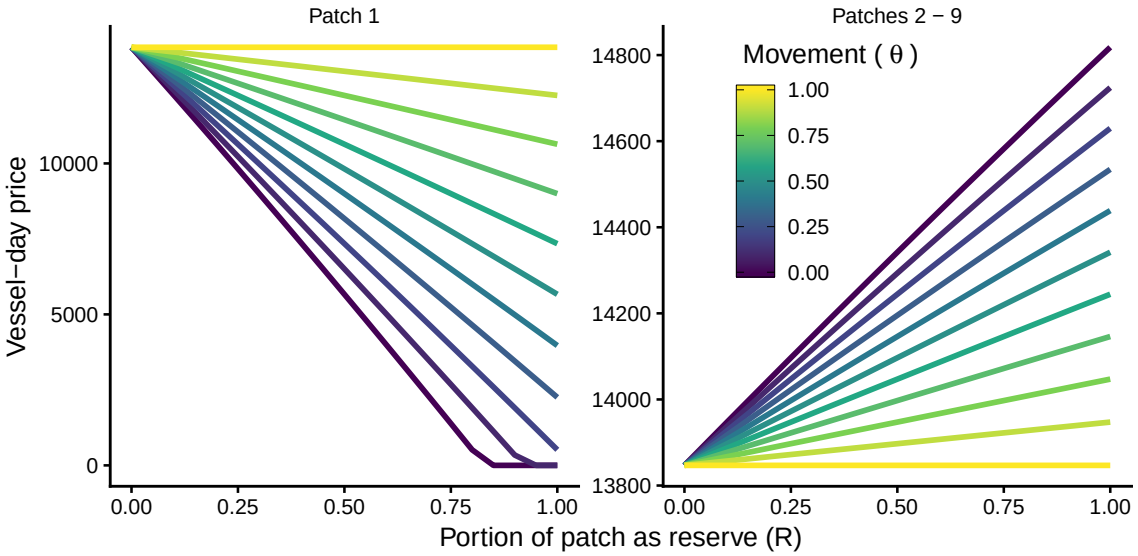

Figure S1: Vessel-day prices (vertical axis) for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ) for the country with spatial closure and other countries (left - right, respectively) when there is no trading.

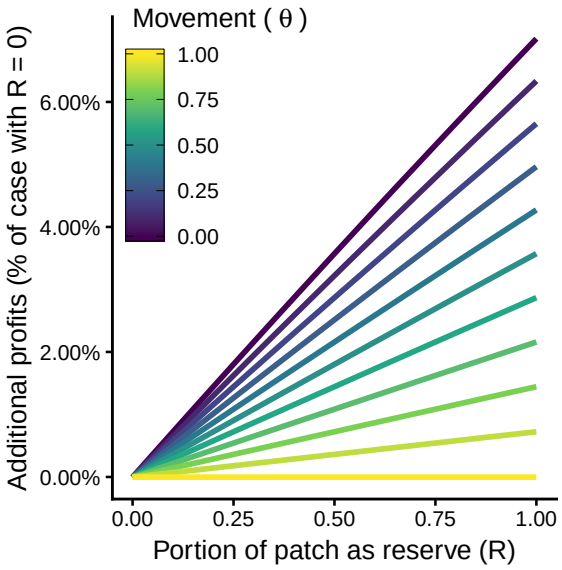

Figure S2: Relative change in revenue for countries 2 - 9 (vertical axis) for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ) when there is no trading.

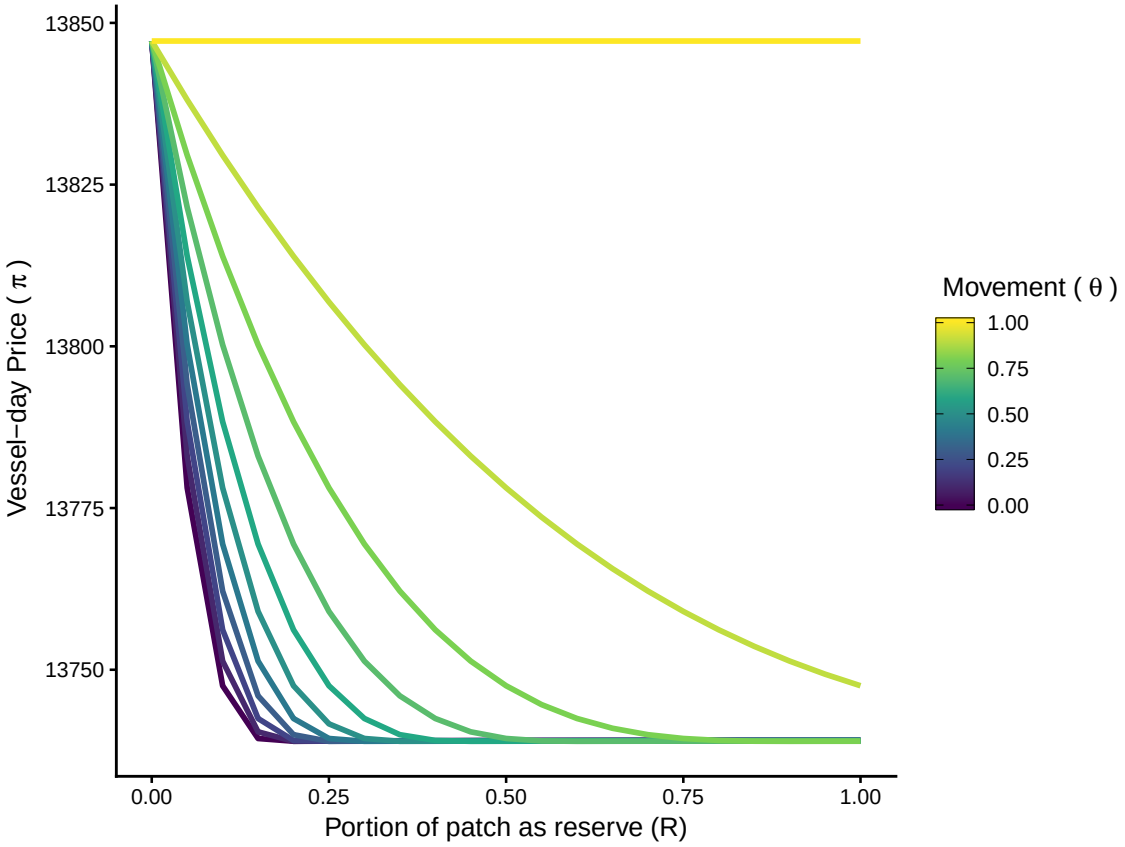

Figure S3: PNA-wide vessel-day prices (vertical axis) with trading, for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ).

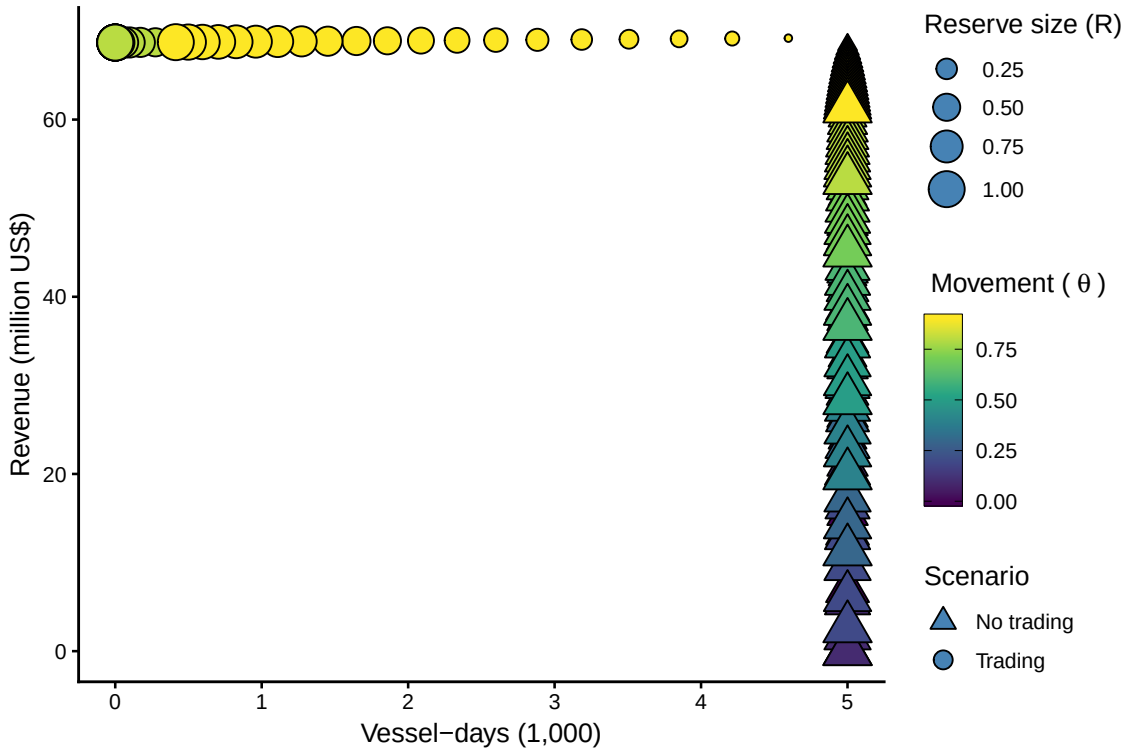

Figure S4: Effort and revenue in Patch 1 for a combination of reserve sizes (R), different within-country movement (θ), and with and without trading. With trading, the relative drop in effort is always larger than the relative drop in revenue as R increases. The exact opposite relationship holds without trading: effort remains fixed as revenue declines with increasing R.

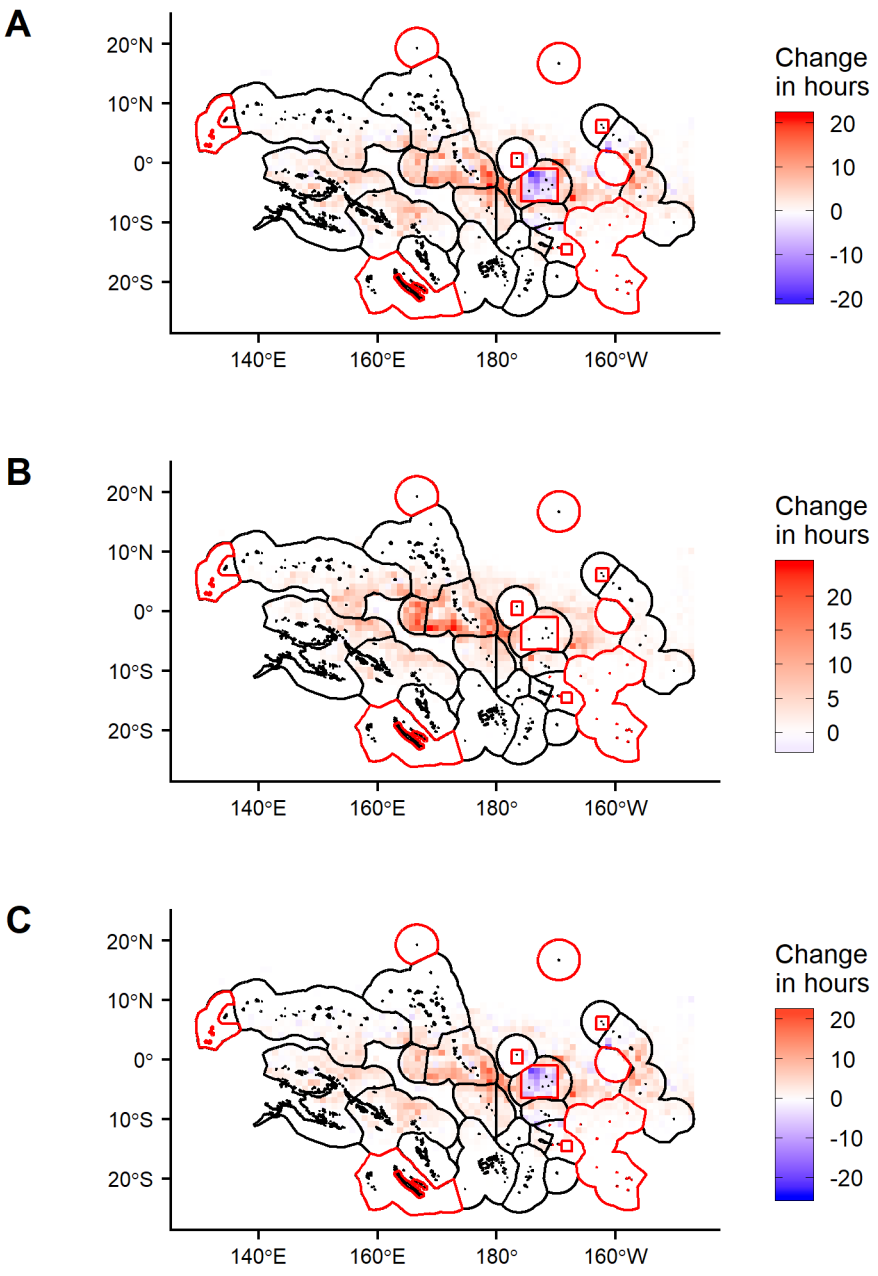

Figure S5: Change in spatial footprint of analyzed vessels. Black lines show Exclusive Economic Zone (EEZ), red lines show Marine Protected Areas. Panels A and B show the change through time (after - before) for displaced (A) and non-displaced vessels (B). Panel C shows the difference between A and B (displaced - non-displaced), highlighting areas where displaced vessels redistributed to, relative to non-displaced vessels. Note that displaced vessels allocate more hours to the Gilbert Islands and Line islands EEZs, but also Tuvalu and the high seas surrounding PIPA and Kiribati's EEZ.

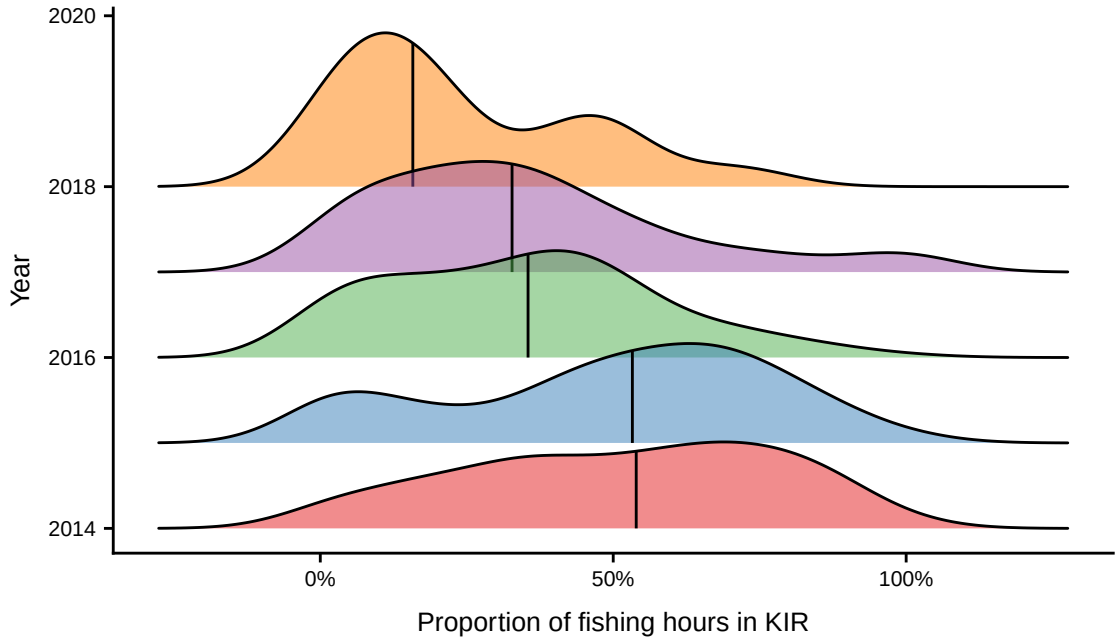

Figure S6: Ridgeplot for the density of the % of total fishing hours that took place within Kiribati EEZ waters by year for displaced vessels where the unit of observation is an individual vessel. The vertical lines represent the median of each year.

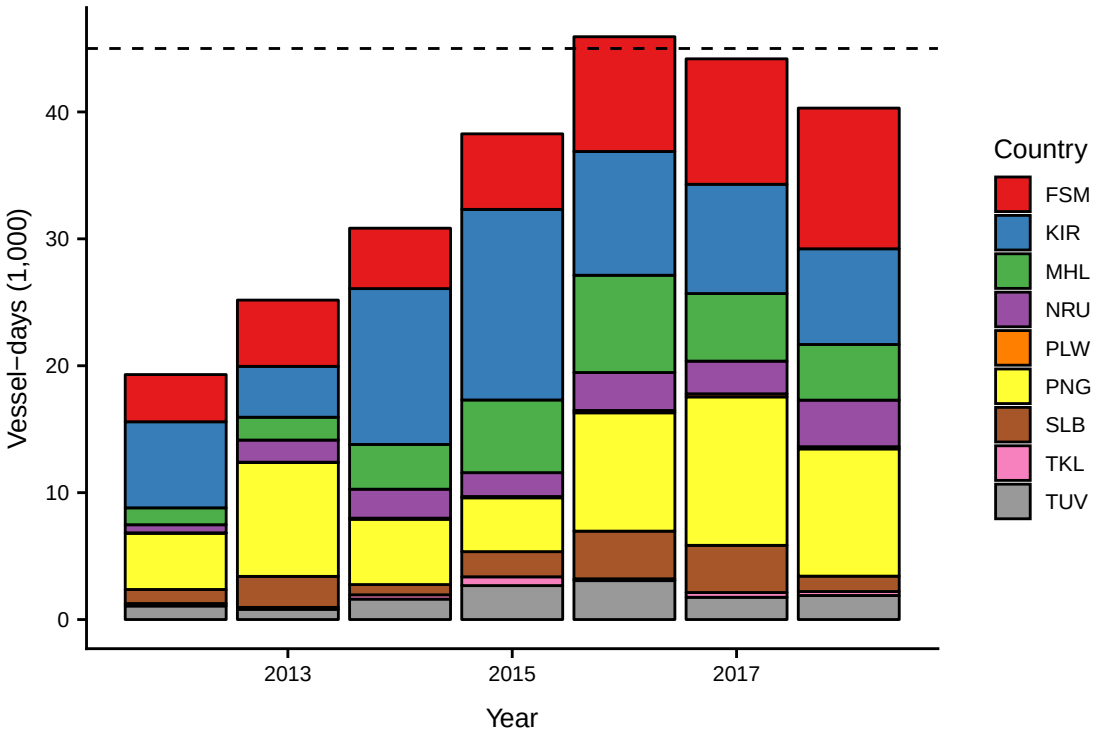

Figure S7: Annual vessel-days for all PNA countries, by country.

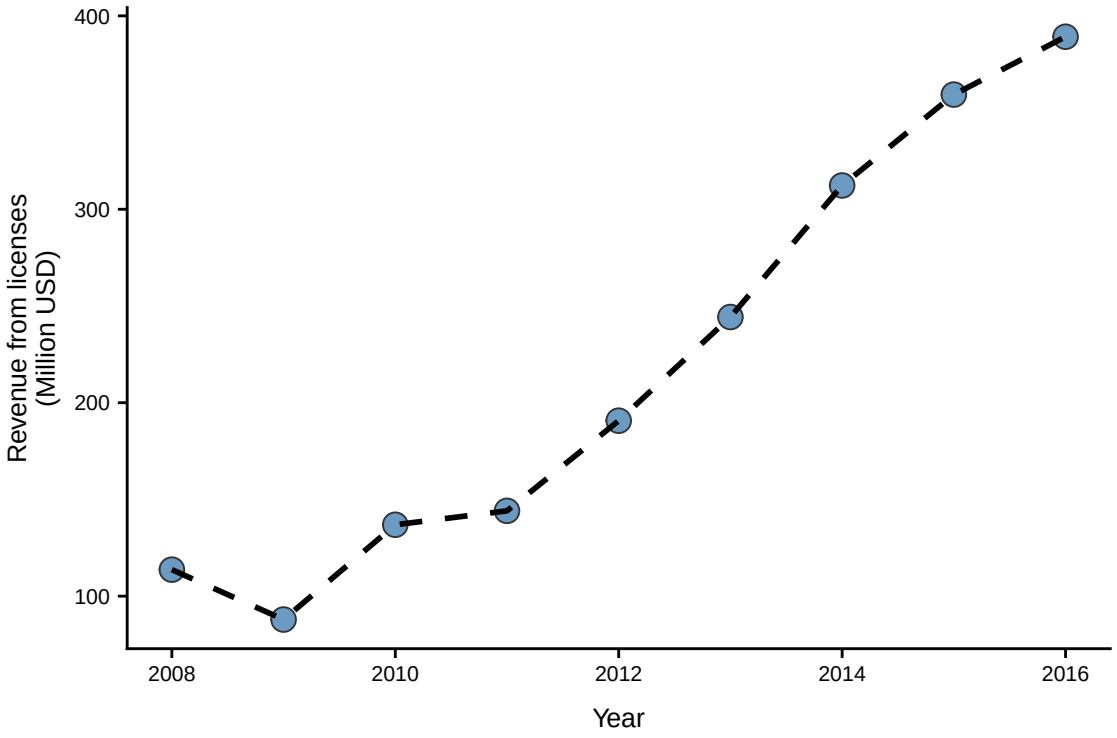

Figure S8: Total revenues for all PNA countries combined.

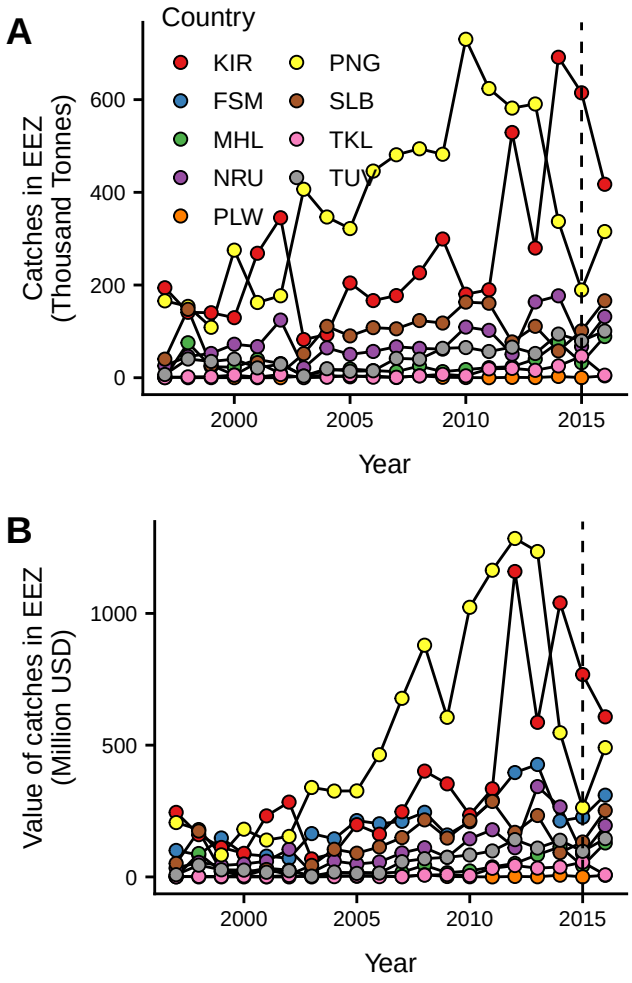

Figure S9: Financial indicators for PNA countries. A) Total annual purse seine catch by EEZ and, B) Total annual value of purse seine catch by EEZ. Vertical dashed line in both plots denotes implementation of PIPA.

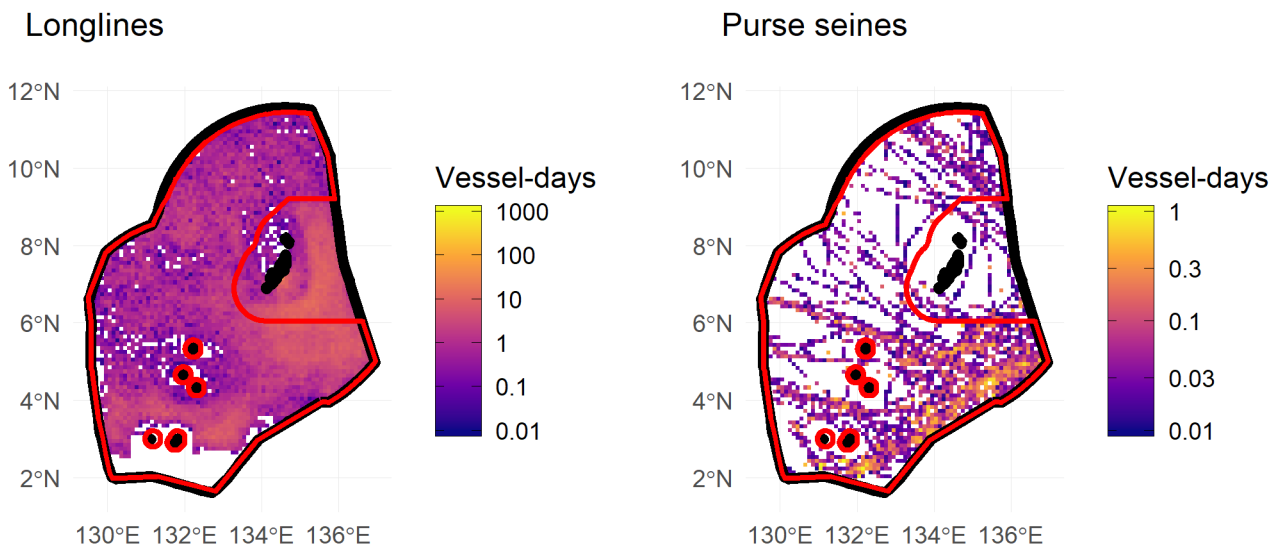

Figure S10: Longline and purse seine fishing effort in Palau during 2018 at a 0.5 degree resolution. The red polygon shows the proposed Palau National Marine Sanctuary, containing 56% and 91% of longline and purse seine fishing effort, respectively. Note that the colorbars are presented in log_{10} transformed scale for better visualization.

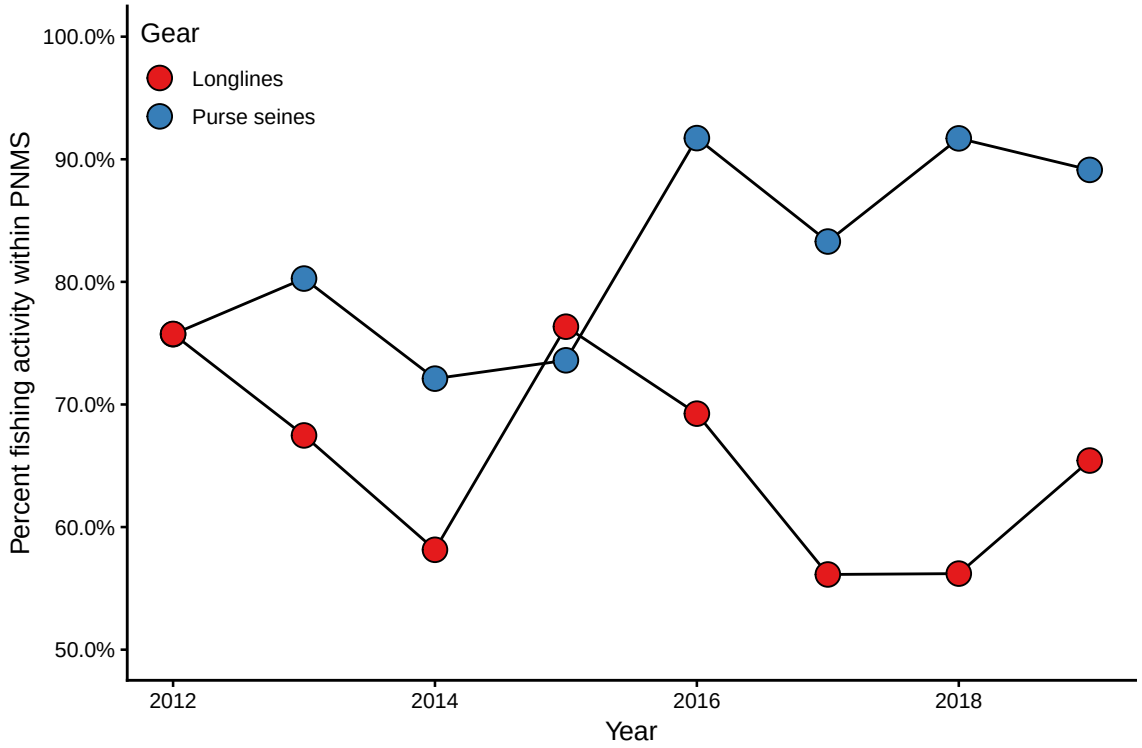

Figure S11: Time series of the annual proportion of longline and purse seine effort within the proposed PNMS boundaries.