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

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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.

Table S1: Model parameters.

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 [1]
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

2 Balance on observables

We observe four characteristics for every vessel: crew size, engine power, vessel length, and tonnage capacity. Figure S5 shows the distribution of these variables for each group of vessels. Table S2 presents the mean and standard deviation of each observable. Groups of vessels are similar on observables, and the choice to fish inside PIPA before implementation does not appear to be driven by observable characteristics.

Table S2: Mean values on observable characteristics by vessel for displaced (n = 64), and non-displaced vessels (n = 254). Numbers in parentheses indicate standard deviation. The last column contains the difference in means (t-scores), with asterisks indicating significant differences as indicated by a two-tailed t-test (* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$).

Characteristic	Displaced	Non-displaced	Difference
Crew size (n)	26.38 (3.94)	30.46 (6.25)	4.08 (6.49) ***
Engine Power (KW)	2983.6 (558.76)	2559.89 (588.28)	-423.71 (-5.36) ***
Length (m)	74.23 (9.71)	68.97 (8.42)	-5.25 (-3.97) ***
Tonnage (GT)	1718.14 (653.38)	1383.41 (533.56)	-334.73 (-3.79) ***

3 Supplementary figures

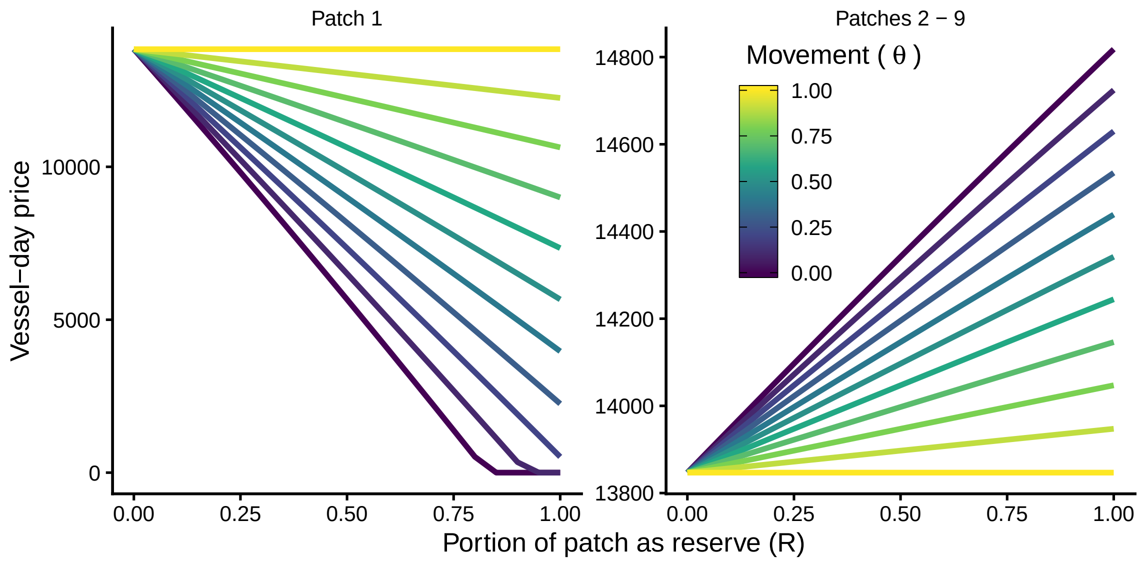

Figure S1: Vessel-day prices (vertical axis) for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ) for the country with spatial closure and other countries (left - right, respectively) when there is no trading.

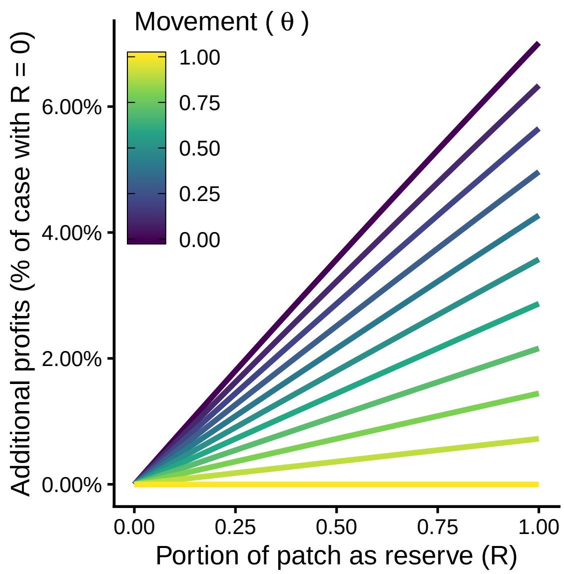

Figure S2: Relative change in revenue for countries 2 - 9 (vertical axis) for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ) when there is no trading.

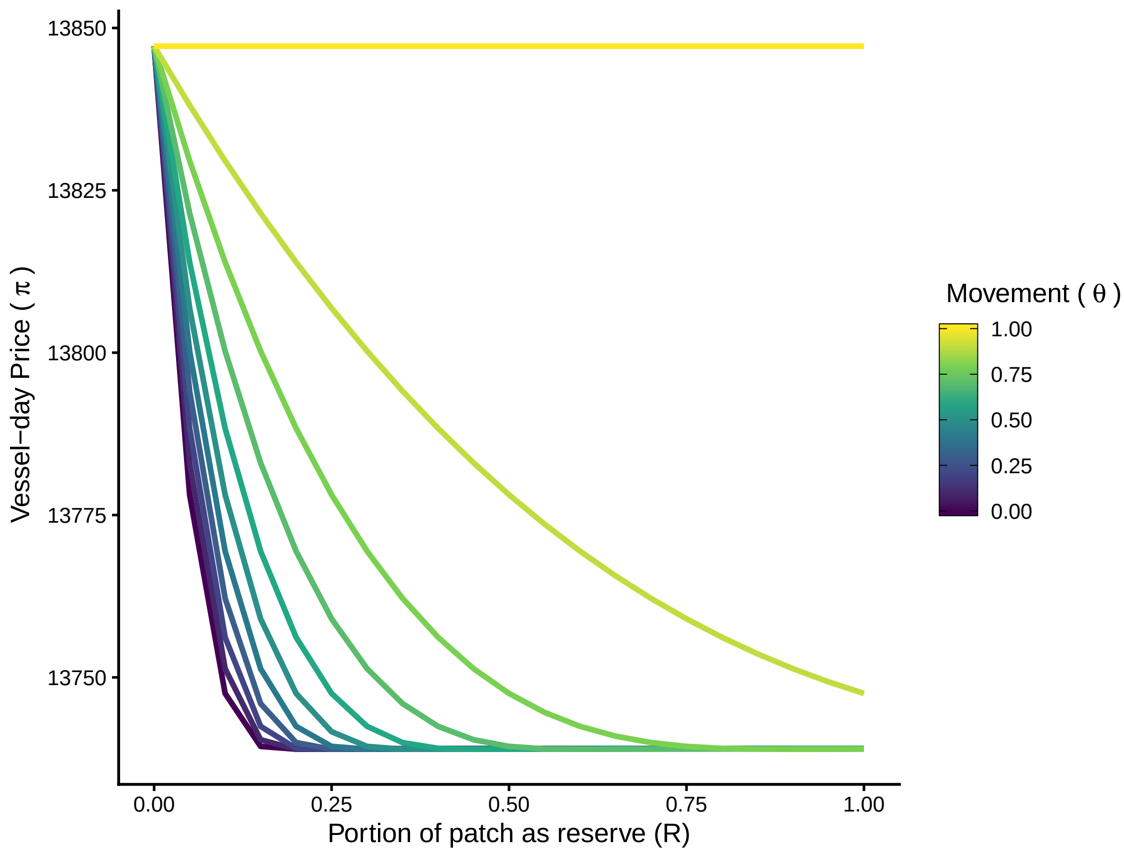

Figure S3: PNA-wide vessel-day prices (vertical axis) with trading, for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ).

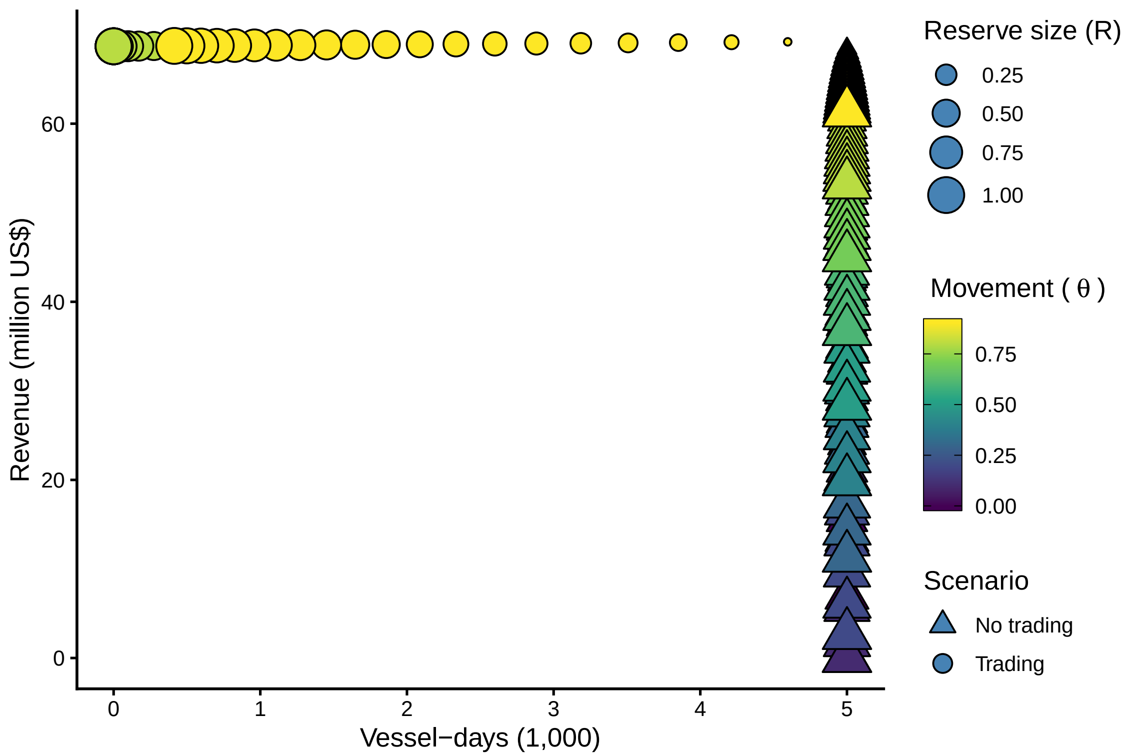

Figure S4: Effort and revenue in Country 1 for a combination of reserve sizes (R), different within-country movement (θ), and with and without trading. With trading, the relative drop in effort is always larger than the relative drop in revenue as R increases. The exact opposite relationship holds without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

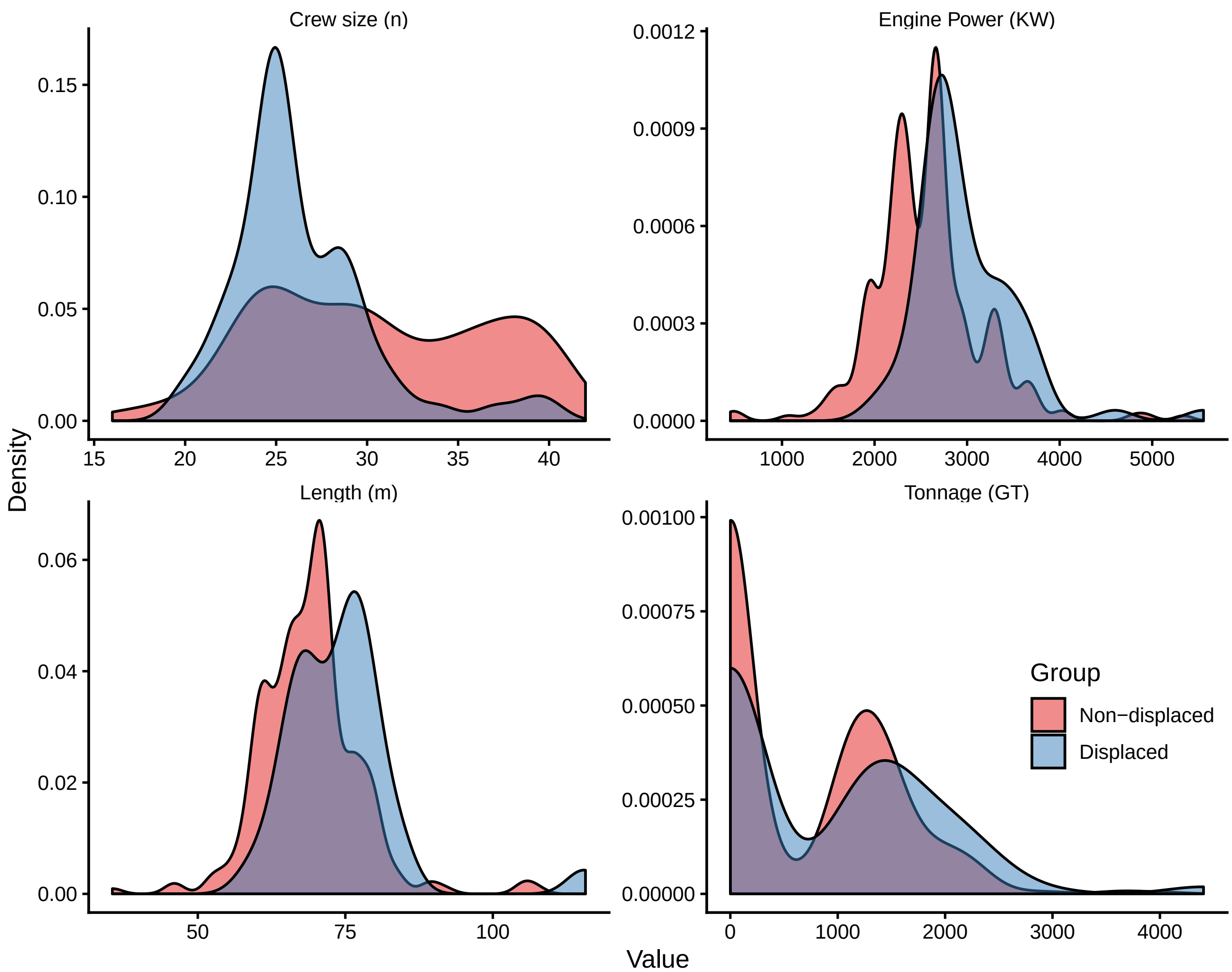

Figure S5: Distribution of observable characteristics by vessel for displaced (n = 64), non-displaced vessels (n = 254).

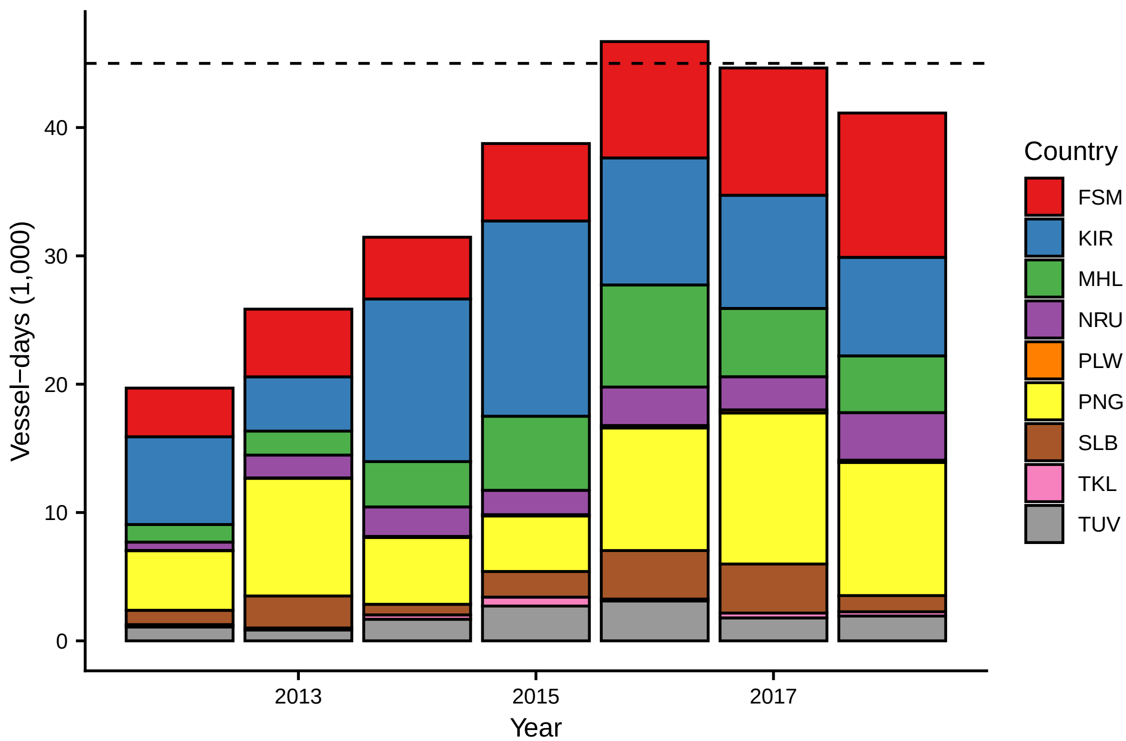

Figure S6: Annual country-level vessel-days for all PNA countries by 318 tuna purse seiners.

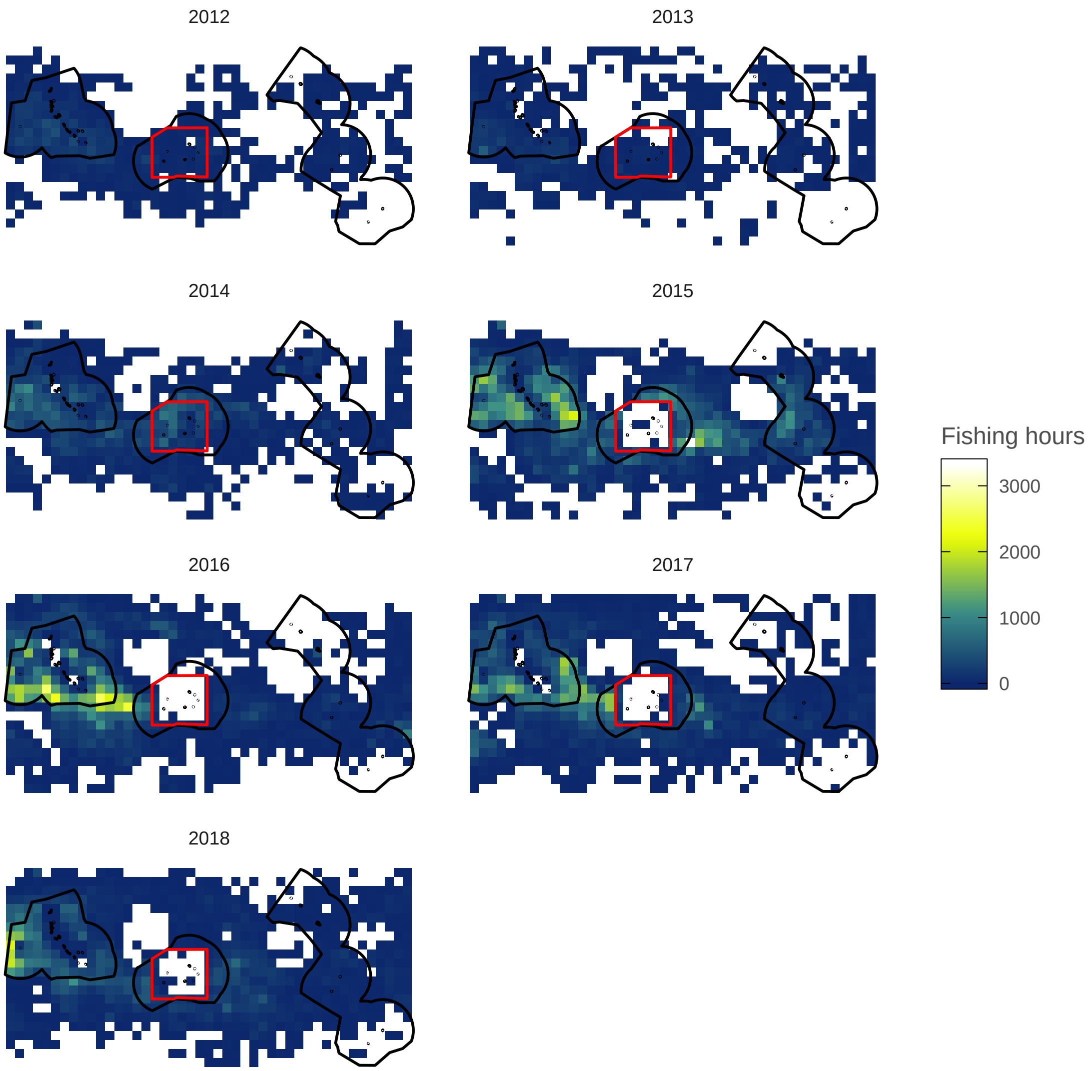

Figure S7: Annual fishing effort (hours) on a 1-degree grid around PIPA (red polygon) and Kiribati (black polygons). There is no clear evidence of a "fishing the line" effect, with the greatest effort applied on the Gilbert islands (Kiribati) after 2015.

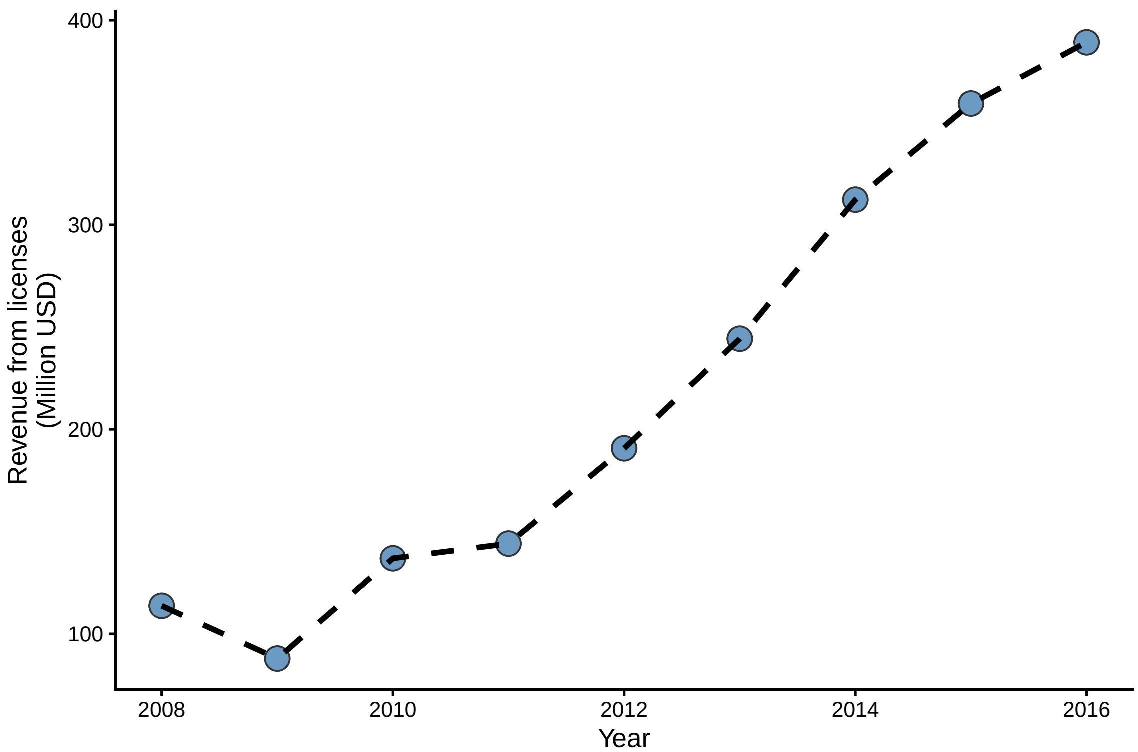

Figure S8: Total revenues for all PNA countries combined.

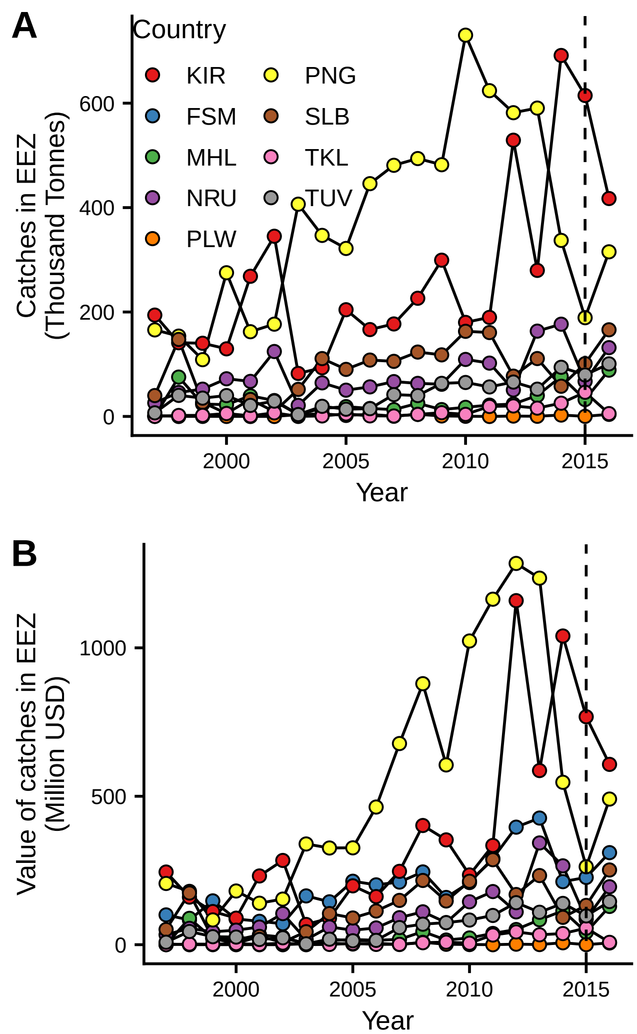

Figure S9: Financial indicators for PNA countries. A) Total annual purse seine catch by EEZ and, B) Total annual value of purse seine catch by EEZ. Vertical dashed line in both plots denotes implementation of PIPA.

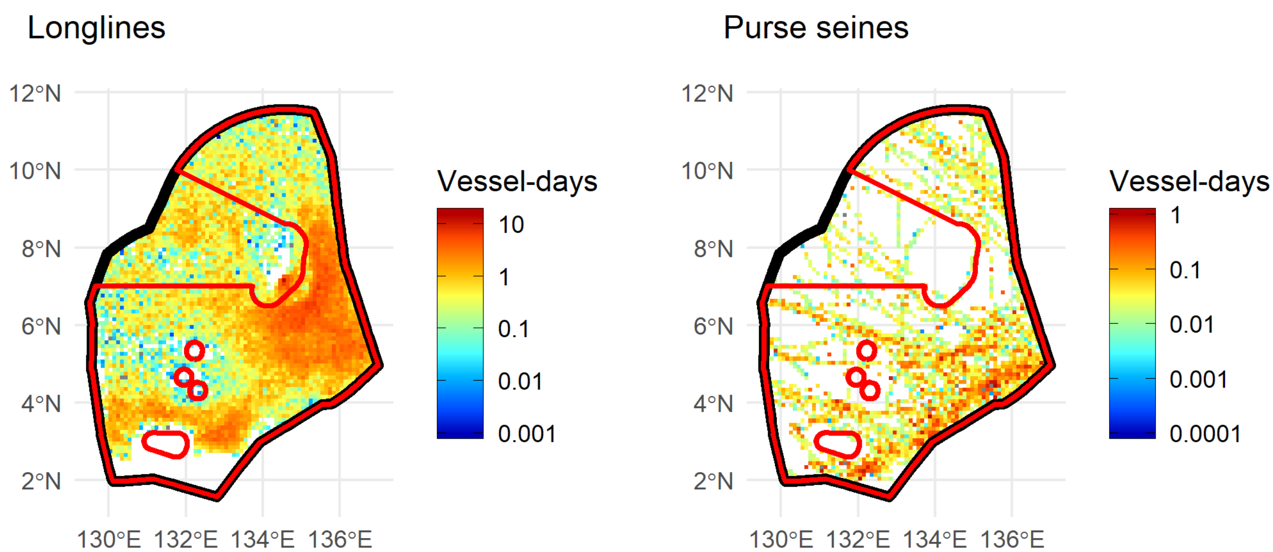

Figure S10: Longline and purse seine fishing effort in Palau during 2018 at a 0.5 degree resolution. The red polygon shows the proposed Palau National Marine Sanctuary, containing 56% and 91% of longline and purse seine fishing effort, respectively. Note that the colorbars are presented in log_{10} transformed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

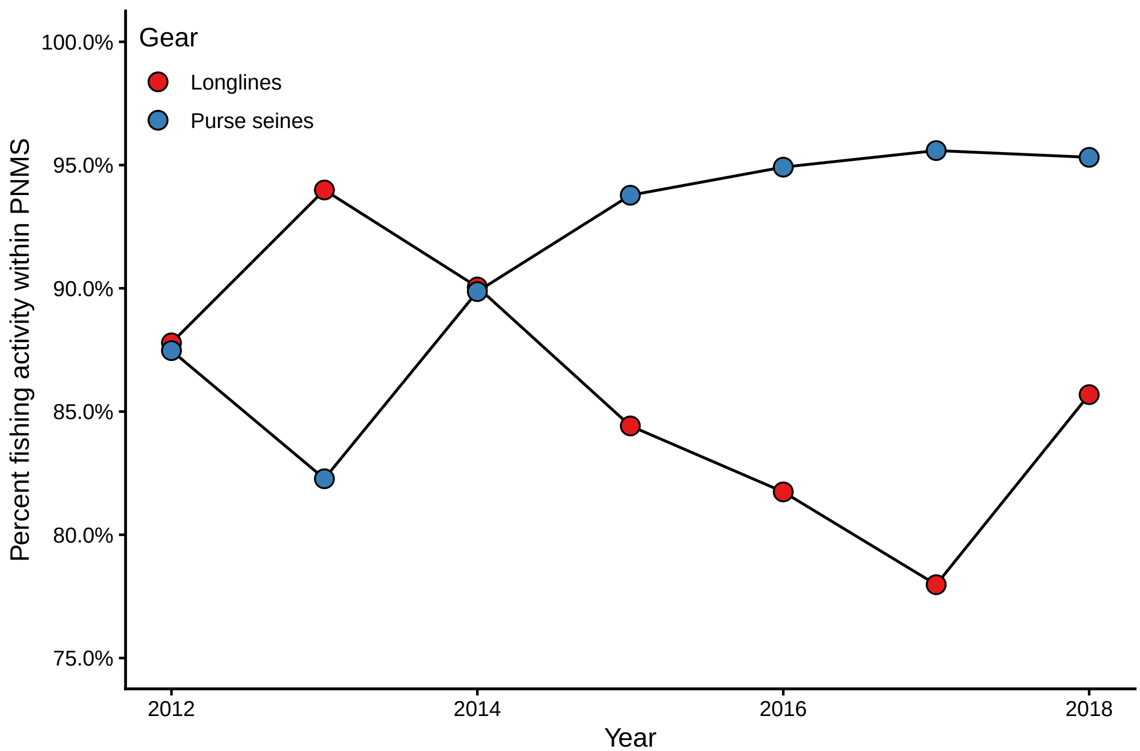

Figure S11: Time series of the annual proportion of longline and purse seine effort within the proposed PNMS boundaries.

References

[1] Costello, C., Ovando, D., Clavelle, T., Strauss, C. K., Hilborn, R., Melnychuk, M. C., Branch, T. A., Gaines, S. D., Szuwalski, C. S., Cabral, R. B., Rader, D. N., and Leland, A. *Proceedings of the National Academy of Sciences of the United States of America* **113**(18), 5125–5129 may (2016).