Supplementary Materials for: "Environmental Market Design for Large-Scale Marine Conservation"

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1 Supplementary Methods

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.

Supplementary Table 1: 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

1.2 Balance on observables

We observe six characteristics for every vessel: flag, crew size, engine power, vessel length, tonnage capacity, and fishing hours within PNA waters in 2014. Figure 5 shows the distribution of the numeric variables for each group of vessels. Table 2 presents the mean and standard deviation of each observable, and table 3 shows the composition of each group by flag. On average, displaced vessels have smaller crew sizes, more engine power, are larger than non-displaced vessels, and fished more in PNA waters during 2014. The largest relative difference is in terms of gross tonnage.

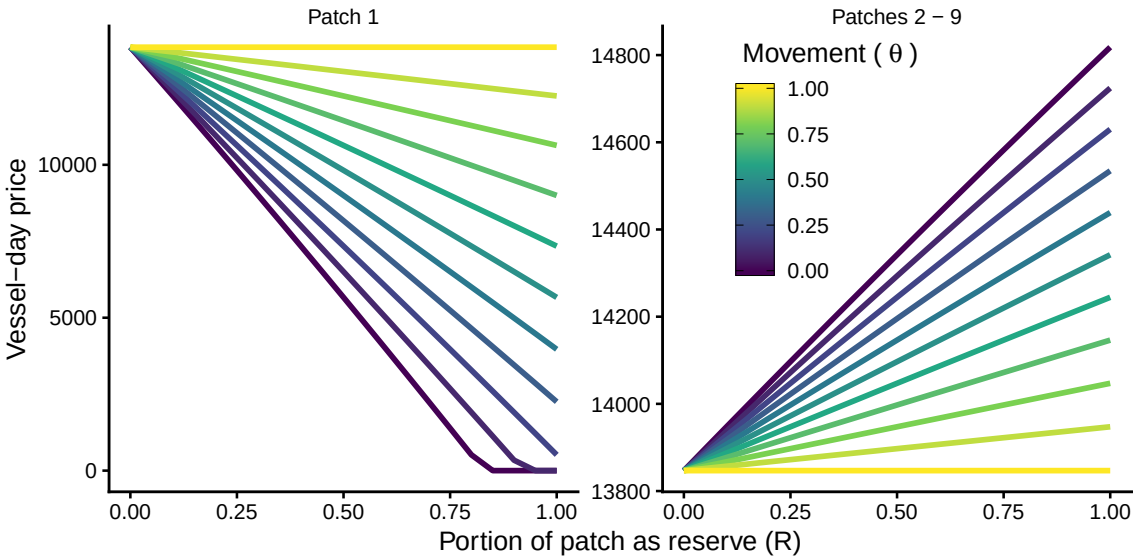
Supplementary Table 2: Mean values on observable characteristics by vessel for displaced (n = 64), and non-displaced vessels (n = 254). Numbers in parentheses indicate standard deviation. The last column contains the difference in means (t-scores), with asterisks indicating significant differences as 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) ***
PNA fishing in 2014 (hours)	667.57 (489.24)	529.33 (380.11)	-138.24 (-1.89) *
Tonnage (GT)	1718.14 (653.38)	1383.41 (533.56)	-334.73 (-3.79) ***

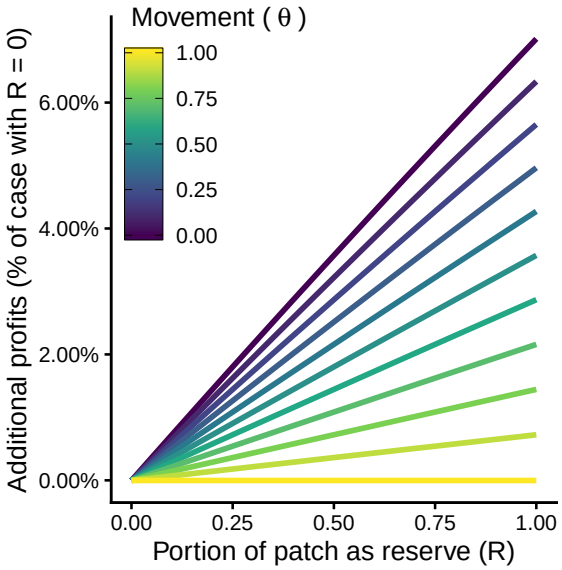
Supplementary Table 3: Proportion of vessel flags by group. Note that we do not observe the flag for two vessels (0.78%) in the non-displaced group.

Flag	Non-displaced	Displaced
CHN	10.24	0.00
ECU	1.57	4.69
ESP	0.39	4.69
FSM	8.27	3.12
GTM	0.39	1.56
JPN	16.93	0.00
KIR	2.76	12.50
KOR	3.54	45.31
MEX	1.18	0.00
MHL	3.54	1.56
NIC	0.39	0.00
NRU	0.39	0.00
NZL	1.18	3.12
PAN	0.79	0.00
PHL	7.87	1.56
PNG	11.42	1.56
SLB	1.57	0.00
SLV	0.79	0.00
TWN	11.81	3.12
USA	12.20	17.19
VUT	1.97	0.00
Not reported	0.79	0.00
Total	100.00	100.00

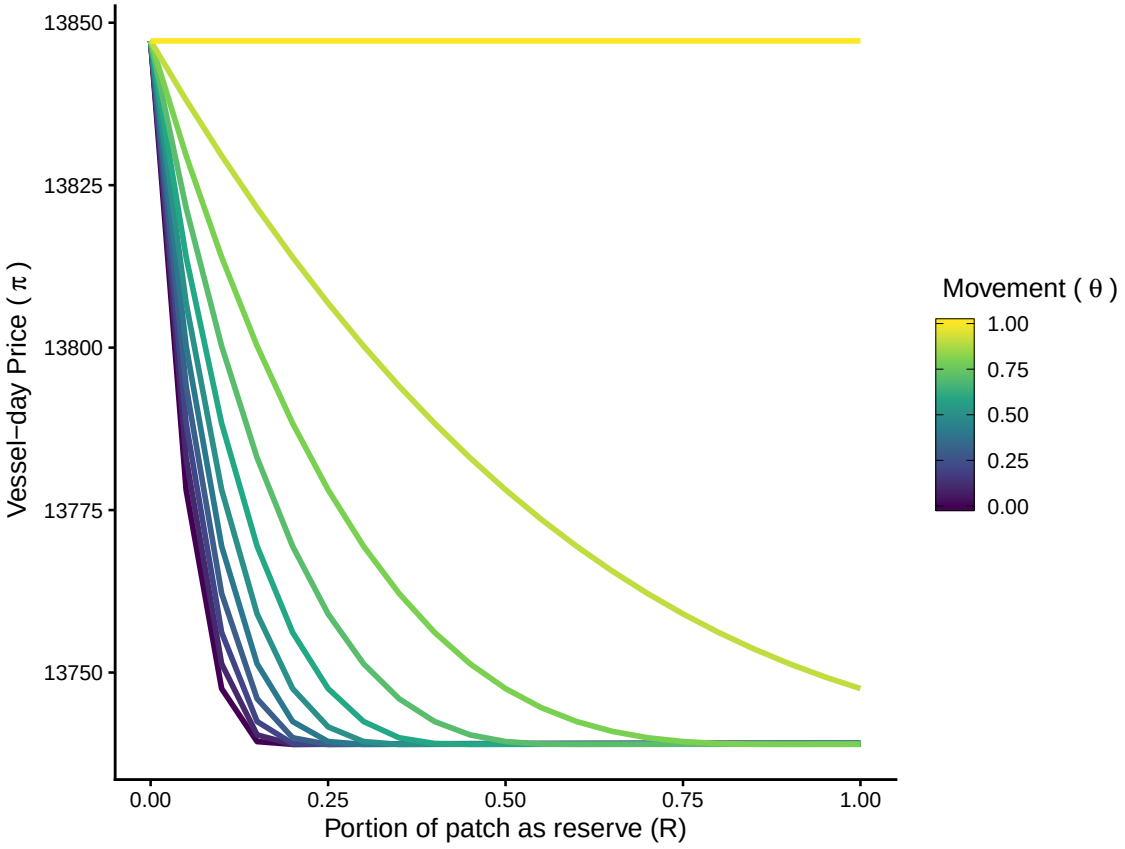
2 Supplementary figures



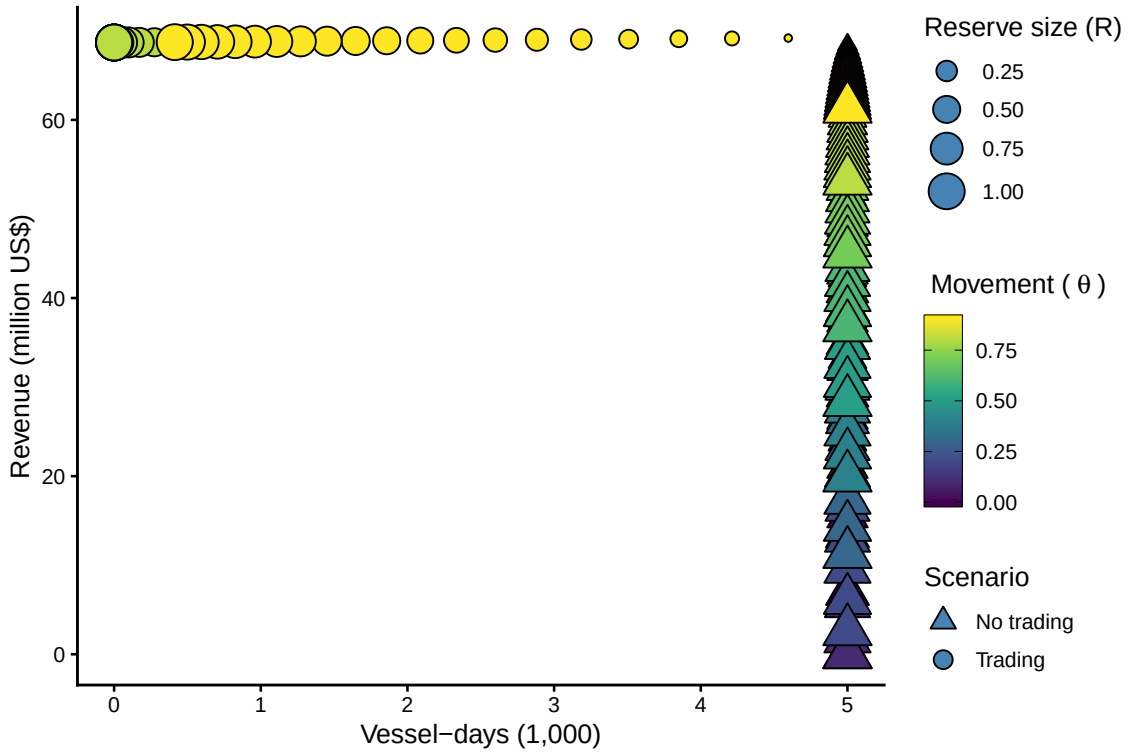
Supplementary Figure 1: Vessel-day prices with conservation and no trading. Vessel-day prices (vertical axis) are shown for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ) for the country with spatial closure and other countries (left - right, respectively) when there is no trading.



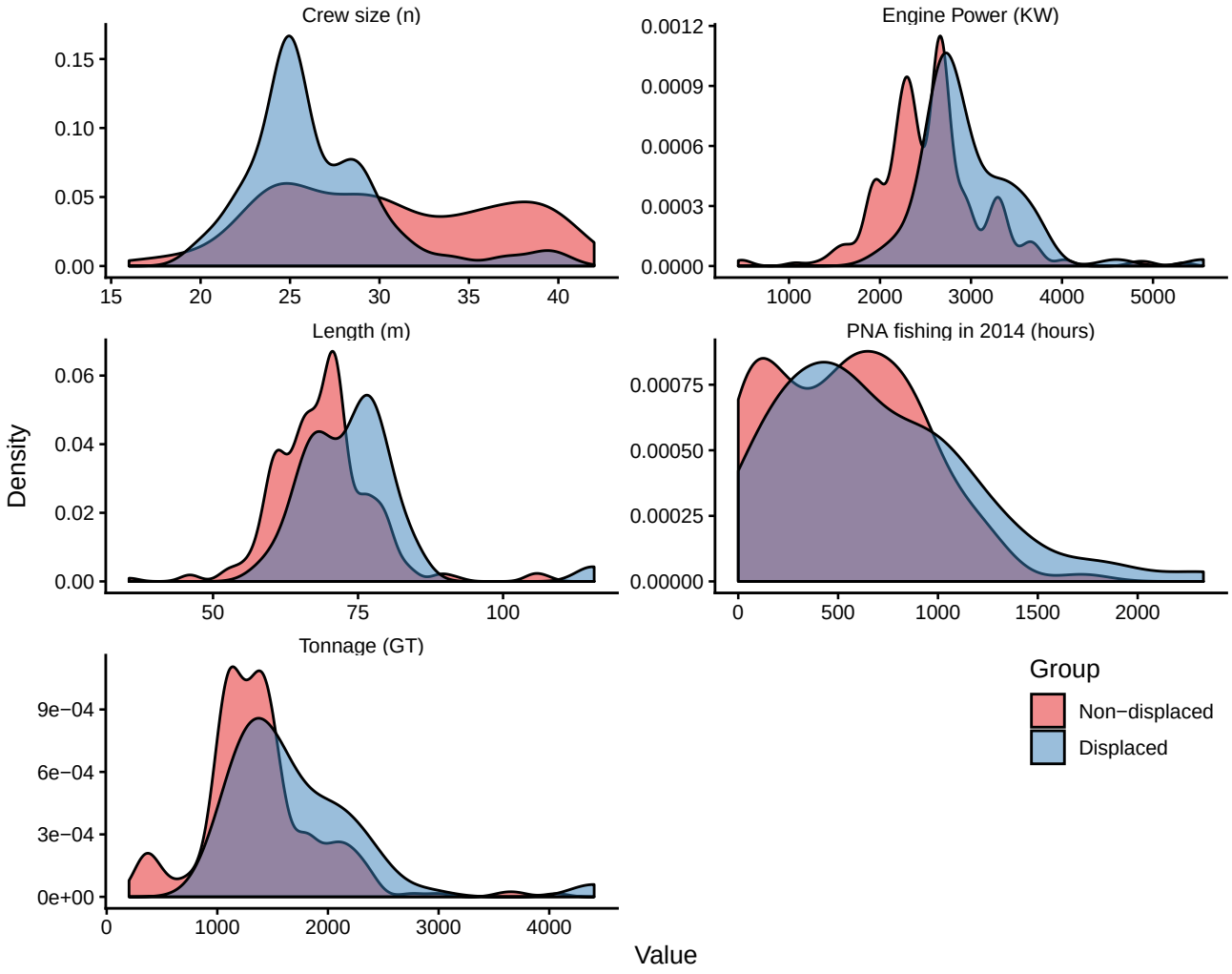
Supplementary Figure 2: Change in revenues to non-conserving countries. Relative change in revenue for countries 2 - 9 (vertical axis) for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ) when there is no trading.



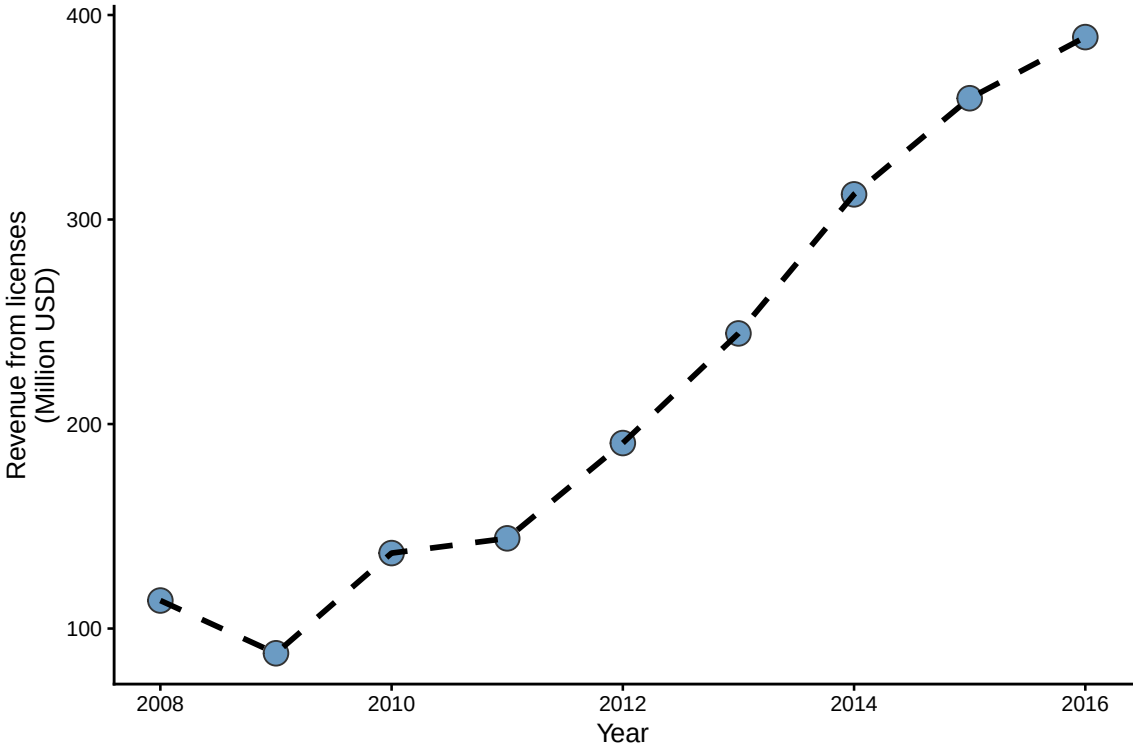
Supplementary Figure 3: Vessel-day prices with conservation and trading. PNA-wide vessel-day prices (vertical axis) with trading, for a combination of reserve sizes (R in the horizontal-axis) and different within-country movement (θ).



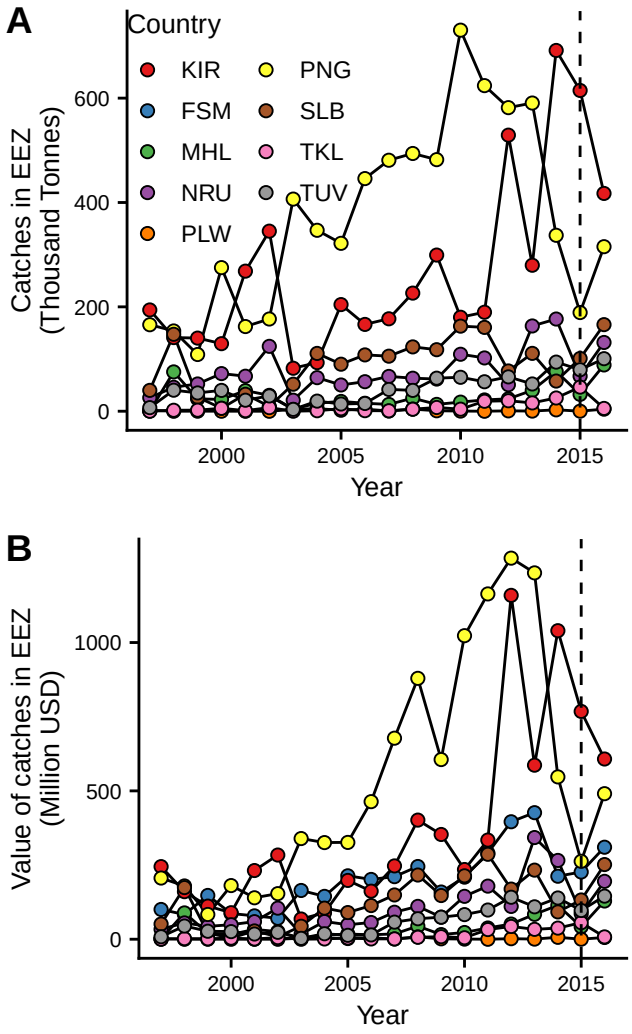
Supplementary Figure 4: Effort and revenues to the conserving country with and without trading. Effort and revenue in Country 1 are shown for a combination of reserve sizes (R), different within-country movement (θ), and with and without trading. With trading, the relative drop in effort is always larger 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.



Supplementary Figure 5: Vessel characteristics for 318 tuna purse seiners. Distribution of observable characteristics by vessel for displaced (n = 64), non-displaced vessels (n = 254).



Supplementary Figure 6: Total revenues for all PNA countries combined.



Supplementary Figure 7: 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.

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).