El Niño drives foreign fishing

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Warming oceans are causing marine taxa to redistribute poleward and to deeper waters [Pinsky et al., 2013]. As species shift poleward, stocks are expected to move out of, into, and across Exclusive Economic Zones [Poloczanska et al., 2013], having major implications for fisheries management and livelihoods of these countries. This redistribution can also be caused by processes acting at a shorter timescale, like El Niño Southern Oscillation (ENSO). For example, Pacific Island Nations that are Parties to the Nauru Agreement (PNA) manage tuna stocks within their EEZs under a vessel-day scheme similar to a cap-and-trade regulation. La Niña and El Niño phases are associated with greater catches in the western and eastern boundaries of the PNA regions, respectively. As productivity shifts longitudinally, fishing permits and therefore allocation of fishing effort follow [Aqorau et al., 2018].

This problem has led to calls from the scientific community to generate institutions that can provide resilience to climate variation and prepare ocean governance for "species on the move" [Pinsky et al., 2018]. However, the extent to which these short- and long-term shifts result in behavioral changes from resource users has not been explored or empirically estimated. In this paper we combine vessel-detection technology and empirical identification strategies to quantify the effect of climate variability (*i.e.* ENSO) on foreign fishing behavior.

We use data from Global Fishing Watch (GFW; globalfishingwatch.org) to quantify the effect that ENSO has on foreign fishing. The vessel-detection database is a panel of fishing vessels for which we observe flag, gear, position (*i.e.* latitude, longitude) and duration of fishing events (hours) from 2012 to present [Kroodsma et al., 2018]. Our dataset contains information for a total of 26000 vessels from 13 countries (Fig 1). We define foreign fishing as any fishing event in which a vessel's reported flag does not match the jurisdiction of the Exclusive Economic Zone in which fishing takes place, and restrict our analyses to two main fishing gears: longliners and purse seiners. Longliners use a mother line with hundreds to thousands of baited hooks every few meters. Purse seiners use nets to enclose large schools of fish. Both methods are largely used for commercially important species, like Tuna and Swordfish.

Temperature is one of the main environmental variables that drives species redistribution [Pinsky et al., 2013]. However, climate indices can be useful summaries of systemic, environmental variation [Meng et al., 2016]. We use a time series of ENSO anomalies (NINO3; Fig 2) and combine it with a spatially-explicit time series of global Sea Surface Temperature (SST) to identify regions where changes in NINO3 correspond to changes in SST. This approach has been previously used to identify "ENSO-teleconnected regions" [Hsiang et al., 2011]. This allows us to identify regions where fishing effort is likely to be affected by changes between negative and positive ENSO phases (Fig. 3).

Our empirical strategy uses a difference-in-differences approach. We estimate the effects of ENSO on Foreign Fishing by comparing the effects between regions impacted by ENSO and regions not impacted by ENSO:

$$log(FF_{rgct}) = \beta ENSO_t \times \mathbb{I}_{Lat,Lon\epsilon r} + \gamma ENSO_t + \xi \mathbb{I}_{Lat,Lon\epsilon r} + \theta_g + \phi_t + \lambda_c + \epsilon_{rgct}$$

FF_{gct} represents the foreign fishing variable of interest by gear, country and year. In the main specification, we use an inverse hyperbolic sine of foreign fishing, which approximates a log transform of FF[1], to transform zeroes in our data Burbidge et al. [1988], Card and DellaVigna [2017]. α is a constant and β captures the linear effect of ENSO on affected regions compared to regions unaffected by ENSO. The treatment is ENSO and it is interacted with a dummy, $\mathbb{I}_{Lat,Lon \epsilon r}$, that equals 1 for regions in the ENSO-affected region and 0 for counties in unaffected-ENSO regions. γ is the average effect of ENSO over both the treated and untreated regions and ξ is the average effect of being in the treatment region vs. not being in the treatment region. θ_g are gear fixed effects, ϕ_t are monthly fixed effects and λ_c are country (flag) fixed effects.

Our results suggest that positive ENSO phases lead to an increase in foreign fishing hours. The result is robust across a set of specifications and to both measures of foreign fishing (*i.e.* hours and their hyperbolic transformation; Table 1). The base model shows that, on average, a one-unit increase in the NINO3 index leads to a 2% increase in foreign fishing hours per month for all vessels (*i.e.* vessels in treated and untreated regions). At the same time, we find a positive interaction effect of 4% additional foreign fishing hours per unit increase in NINO3 index for vessels in ENSO-affected regions. The NINO3 index can often vary by more than two-and-a-half units on either direction (see Fig. 2), which would translate as a 10% increase in foreign fishing. We also run this on a subsample of boats that fish in both the treated and untreated region.

Our results also suggest that the change in foreign fishing hours is greater for longliners than for purse seiners. This may be related to how adaptive these gears are, or to the restriction that a variable climate induces on each gear. For example, positive ENSO phases are known to increase thermocline depth causing species such as tuna to swim deeper in search of cooler temperatures. This facilitates escapement of tuna in shallow purse seine nets and increases the proportion of null sets[2] in Mexican tuna purse seiners [Dreyfus-Leon, 2015]. This may also be due to the fact that longliners are harder to regulate since they are the most abundant vessels and are highly mobile [Sala et al., 2018, Ortuño-Crespo et al., 2018].

Our results suggest that positive ENSO phases lead to an increase in foreign fishing hours. This quantitative evidence linking climate and fishing behavior has important implications for fisheries management, economics of climate projections and adaptation of this sector.

[1] $ln(FF + \sqrt{1 + FF^2}) \rightarrow ln(2L)$

[2] Null sets are described as events where purse seiners cast their nets around tuna, but these manage to escape under the net before the set is completed.

Figures and tables

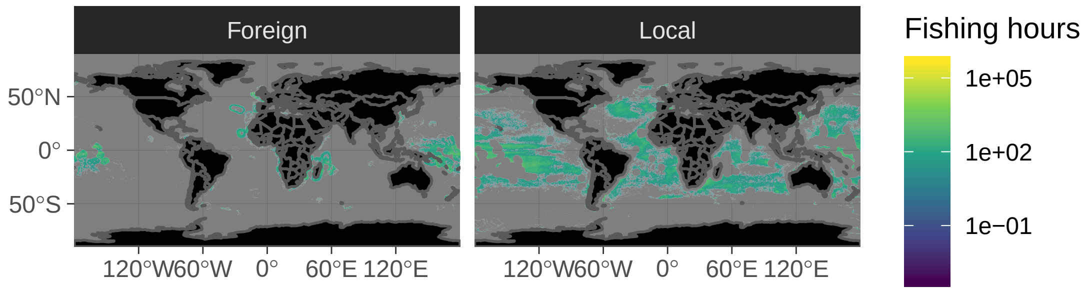

Figure 1: Local and foreign fishing effort from 2012 - 2017 (hours).

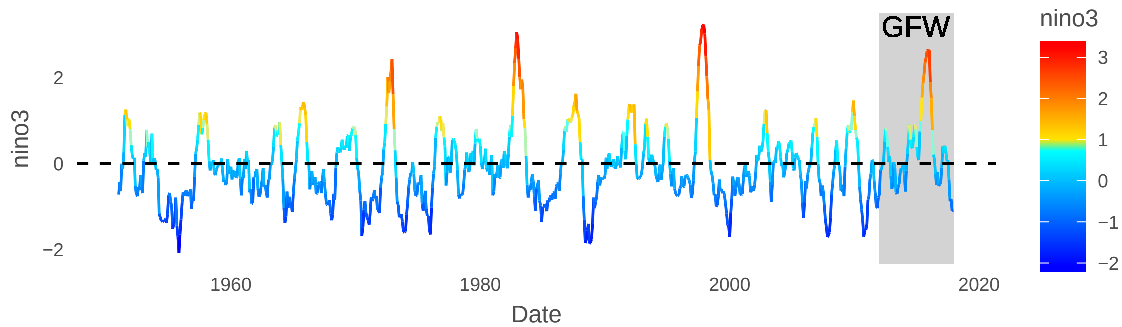

Figure 2: Timeseries of NINO3 index (detrended). The gray shaded area higlights the period with vessel data coverage

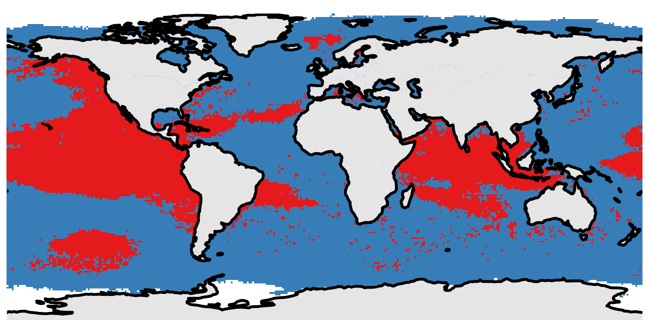

Figure 3: ENSO-Teleconnected marine regions. Red and blue indicate the when where SST showed a positive (r > 0) and significant (p < 0.1) correlation with NINO3 index for at least 3 months. White areas represent areas where SST data is no available.

Table 1: Foreign fishing hours and NINO3. Columns 1 - 4 represent the log-transformed hours. Columns 5 - 8 represent the hyperbolic sine transformed fishing hours.

	Dependent variable:							
	log_hours				hyperbolic sine transformed			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NINO3	0.037^{***}	0.042^{***}	0.032^{***}	0.022^{***}	0.037^{***}	0.037^{***}	0.031^{***}	0.021^{***}
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Treated	-0.030^{***}	0.083^{***}	0.093^{***}	0.013^{***}	-0.021^{***}	-0.021^{***}	0.098^{***}	0.017^{***}
	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)
$NINO3 \times Treated$	0.024^{***}	0.021^{***}	0.021^{***}	0.041^{***}	0.025^{***}	0.025^{***}	0.022^{***}	0.042^{***}
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	2.877^{***}	2.763^{***}	2.882^{***}	2.681^{***}	3.567^{***}	3.567^{***}	3.574^{***}	3.381^{***}
	(0.003)	(0.003)	(0.007)	(0.033)	(0.003)	(0.003)	(0.007)	(0.032)
Gear FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No	Yes	Yes
Country FE	No	No	No	Yes	No	No	No	Yes
Observations	447,938	447,938	447,938	447,938	449,316	449,316	449,316	449,316
R^2	0.002	0.046	0.051	0.069	0.002	0.002	0.050	0.068
Note:	*p<0.1; **p<0.05; ***p<0.01; Numbers in parentheses are heteroskedastic-robust standard errors.							

References

Transform Aqorau, Johann Bell, and John N. Kittinger. Good governance for migratory species. *Science*, 361 (6408):1208.2–1209, sep 2018. ISSN 0036-8075. doi: 10.1126/science.aav2051.

John B Burbidge, Lonnie Magee, and A Leslie Robb. Alternative transformations to handle extreme values of the dependent variable. *J. Am. Stat. Assoc.*, 83(401):123–127, 1988.

David Card and Stefano DellaVigna. What do editors maximize? evidence from four leading economics journals. Working Paper 23282, National Bureau of Economic Research, March 2017.

Michel J Dreyfus-Leon. Analysis of null sets (zero catch) made by the mexican tuna purse seine fleet (2000–2013). *Cienc Mar*, 41(2):85–92, jun 2015. ISSN 01853880. doi: 10.7773/cm.v41i2.2471.

Solomon M Hsiang, Kyle C Meng, and Mark A Cane. Civil conflicts are associated with the global climate. *Nature*, 476(7361):438–441, aug 2011. ISSN 1476-4687. doi: 10.1038/nature10311.

David A Kroodsma, Juan Mayorga, Timothy Hochberg, Nathan A Miller, Kristina Boerder, Francesco Ferretti, Alex Wilson, Bjorn Bergman, Timothy D White, Barbara A Block, Paul Woods, Brian Sullivan, Christopher Costello, and Boris Worm. Tracking the global footprint of fisheries. *Science*, 359(6378): 904–908, feb 2018. ISSN 0036-8075. doi: 10.1126/science.aao5646.

Kyle C Meng, Kimberly L Oremus, and Steven D Gaines. New england cod collapse and the climate. *PLoS ONE*, 11(7):e0158487, jul 2016. doi: 10.1371/journal.pone.0158487.

Guillermo Ortuño-Crespo, Daniel C. Dunn, Gabriel Reygondeau, Kristina Boerder, Boris Worm, William Cheung, Derek P. Tittensor, and Patrick N. Halpin. The environmental niche of the global high seas pelagic longline fleet. *Sci. Adv.*, 4(8):eaat3681, aug 2018. ISSN 2375-2548. doi: 10.1126/sciadv.aat3681.

Malin L Pinsky, Boris Worm, Michael J Fogarty, Jorge L Sarmiento, and Simon A Levin. Marine taxa track local climate velocities. *Science*, 341(6151):1239–1242, sep 2013. ISSN 0036-8075. doi: 10.1126/science.1239352.

Malin L Pinsky, Gabriel Reygondeau, Richard Caddell, Juliano Palacios-Abrantes, Jessica Spijkers, and William W L Cheung. Preparing ocean governance for species on the move. *Science*, 360(6394):1189–1191, jun 2018. ISSN 0036-8075. doi: 10.1126/science.aat2360.

Elvira S. Poloczanska, Christopher J. Brown, William J. Sydeman, Wolfgang Kiessling, David S. Schoeman, Pippa J. Moore, Keith Brander, John F. Bruno, Lauren B. Buckley, Michael T. Burrows, Carlos M. Duarte, Benjamin S. Halpern, Johnna Holding, Carrie V. Kappel, Mary I. O'Connor, John M. Pandolfi, Camille Parmesan, Franklin Schwing, Sarah Ann Thompson, and Anthony J. Richardson. Global imprint of climate change on marine life. *Nat Clim Chang*, 3(10):919–925, oct 2013. ISSN 1758-678X. doi: 10.1038/nclimate1958.

Enric Sala, Juan Mayorga, Christopher Costello, David Kroodsma, Maria L. D. Palomares, Daniel Pauly, U. Rashid Sumaila, and Dirk Zeller. The economics of fishing the high seas. *Sci. Adv.*, 4(6):eaat2504, jun 2018. ISSN 2375-2548. doi: 10.1126/sciadv.aat2504.