

From Sea to Shore: The Impact of Ocean Acidification on Child Health

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Teaching material

The pH of the ocean is decreasing

- ① Ocean water acidity has increased **26%** (Doney et al. 2020)
- ② Increased acidity affects marine life (IPCC 2022)

What is the impact of **ocean acidification** on child health in L&MICs?

How is ocean acidity affecting marine life?

- ① **Directly** affects the physiology of marine species (Gattuso and Hansson 2011)
- ② **Degrades** key marine habitats such as coral reefs and macroalgal forests
- ③ Evidence suggests that **commonly-consumed** species are **more vulnerable** to these effects (Maire et al. 2021)
- ④ Any change in species occurrence could potentially impact **income**, **health**, and **nutrition**

We focus on L&MICs

- ① In coastal regions, seafood is a **significant part** of their diet (FAO 2022)
- ② L&MICs host **97%** of all marine capture workers, most of whom support local consumption through small-scale fisheries (Simmanee et al. 2022)
- ③ The ability to balance changes in local supply with imports is **limited** (McCauley et al. 2018)
- ④ **36** L&MICs in Africa, Asia and Latin America from **1972–2018**
- ⑤ **41%** of the world's coastal population

A preview of our findings

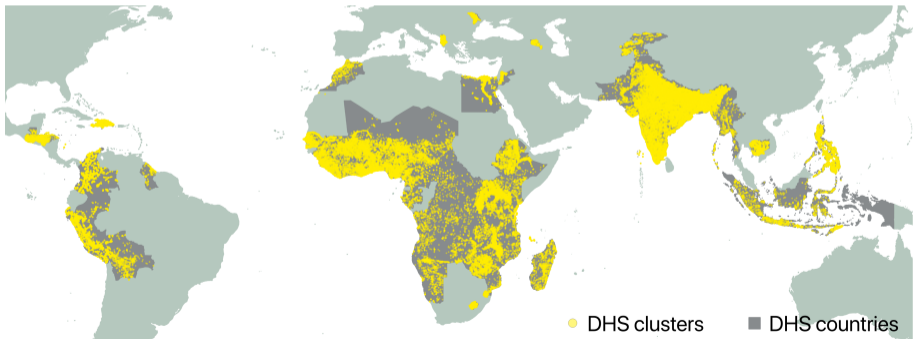
- ① Higher acidity **reduces** the quantity and value of seafood caught by small-scale fisheries
- ② These negative shocks **raise** local seafood prices, reducing the likelihood of consumption and increasing **malnutrition** during pregnancy
- ③ A **1%** increase in acidity raises **NMR** by 1.5 deaths per 1,000 live births in coastal communities
- ④ **No changes** in maternal and child health investments
- ⑤ Conditional on survival, **boys** exhibit better health, while **girls** face higher rates of stunting.

How does this paper fit within the existing literature?

- ① **Effects of climate change:** Focus on the **ocean**
- ② **Early stages of children's development:** We study a **unique** shock
- ③ **Role of wildlife in human and economic development:** New evidence on the importance of **marine** wildlife for human and economic development

Sample: Coastal areas of L&MICs

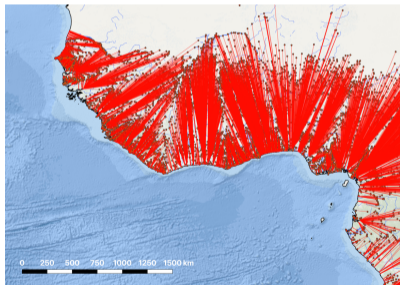
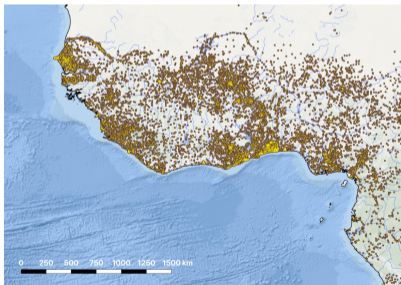
Demographic and Health Surveys: 95 geocoded surveys from 1990 to 2018 covering 36 countries [Surveys](#)



Sample: Coastal areas of L&MICs

Demographic and Health Surveys: 95 geocoded surveys from 1990 to 2018 covering 36 countries Surveys

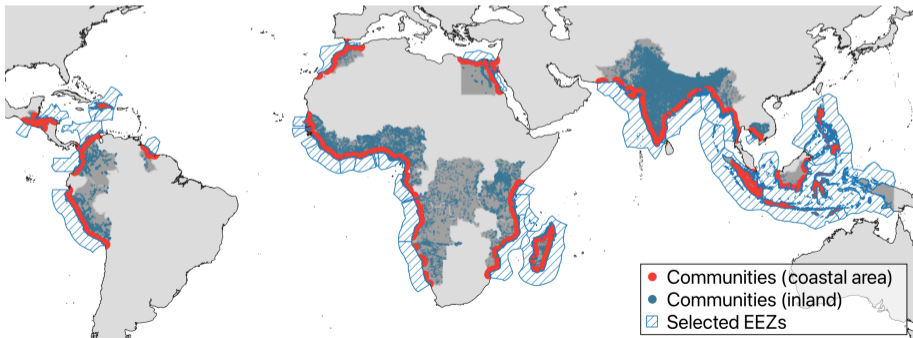
- **Coastal area** (United Nations 2003): 100km from the coast Coastal vs Inland



Sample: Coastal areas of L&MICs

Demographic and Health Surveys: 95 geocoded surveys from 1990 to 2018 covering 36 countries Surveys

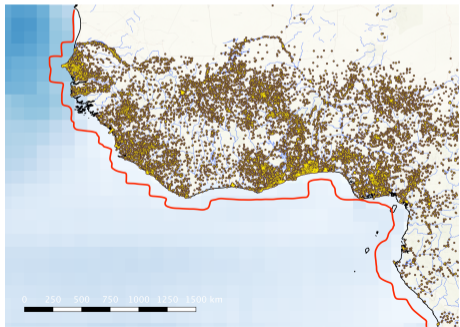
- **Coastal area** (United Nations 2003): 100km from the coast Coastal vs Inland
- **1.5 million live births** from 1972–2018 and **0.5 million adult women**



Exposure to ocean acidity

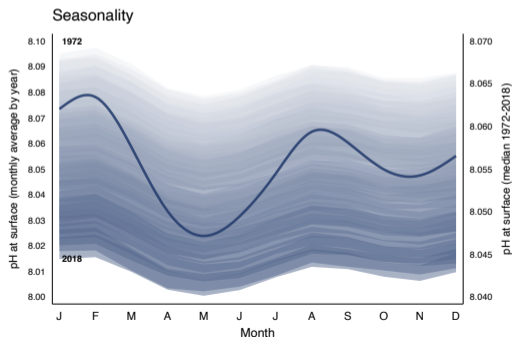
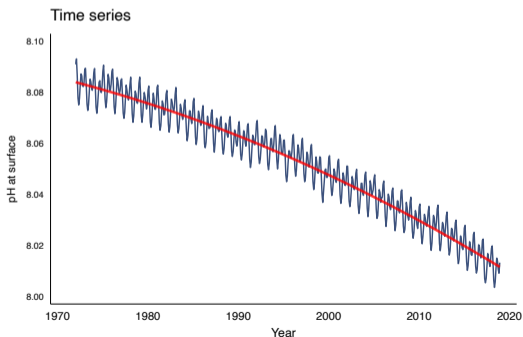
HadGEM2-ES: pH at surface in open waters at monthly and $1^\circ \times 1^\circ$ resolution

- Match each date of birth or interview with ocean acidity in the closest point from their location
- Exposure is the average pH in corresponding period – main focus *in-utero*



Features of ocean acidity

- ① **Natural cycle similar to weather:** given spatial area, short-run variation as random draws from long-run distribution
- ② **Ocean acidification:** climate-change-induced exogenous and spatially-heterogeneous increases in water acidity



Ocean exploitation – SeaAroundUs

- ① Quantity, price, and landed value of catches are categorized by seafood groups within exclusive economic zones (EEZs)
- ② Quantities are reported in kilotons, and landed values are calculated using nominal ex-vessel prices in local currency, converted to 2010 US dollars
- ③ We only include catches used for **direct human consumption** and distinguish between industrial and small-scale sectors

Ocean exploitation – Extractive vs. night-time fishing

- ① **Global Fishing Watch:** Hours industrial fishing vessels spent at specific coordinates
- ② **Automatic Boat Identification System:** Time and coordinates of boats using nightlight as measured from satellite imaging

Empirical strategy

Exposure to pH as short-run deviations in acidity levels from the spatially-specific long-run trend

Multi-way FE model: few identifying assumptions (Dell2014)

$$y_{ic,mt} = \beta \text{pH}_{c,mt} + \mathbf{X}_{ic,mt}\gamma + [\text{FEs}] + \epsilon_{ic,mt}$$

- **Benchmark:** FEs include community, time, local trend and seasonality
- **Within-sibling:** benchmark + mother FE

Empirical strategy

When analyzing data about seafood catch, the unit of analysis is at the seafood-group-country-year level:

$$y_{ic,t} = \beta p H_{c,t} + \mathbf{X}_{c,t} \gamma + [\text{FEs}] + \epsilon_{ic,t}$$

- **Location:** Seafood group by country FEs
- **Time effects:** Fishing area by year FEs

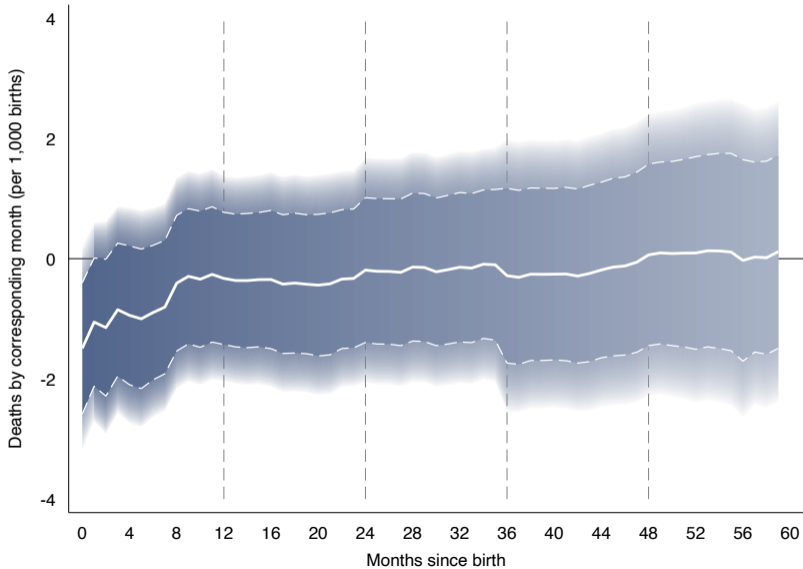
Small-scale fisheries perform worse

Dependent variables:	Marine catch for human consumption				Economic activity	
	Small-scale fishing Quantity (1)	Value (2)	Industrial fishing Quantity (3)	Value (4)	Median price (5)	Night-time luminosity (6)
pH in proximity to the coast	0.132	0.199	0.019	0.033	-0.091	0.006
	(0.068) [0.061]	(0.081) [0.019]	(0.088) [0.829]	(0.099) [0.742]	(0.045) [0.049]	(0.044) [0.896]
Mean (dep.var.)	1.50	1.51	1.00	1.00	1.00	2.26
Identifying observations	19,129	19,129	19,129	19,129	13,603	777
Singleton observations	0	0	0	0	0	0
Countries	36	36	36	36	36	36
Year range	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1992–2012

Ocean acidity affects women's nutrition

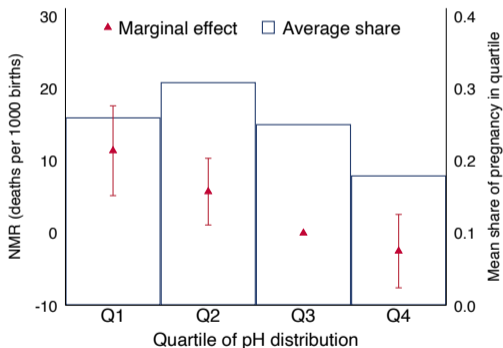
Dependent variable:	Nutrition		Prevalence of anemia	
	Consumed seafood (1)	Underweight (2)	Overall (3)	In pregnancy (4)
pH in the nearest waters	0.025 (0.012) [0.029]	-0.004 (0.002) [0.073]	0.001 (0.005) [0.841]	-0.017 (0.007) [0.013]
Mean (dep.var.)	0.296	0.120	0.427	0.454
Identifying observations	49,045	407,699	272,688	14,672
Singleton observations	2	3	2	36
Communities	5,952	24,301	17,371	8,993
Countries	14	32	26	26
Interview year range	2005–2016	1992–2018	2000–2018	2000–2018

Ocean acidity increases neonatal mortality

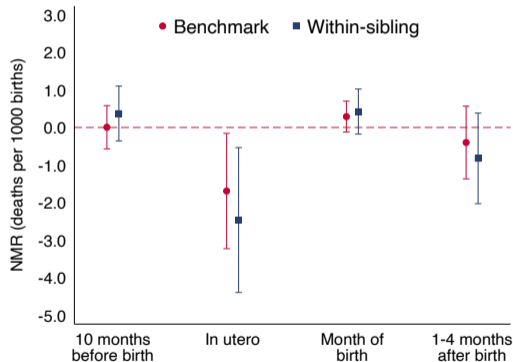


The effect is specific to lower pH and in-utero exposure

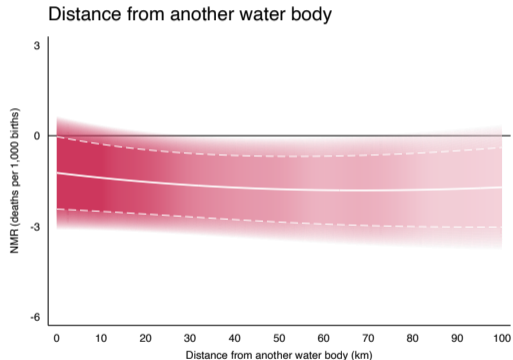
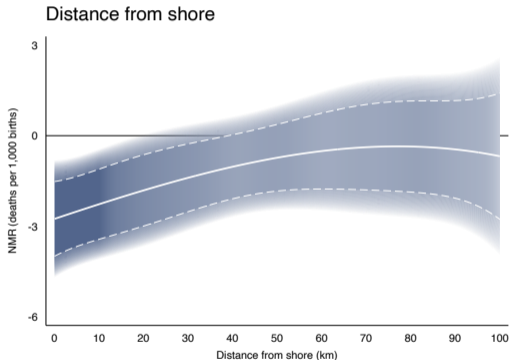
A. Positive vs negative deviations



B. Timing



And it fades as you move away from the coast



No changes in investments on maternal or child health

Dependent variables:	Antenatal	Delivery	Postnatal		
			Healthcare	Breastfed	Vaccinated
	(1)	(2)	(3)	(4)	(5)
pH in the nearest waters (<i>in utero</i>)	-0.002 (0.007) [0.820]	-0.002 (0.004) [0.727]	0.004 (0.009) [0.629]	0.001 (0.003) [0.699]	-0.002 (0.006) [0.804]
Mean (dep.var.)	1.808	1.359	0.441	0.972	0.435
Identifying observations	155,980	168,460	101,075	206,350	208,765
Singleton observations	217	481	3,078	2,336	2,269
Communities	14,669	18,481	18,445	28,029	27,887
Countries	29	29	34	36	36
Birth year range	1985–2018	1985–2018	2002–2018	1987–2018	1987–2018

Ocean acidity affects physical development

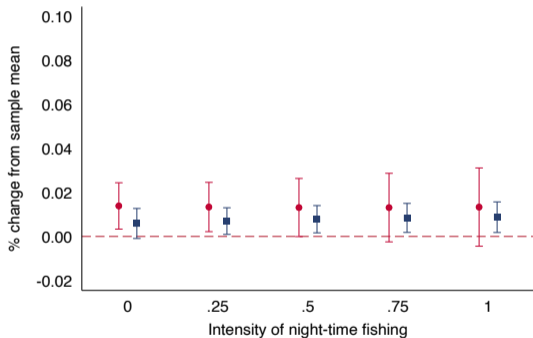
Dependent variables:	z-scores		Indicators	
	Weight-for-height (1)	Height-for-age (2)	Wasted (3)	Stunted (4)
pH in the nearest waters (<i>in utero</i>)	-0.021 (0.016) [0.196]	-0.012 (0.015) [0.405]	0.006 (0.003) [0.090]	0.004 (0.004) [0.279]
Mean (dep.var.)	-0.309	-0.984	0.080	0.234
Identifying observations	232,339	232,575	232,339	232,575
Singleton observations	1,106	1,124	1,106	1,124
Communities	24,824	25,110	24,824	25,110
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018

Ocean acidity affects physical development

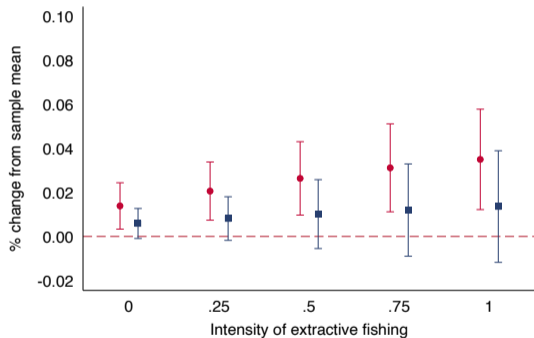
Dependent variables:	z-scores		Indicators	
	Weight-for-height (1)	Height-for-age (2)	Wasted (3)	Stunted (4)
pH in the nearest waters (<i>in utero</i>)	-0.001 (0.017) [0.969]	-0.033 (0.020) [0.100]	0.008 (0.006) [0.179]	0.011 (0.007) [0.147]
× female	-0.014 (0.020) [0.461]	0.057 (0.028) [0.047]	-0.011 (0.010) [0.303]	-0.023 (0.010) [0.022]
Mean (dep.var.)	-0.312	-0.993	0.080	0.236
Identifying observations	226,567	226,685	226,567	226,685
Singleton observations	6,878	7,014	6,878	7,014
Communities	23,979	24,248	23,979	24,248
Countries	33	33	33	33
Birth year range	1985–2018	1985–2018	1985–2018	1985–2018

Extractive fishing worsens the effect on NMR

A. Heterogeneity by night-time fishing

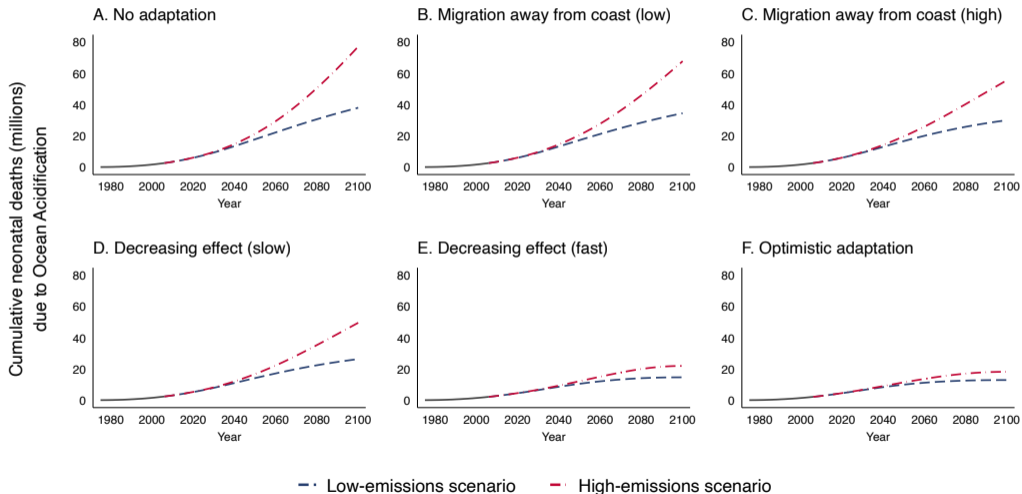


B. Heterogeneity by extractive fishing



• Neonatal mortality ■ Physical development


Projections on the effect of ocean acidification



Conclusion

- ① Ocean acidification harms local fishing and women's nutrition
- ② Exposure to worsening oceanic conditions raises NMR and drives mortality selection, with (potentially) long-term implications
- ③ Without adaptation, coastal communities face growing economic, nutritional, and health burdens

Robustness checks and additional results

- Aggregate shocks 
- Alternative coastal areas 
- Alternative specifications 
- Clustering 
- Fertility 
- Heterogeneity 
- Measurement error 
- Permutation-based inference 
- Selective migration 
- Long-run effects 

Coastal vs inland areas Data

	Coastal area		Inland area		Observations (5)
	Mean (1)	Std. dev. (2)	Mean (3)	Std. dev. (4)	
A. Children					
Child is alive	0.92	0.27	0.91	0.29	4555492
Child is female	0.48	0.50	0.48	0.50	4555492
Birth order	2.54	1.80	2.66	1.84	4555492
Birth order in a multiple birth	0.03	0.23	0.03	0.22	4555492
Years since birth	12.29	7.87	12.10	7.77	4555492
Mother's age at birth of child	24.43	5.76	24.16	5.54	4555492
pH in the nearest waters (<i>in utero</i>)	8.05	0.03	8.06	0.03	4555492

	Coastal area		Inland area		Observations (5)
	Mean (1)	Std. dev. (2)	Mean (3)	Std. dev. (4)	
B. Adult Women					
Age at first delivery	20.88	4.24	20.45	3.83	1385467
Current age	30.65	9.81	29.97	9.76	1951250
Years of schooling	7.51	4.89	6.22	5.12	1950621
pH in the nearest waters (<i>in utero</i>)	8.07	0.03	8.08	0.03	1474866
At least primary schooling	0.69	0.46	0.60	0.49	1951201
Married	0.67	0.47	0.70	0.46	1950104
Working	0.48	0.50	0.46	0.50	1355025
Household head is female	0.22	0.41	0.17	0.37	1951247
Household head's age	46.10	13.11	46.37	13.17	1949918
Household members	5.62	3.03	6.05	3.11	1951250
Household wealth	3.40	1.34	2.94	1.41	1755397
Living in urban area	0.53	0.50	0.34	0.47	1951250
Distance from shore	31.26	30.21	462.18	289.55	1951250
Distance from another water body	47.26	101.98	24.87	23.99	1951250
Altitude	189.80	408.19	489.32	612.81	1951250
Temperature (° C)	26.31	3.29	25.25	3.77	1951250
Precipitations (mm)	1560.29	674.43	1303.71	671.73	1951250
Intensity of extractive fishing	0.12	0.38	0.01	0.14	1951250
Intensity of night-time fishing	0.13	0.32	0.03	0.14	1951250

	Coastal area		Inland area		Observations (5)
	Mean (1)	Std. dev. (2)	Mean (3)	Std. dev. (4)	
C. Mortality rates					
Neonatal	27.39	163.22	37.17	189.18	4545390
Postneonatal	23.51	151.51	24.18	153.62	4200570
Child	21.50	145.04	27.55	163.68	3265547
Infant	50.39	218.74	60.63	238.65	4355601
Under-five	73.76	261.38	89.29	285.16	3504461

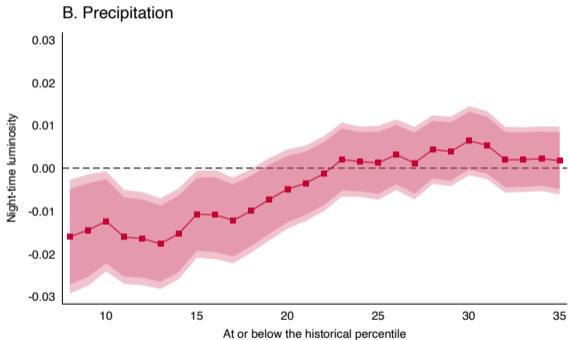
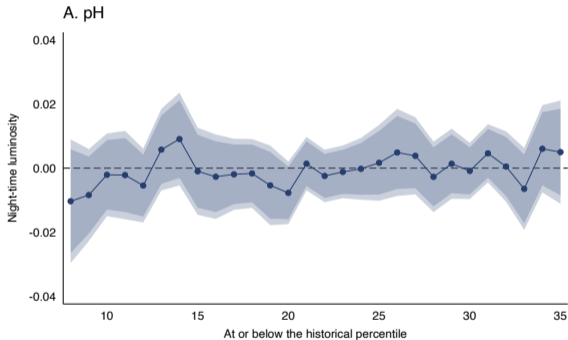
List of surveys [▶ Data](#)

Country	DHS surveys available	Birth years matched
Angola	2015	1980-2016
Bangladesh	2000, 2004, 2007, 2011, 2014	1972-2014
Benin	1996, 2001, 2012	1972-2012
Cambodia	2000, 2005, 2010, 2014	1972-2014
Cameroon	1991, 2004, 2011	1972-2011
Colombia	2010	1974-2010
Comoros	2012	1975-2012
DR Congo	2007, 2013	1974-2013
Côte d'Ivoire	1994, 1998, 2012	1972-2012
Dominican Republic	2007, 2013	1972-2013
Egypt	1992, 1995, 2000, 2005, 2008, 2014	1972-2014
Gabon	2012	1975-2012
Ghana	1993, 1998, 2003, 2008, 2014	1972-2014
Guatemala	2015	1978-2015
Guinea	1999, 2005, 2012, 2018	1972-2018
Guyana	2009	1974-2009
Haiti	2000, 2006, 2012, 2016	1972-2017
Honduras	2011	1975-2012
India	2015	1976-2016

List of surveys [▶ Data](#)

Country	DHS surveys available	Birth years matched
Indonesia	2003	1972-2003
Kenya	2003, 2008, 2014	1972-2014
Liberia	2007, 2013	1972-2013
Madagascar	1997, 2008	1972-2009
Morocco	2003	1972-2004
Mozambique	2011	1975-2011
Myanmar	2016	1980-2016
Namibia	2000, 2006, 2013	1972-2013
Nigeria	1990, 2003, 2008, 2013, 2018	1972-2018
Pakistan	2006	1973-2007
Peru	2000, 2004, 2009	1972-2009
Philippines	2003, 2008, 2017	1972-2017
Senegal	1993, 1997, 2005, 2010, 2012, 2014, 2015, 2016	1972-2016
Sierra Leone	2008, 2013	1973-2013
Tanzania	1999, 2010, 2015	1972-2016
Timor-Leste	2009, 2016	1974-2016
Togo	1998, 2013	1972-2014

Aggregate shocks

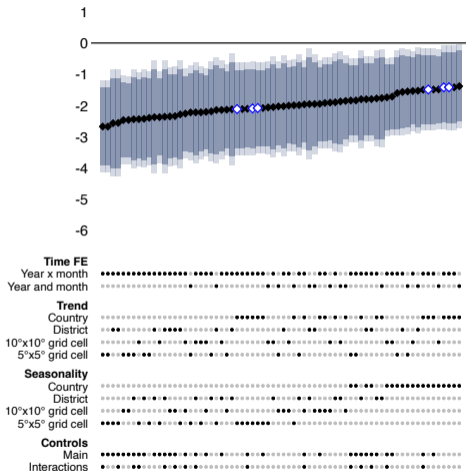


Alternative definitions of coastal areas

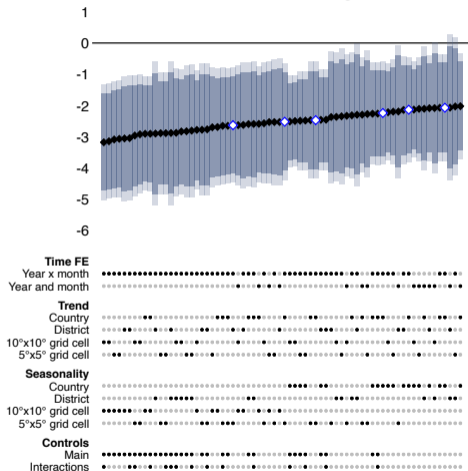
Dependent variable:	NMR (deaths per 1,000 births)					
	<i>Altitude criteria:</i> <i>Distance restriction:</i> <i>Exclusion of estuaries:</i>	$\leq 100m$	$\leq 100m$	- $\leq 40km$	- $\leq 40km$	$\leq 100m$ $\leq 40km$
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (<i>in utero</i>)	-1.632	-1.601	-2.929	-3.080	-2.945	-3.075
	(0.776)	(0.758)	(0.797)	(0.943)	(0.836)	(0.994)
	[0.036]	[0.035]	[0.000]	[0.001]	[0.000]	[0.002]
Mean (dep.var.)	31.116	31.431	29.489	29.631	29.938	30.113
Identifying observations	1,137,356	978,016	1,061,342	893,056	845,155	685,815
Singleton observations	19	15	25	21	22	18
Communities	22,612	18,801	21,682	17,616	17,600	13,789
Countries	36	36	36	36	36	36
Birth year range	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018


Alternative specifications

A. Benchmark



B. Within-sibling



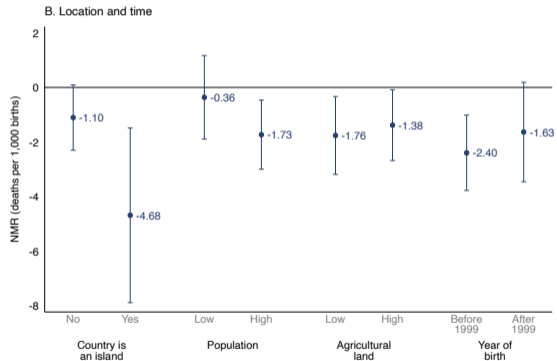
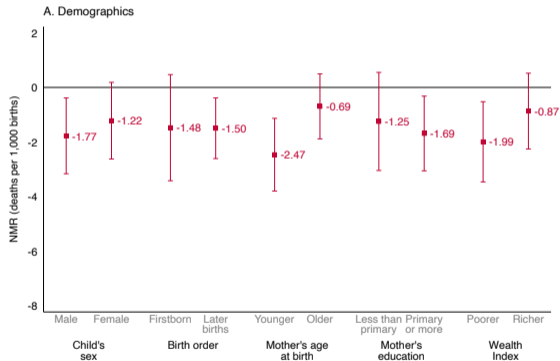
 Main specifications  Point estimate  95% CI  90% CI

Clustering

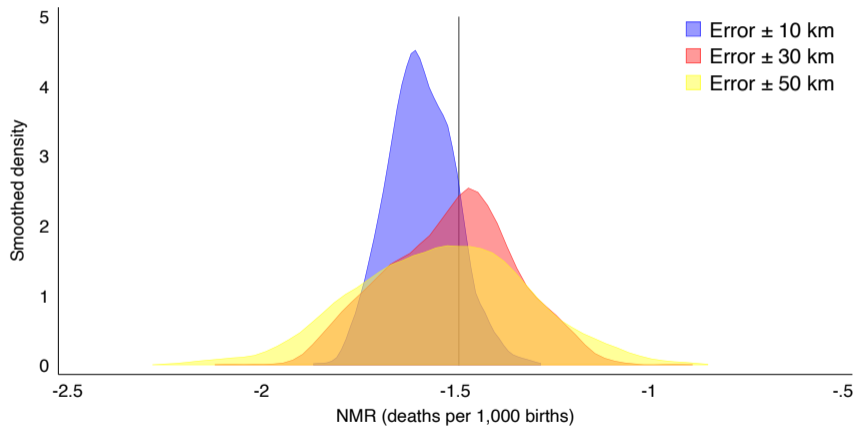
Dependent variable: <i>Level of clustering:</i>	NMR (deaths per 1,000 births)					
	None	1°x1° grid cell	Matched ocean cell	5°x5° grid cell	Country x survey year	Community
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (<i>in utero</i>)	-1.493	-1.493	-1.493	-1.493	-1.493	-1.493
	(0.663)	(0.625)	(0.429)	(0.667)	(0.647)	(0.610)
	[0.025]	[0.017]	[0.001]	[0.025]	[0.023]	[0.015]
Mean (dep.var.)	30.474	30.474	30.474	30.474	30.474	30.474
Identifying observations	1,581,815	1,581,815	1,581,815	1,581,815	1,581,815	1,581,815
Singleton observations	25	25	25	25	25	25
Communities	31,380	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36
Birth year range	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018

Dependent variable:	First birth		Last terminated pregnancy	
	(1)	(2)	(3)	(4)
pH in the nearest waters (previous year)	0.000 (0.003) [0.918]	-0.000 (0.003) [0.883]	-0.000 (0.001) [0.521]	-0.000 (0.001) [0.680]
Mean (dep.var.)	0.111	0.111	0.013	0.013
Identifying observations	1,096,011	1,096,011	1,204,419	1,204,419
Singleton observations	1,082	1,082	47	47
Communities	19,153	19,153	15,630	15,630
Countries	28	28	26	26
Birth year range	1960–2003	1960–2003	1961–2002	1961–2002
Weather controls	-	Yes	-	Yes

Heterogeneity



Measurement error

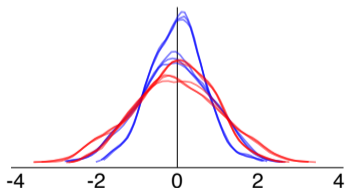


Permutation-based inference

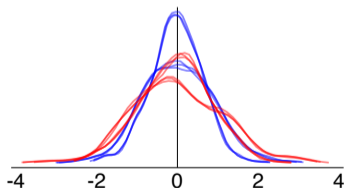
Three types of **random exposure to shocks**

- 1 **Birth dates within communities:** pH is random conditional on location
- 2 **Birth dates within countries:** pH is random conditional on country
- 3 **Communities:** pH is fully random

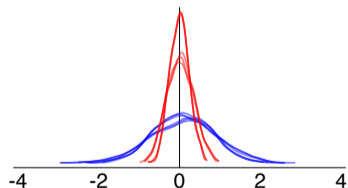
A. Birth dates within communities



B. Birth dates within countries



C. Across communities



NMR (deaths per 1,000 births)

— Benchmark specification — Within-sibling specification

Permutation-based inference

	Coefficients	Empirical p -values		
		A	B	C
Benchmark				
specification (1)	-1.421	0.016	0.018	0.010
specification (2)	-1.423	0.024	0.020	0.022
specification (3)	-1.493	0.012	0.020	0.016
specification (4)	-2.120	0.008	0.006	0.006
specification (5)	-2.100	0.012	0.010	0.006
specification (6)	-2.086	0.010	0.010	0.006
Within-sibling				
specification (1)	-2.077	0.010	0.012	0.000
specification (2)	-2.139	0.006	0.010	0.000
specification (3)	-2.246	0.002	0.004	0.000
specification (4)	-2.476	0.006	0.012	0.000
specification (5)	-2.526	0.010	0.010	0.000
specification (6)	-2.638	0.008	0.010	0.000

Selective migration

Dependent variable: Sub-sample of children:	NMR (deaths per 1,000 births)					
	All	All	All	All	Mother is migrant	Mother is long-term migrant
	(1)	(2)	(3)	(4)	(5)	(6)
pH in the nearest waters (<i>in utero</i>)	-1.903 (0.775) [0.014]	-1.938 (0.773) [0.013]	-1.893 (0.772) [0.015]	-1.916 (0.770) [0.013]	-1.967 (1.142) [0.086]	-2.631 (0.982) [0.008]
Mean (dep.var.)	30.069	29.674	30.157	29.644	27.624	30.406
Identifying observations	1,318,153	1,284,406	1,276,164	1,233,551	304,197	157,073
Singleton observations	115	116	149	153	871	832
Communities	31,236	31,233	31,175	31,169	19,631	15,115
Countries	36	36	36	36	28	28
Birth year range	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018
Selected surveys:	All (Appendix Table 4)				With migration data	
Exclusion condition:	Mother migrated after gestation		Mother migrated after the year before gestation		Mother migrated after gestation	
Source of migration data:	Yes	-	Yes	-	Yes	Yes
Survey + imputed	-	Yes	-	Yes	-	-

Suggestive long-run effects

Dependent variables:	z-scores		Indicators	
	W/h (1)	H/a (2)	Wasted (3)	Stunted (4)
pH in the nearest waters (<i>in utero</i>)	0.011 (0.007) [0.121]	0.010 (0.005) [0.072]	0.000 (0.001) [0.957]	-0.008 (0.003) [0.021]
Mean (dep.var.)	-0.310	-1.386	0.082	0.301
Identifying observations	324,160	327,124	324,160	327,124
Singleton observations	554	683	554	683
Communities	22,635	22,848	22,635	22,848
Countries	32	32	32	32
Birth year range	1972–2003	1972–2003	1972–2003	1972–2003

Ocean acidity increases neonatal mortality

Dependent variable:	Neonatal mortality rate (deaths per 1,000 births)					
	(1)	(2)	(3)	(4)	(5)	(6)
A. Benchmark specification						
pH in the nearest waters (<i>in utero</i>)	-1.421 (0.691) [0.040]	-1.423 (0.682) [0.038]	-1.493 (0.663) [0.025]	-2.120 (0.755) [0.005]	-2.100 (0.762) [0.006]	-2.086 (0.739) [0.005]
Mean (dep.var.)	30.473	30.473	30.474	30.474	30.474	30.475
Identifying observations	1,583,706	1,583,706	1,581,815	1,583,703	1,583,703	1,581,812
Singleton observations	25	25	25	28	28	28
Communities	31,380	31,380	31,380	31,380	31,380	31,380
Countries	36	36	36	36	36	36
Birth year range	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

Ocean acidity increases neonatal mortality

Dependent variable:	Neonatal mortality rate (deaths per 1,000 births)					
	(1)	(2)	(3)	(4)	(5)	(6)
B. Within-sibling specification						
pH in the nearest waters (<i>in utero</i>)	-2.077 (0.873) [0.018]	-2.139 (0.854) [0.013]	-2.246 (0.837) [0.008]	-2.476 (0.954) [0.010]	-2.526 (0.953) [0.008]	-2.638 (0.936) [0.005]
Mean (dep.var.)	31.476	31.476	31.476	31.476	31.476	31.476
Identifying observations	1,474,945	1,474,945	1,474,945	1,474,941	1,474,941	1,474,941
Singleton observations	108,786	108,786	108,786	108,790	108,790	108,790
Communities	31,356	31,356	31,356	31,356	31,356	31,356
Countries	36	36	36	36	36	36
Birth year range	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018	1972– 2018
Weather controls	-	Yes	Yes	-	Yes	Yes
Demographic controls	-	-	Yes	-	-	Yes
Seasonality	Country	Country	Country	Cell	Cell	Cell

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