The Ocean and Early-Childhood Mortality and Development*

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Abstract

Evidence on the exact mechanism linking *in utero* shocks with early-childhood outcomes remains scarce because biological factors are often tangled with changes in parental inputs. This paper addresses this issue by exploiting exogenous variation in the ocean's productivity resulting from water acidification, a consequence of climate change that is negatively affecting marine life and has been largely ignored in the literature. Ocean acidification provides a unique setting to study prenatal nutritional deprivation as water chemistry affects fish stocks, but is not directly observed or felt by mothers. This isolates the channel of transmission to the availability of resources. We estimate the causal impact of the ocean's acidity while *in utero* on early-childhood mortality and development at a global scale, analyzing more than 1.5 million geocoded births taking place over the last 50 years in 36 developing countries. We compare children, including siblings, born in the same location but on different dates, controlling for a set of high-dimensional fixed effects. In coastal areas, a 0.01 unit increase in acidity causes 2 additional neonatal deaths per 1,000 live births. Using a novel measure of fishing pressure that combines local and industrial fishing, we show that the effect is strictly related to reduced access to nutrients during gestation. We find no evidence of parental adaptation on other inputs. Deprivation selectively affects the weakest children, creating small differences in child development. These results provide the first quantitative evidence linking the exploitation of renewable natural resources with malnutrition and neonatal selection.

JEL codes: I15, H51, Q54, Q2.

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Fishing has been a widespread activity throughout human history and remains one of the most widespread activities to extract natural resources. More than 3 billion people depend on it for survival (United Nations, 2015). Although the ocean is critical to global food security, industrial and habitat-destructive fishing, pollution, and coastal urbanization have led to a sustained decrease in fish stocks over the last decades (Golden et al., 2016). This downward trend is central to the future of children in developing countries (United Nations, 2012). Their populations are heavily reliant on fish not only as a food source but also as a means to avoid malnutrition-related diseases (FAO, 2018). At the same time, these regions have experienced the largest decline in fish stocks (Pauly and Zeller, 2016; Golden et al., 2016). Because the consumption of nutrients contained in fish is vital during pregnancy, a reduction in their availability can have dire consequences (FAO, 2020). Nevertheless, it remains unclear how the dependence on the ocean can shape early-childhood development, a fundamental factor explaining poverty in developing countries (Heckman, 2008).

Since the beginning of the literature on the fetal origins hypothesis (Barker, 1995), the interest has revolved around identifying the effects of prenatal nutritional deprivation. While most studies aim at isolating its biological effects–the effects of deprivation holding other inputs constant–estimates are often tangled with maternal distress or parental investments (Royer, 2009; Currie and Almond, 2011). These confounding factors are present when analyzing the adverse effects of famines (Razzaque et al., 1990), fasting (Almond and Mazumder, 2011; Majid, 2015), or alcohol consumption (von Hinke Kessler Scholder et al., 2014). Even when exogenous shifts such as the provision of nutrient supplementation improve prenatal nutrition, direct effects on fetal health can be confounded with changes in parental investments (Adhvaryu and Nyshadham, 2016; Feyrer et al., 2017). Evidence on the relative importance of each channel remains highly limited (Almond et al., 2018).

This paper addresses these limitations by isolating the pure effect of mild nutritional deprivation on early-childhood mortality and development. We focus on exposure while *in utero* to ocean acidification, climate change's dramatic impact on the ocean's chemical composition. Since the Industrial Revolution, the ocean has absorbed 30% of anthropogenic CO_2, resulting in a 26% increase in water acidity (Fabry et al., 2008). Ocean acidification has a direct effect on the already declining fish stocks (United Nations, 2012). It hinders the development of marine life by lowering the availability of minerals needed to calcify bones and bleaches coral reefs, an essential ecosystem for subsistence and artisanal fisheries (Hoegh-Guldberg et al., 2007; Golden et al., 2016; Pendleton et al., 2016).

Ocean acidification is fundamentally different from any previously studied shock. Water chemistry is not directly observed or felt by individuals. As a consequence, they should not adjust or feel distressed by it. This allows isolating the channel of the effect to the sole availability of natural resources for maternal nutrition, while keeping alternative parental inputs constant. We analyze this effect on a global scale and focus on more than 1.5 million live births between 1972 and 2018 across 36 developing countries in Africa, Asia, and Latin America. We collate and homogenize 95 surveys by the Demographic and Health Survey (DHS) Program and build geocoded birth histories. This allows focusing on communities living in coastal areas that are, by definition, the most vulnerable to the consequences of climate change destructive fishing. We match each birth with temporal and spatial variation in the open ocean's acidity while *in utero* using the closest access point to the ocean.

For identification, we exploit two sources of exogenous variation in the ocean's acidity. First, acidification is not occurring uniformly across the globe, with some regions exhibiting faster rates than others. Second, climate change causes local acidification events that affect the natural seasonal variation of water acidity. Both dimensions are not determined by local economic activity because the absorption of CO_2 is determined at a global scale by winds, temperature, sea ice, precipitation, runoff, and ocean circulation (Feely et al., 2008; Turley et al., 2010). Some of these variables have been used in the literature independently as sources of exogenous variation to economic development (see, for instance, Feyrer and Sacerdote, 2009).[1]

By comparing children born in the same location but on different dates, we estimate the effect of *in utero* exposure to varying levels of the ocean's acidity on the probability of death on several indicators of child development. To capture residual unobserved heterogeneity, we exploit the large space-time dimension of our dataset by including a set of high-dimensional fixed effects. These allow controlling not only for unobservable characteristics of the location and date of birth but also for local variation in trends and seasonality of the ocean's acidity. In more conservative specifications, we introduce mother fixed effects to compare siblings.

The ocean's acidity significantly affects neonatal mortality–the probability of children to die during their first month of life. An increase in 0.01 units in the ocean's acidity while *in utero* increases neonatal deaths by approximately 2 deaths per 1,000 live births in communities living within 100 km from the ocean's shore. The size of this effect is nontrivial. For sampled areas, a 0.01 change in acidity is equivalent to the within-year variation at a specific location or, roughly, one-sixth of the average increment in acidity experienced by all sampled areas between 1972–2018. A 0.01 increase in the ocean's acidity also corresponds to just 3% of the predicted increase by the end of the 21st century by the Intergovernmental Panel on Climate Change (2013). Results are robust to various specifications, including mother fixed effects, variable-specific trends, survey selection, assumptions about unobserved determinants, and various falsification tests.

As *in utero* shocks can have long-term effects on children's health, it becomes crucial to understand whether this effect is persistent throughout children's life or leads to death harvesting–a displacement of mortality that is hastened by the shock.[2] The effect of *in utero* exposure to acidification gradually decreases beyond the first month of life, providing evidence of a death harvesting mechanism where acidification affects mortality selectively among the weakest children.

These effects are indeed driven by nutrition during the gestation period. The largest impact is on communities located on the ocean's shore and areas with relatively high fishing pressure. Increases in neonatal deaths related to acidification are mostly felt by communities where fish is an essential nutritional source, and there are larger reductions in fish supply. A highly geographically-disaggregated analysis of the relationship between fish prices and neonatal mortality, an analysis of consumption

[1] As an additional safeguard, we consider acidity measured in open ocean waters because coastal waters are closely linked to local economic activity (Doney, 2010).

[2] Evidence in favor of a death harvesting mechanism associated with weather-related shocks is mixed in the literature. Deschênes and Moretti (2009) find evidence in favor of harvesting by focusing on the effect of high temperatures in the United States. Conversely, Heutel et al. (2017) and Geruso and Spears (2018a) find evidence against this mechanism for the effect of temperatures in the US and humidity in developing countries, respectively.

patterns at the time of the interview, and anecdotal evidence further support this result.[3]

Results also show small significant effects on child development among living children, mainly in the direction of neonatal selection. Children that experienced higher acidity *in utero* tend to have better anthropometrics and a lower probability of morbidity, but no effect on contemporaneous nutrition indicators are recorded. These modest differences in early-childhood development suggest that our results are not biased by confounding factors associated with health investments beyond nutrition while *in utero*. In fact, households do not engage in any compensating behavior. We do not observe any effect on investments in prenatal and delivery care or breastfeeding practices. The lack of any effect on prenatal care further confirms that no differences are a result of nutrient supplementation during pregnancy (Gebremedhin et al., 2014). Overall, these findings suggest that maternal malnutrition during gestation plays a fundamental role in determining neonatal selection. Also, they highlight that studies focusing on the long-run consequences of prenatal interventions targeting nutrition might fundamentally suffer from sample selection.

These results contribute to three distinct strands of literature. First, this paper provides novel evidence at a global scale on the mechanism linking early-life events with child development. A large literature uncovered the adverse effects of a wide variety of shocks experienced *in utero* on early-childhood health and mortality (see, for instance, Almond et al., 2018). For developing countries, particular attention has been given to the role of atmospheric events (Burke et al., 2014; Heft-Neal et al., 2018; Geruso and Spears, 2018a; Adhvaryu et al., 2020), macroeconomic fluctuations (Baird et al., 2011; Paxson and Schady, 2005; Bhalotra, 2010), sanitation conditions (Geruso and Spears, 2018b), political institutions (Kudamatsu, 2012), and conflict (Wagner et al., 2018). While detectable effects are often identified in both the short and long-run, available evidence does not fully disentangle the mechanism as alternative channels overlap.

Second, this paper provides novel insights into the relationship between the ocean and human development. While the natural productivity of the ocean is associated with long-term economic development (Dalgaard et al., 2015), available evidence relies mainly on economic or ecological models at the macro-level (Brander et al., 2012; Speers et al., 2016). An exception is Axbard (2016) that shows the importance of income associated with fishing to avoid sea piracy in Indonesia. Also, while an extensive literature studies the causes and consequences of natural resource extraction of subsoil assets, there is limited knowledge on renewable natural assets, such as wild fish.[4]

Third, results contribute to the understanding of the effect of climate change on human health. A growing literature documents the negative effects of rising temperatures and varying precipitations on human health (Deschênes and Moretti, 2009; Deschênes et al., 2009; Gasparrini et al., 2015; Barreca et al., 2016). This paper provides evidence of the role of the ocean, which has been largely ignored in the literature. More specifically, we provide novel evidence on the mechanisms driving neonatal

[3]See, for instance, the National Geographic's footage *Fisherman With No Fish* or newspaper articles, such as The Pacific Standard's *There's no fish to catch* (22/05/2019).

[4]For a review of the research related to the exploitation of non-renewable assets, refer to Van der Ploeg (2011). The exploitation of renewable natural assets is different since we must consider the rate of reproduction (Collier, 2010). A recent branch of the literature, which focuses on the exploitation of renewable natural assets, studies forest conservation (see, for instance, Burgess et al., 2012). In this paper, we do not focus on farmed fish.

mortality, which is still widespread in developing countries (Hug et al., 2019). While all neonatal deaths are associated with fetal growth restrictions or sub-optimum breastfeeding, there is limited evidence on how the environment can influence neonatal mortality (Black et al., 2013; Khan et al., 2015). We show how nature's availability of nutritious food during pregnancy determines neonatal mortality and early-childhood development.

1 Linking ocean acidification to nutrition

Local variation in fish stocks is unobservable, and its endogeneity to human development further complicates the identification of an effect on early-childhood outcomes. To address this issue we use ocean acidification as an exogenous source of variation in fish availability. While knowledge about the overall effect of climate change on fish stocks is still limited in terms of fish behavior and geographical redistribution, growing evidence points to a decrease in fish survival because of acidic waters (see, for instance, Sswat et al., 2018).[5] Archaeological evidence also supports this conclusion (see, for instance, Bottjer, 2012).

In the framework of Heckman (2007) and Currie and Almond (2011), ocean acidification can be interpreted as an exogenous shock to prenatal investments in nutrition, a fundamental input in the child production function. For communities relying on fish as a major source of food, a reduction in stocks has a direct consequence on nutrition. Across the globe, fish represents 17% of all animal protein that is consumed. In developing countries, this percentage reaches an average of 26%, with peaks of 50% or more in Small Island Developing States (FAO, 2018). Fish are also rich in micronutrients, such as iron, iodine, omega-3 fatty acids, calcium, and zinc that are crucial for cell, brain and cognitive development (FAO, 2020). For communities relying on the ocean's resources, the importance of fish for nutrition is also highlighted by its centrality in their culture and tradition (FAO, 2018). As dependency on fish for nutrition is highly stable over time (Appendix B.1), a reduction in fish stocks translates into a decrease in the direct intake of nutrients for households living on subsistence fishing, or an increase in prices that would make the consumption of fish less affordable.[6]

In these communities, the consumption of macro and micronutrients contained in fish is vital during pregnancy. In fact, maternal malnutrition contributes to fetal growth restrictions–the main cause of neonatal deaths (Cudd et al., 2004). Deficiencies of micronutrients not only increase neonatal mortality, but also raise the risks of perinatal and maternal mortality, cognitive deficits, and reduced immune function (Black et al., 2013). Proteins and zinc are essential for proper fetal growth (World Health Organization, 2007; Ota et al., 2015). Iron, which helps the mother produce additional blood during gestation, is also associated with decreases in neonatal deaths (Dibley et al., 2012). While developed countries have compensated for the decline in fish catch with international trade, the development of

[5] Fish survival is also affected by ocean warming and the consequent reduction in the water's oxygen content. However, acidification and oxygen content are closely correlated. We discuss this further in Section 2.2.

[6] A rising global demand for fish (also driven by population growth) and a reduction in fish stocks resulted in an increase in the price for fish (Tveterås et al., 2012). Section 4.2 discusses evidence for the Philippines. In terms of consumption, annual per capita fish consumption in developing countries increased from 6.0 kg in 1961 to 19.3 kg in 2015, with consumption being higher in coastal areas and inland water areas (FAO, 2018). This is roughly half the consumption in developed countries (Ye and Gutierrez, 2017).

intensive agricultural production, and the provision of food supplements, communities in developing countries rely mainly on their local harvests. This is particularly relevant in communities with few nutritional alternatives, where pregnant women already suffer from a wide range of nutrient deficiencies (World Health Organization, 2009; Wessells and Brown, 2012).

This channel is amplified by overfishing. Areas with greater biodiversity are in fact more resistant to the negative consequences of acidification (Golden et al., 2016). This is particularly relevant for developing countries as willingness to invest in conservation is lower (Greenstone and Jack, 2015), and industrial fishing, weak governance and population growth are playing a central role in the extraction of resources. In the face of declining fish stocks, the demand for fish in developed countries has been satisfied by an increase in fish caught in the waters of developing countries, both through international trade or by direct fishing. Marine capture fishery production in developed countries is about half its 1980s level, mainly due to stringent regulations, decreased catch rates, and high fuel prices. Instead, production in developing countries has increased steadily since 1950, with a much faster rate since the 1990s (Ye and Gutierrez, 2017). This pattern is largely responsible for the greater declines of fish availability in developing countries.[7] Industrially-caught fish has become a commodity traded between continents rather than consumed in the origin countries where it was caught, with undernourishment generally correlating with a positive trade balance for seafood (Smith et al., 2010; Pauly and Zeller, 2016).

Parents can compensate to the lack of fish-related nutrients by increasing alternative investments that are also entering the child production function. While ocean acidification is not directly observed or felt by individuals, it is important to note that it can indirectly cause a deterioration of the local economic activity (Colt and Knapp, 2016). In this case, a reduction in household income could worsen maternal and child health as individuals would seek lower healthcare (Paxson and Schady, 2005; Bhalotra, 2010; Baird et al., 2011). In developing countries, the relationship between income and health is also strengthened as large shares of the population relies on more volatile income sources, such as agriculture (Dell et al., 2014; Burgess et al., 2017). Lower healthcare during pregnancy is recognized as a strong determinant of early-childhood mortality (Rammohan et al., 2013). Lower income would also lead to the purchase of less nutritious and cheaper food as the price for fish would increase relative to other agricultural products (see, for instance, Subramanian and Deaton, 1996). In Section 4.2 we will discuss further this potential channel.

2 Data

This section describes the data used in the paper. Detailed descriptions of variables used and data sources are provided in Appendix A.1.

[7] United Nations (2012) highlight this issue as central for the human right to food, and set the following two points as priority actions: "regulating the industrial fishing sector to protect the access rights of traditional fishing communities" and "the introduction of exclusive artisanal fishing zones and exclusive user rights for small-scale and subsistence fisheries, where appropriate". For anecdotal evidence in international news, see, for instance, The Guardian's *UK steps in to help West Africa in fight to overturn EU fishing abuses* (18/03/2012) and *Developing nations' fishing grounds should be protected, UN says* (31/10/2012).

2.1 Early-childhood mortality and development

For developing countries, complete information about mortality collected by governmental agencies is generally scarce. To bypass this limitation, we collate and homogenize 95 household surveys from 36 countries collected from 1990 to 2018 by the DHS Program (ICF, 2019). Individual surveys provide nationally representative data on health and population in developing countries, with a particular focus on maternal and child health, and have been widely used to build mortality rates among children thanks to its detailed and accurate birth histories. The dataset is supplemented with indicators of child development and nutrition, such as height, weight and anemia. The program surveys women aged 15–49 and includes information about their demographics, such as education, employment, and marital status. It also collects similar data on their current partners. Each surveyed woman's birth history is recorded and includes information on the children's year and month of birth, sex, birth order, whether they are twins, and the date of death when it applies.[8]

Our dataset includes all available surveys with coordinates at the cluster level and only considers countries with direct access to the ocean, thus excluding landlocked countries and those that only have access to a sea. Panel A in Figure 1 shows the geographical coverage of the DHS surveys and selected countries. Appendix A.2 provides the full list of countries and surveys included in the study, and discusses alternative selection criteria. We use all available surveys and re-weight observations to correct for oversampling of countries that were surveyed multiple times.

The primary sampling unit in DHS surveys is a cluster, which represents a village or a neighborhood (Croft et al., 2018). Geolocation of survey clusters allows for restricting the sample to households living in proximity to the ocean's shore. We identify them using two alternative sample restrictions. First, following the United Nations Millennium Assessment (2003), a *coastal area* is defined as the buffer extending landward from the ocean's shore up to a distance of 100 km. Second, we use an alternative restriction selecting clusters in higher proximity with the ocean. *Vulnerable coastal area* is defined as the buffer extending landward from the ocean's shore up to a distance of 40 km. Distances from shore are computed as the minimum straight distance from the DHS cluster to the shoreline of continental landmasses and ocean islands. Appendix A.3 details the procedure followed to compute distance from shore. Panel B in Figure 1 visualizes, for selected DHS countries, the selected clusters by distinguishing between coastal and inland areas.[9]

Table 1 presents descriptive statistics for the sample. Columns (1)–(4) select all clusters in the coastal area, while columns (5)–(8) select clusters in the vulnerable coastal area. Panel A explores birth-level characteristics, including developmental outcomes, while Panel B and Panel C focus on mother-level and household-level characteristics. Panel D reports average early-childhood mortality rates. Birth-level and mother-level characteristics are highly comparable between coastal and vulnera-

[8] Birth histories are collected retrospectively, which might lead to recall bias. The DHS Program does not record stillbirths, which might also lead to measurement error if pre-birth mortality is misinterpreted (Croft et al., 2018). Since the death of a child is a tragic event, we assume measurement error is minimal. Results are robust to restricting the sample to births within 5 or 10 years from the interview (Appendix B.2).

[9] Appendix B.3 shows robustness of our main results to potential sources of measurement error in the distance from the shore. Appendix B.12 shows instead robustness to potential issues deriving from selective migration. The 40-km bound selects a sample that maximizes the absolute value of the point estimate of *in utero* exposure to the ocean's acidity on NMR. Results are robust to alternative definitions of coastal area (Appendix B.4).

ble coastal areas, with similar fertility indicators such as the birth order of sampled births, the number of twins, or the years since birth. Also, in terms of household characteristics, observations are comparable, with households in vulnerable coastal areas being slightly wealthier than the whole coastal area. Households in vulnerable coastal areas are living closer to the shore, and consequently at lower altitudes, but further away from other water bodies. Temperature and rainfall at the time of the interview are comparable between the two samples. Similarly, early-childhood mortality rates are similar in both samples. Overall, as larger cities and urban areas generally agglomerate near the ocean, households living in coastal areas present better development indicators as compared to households in inland areas (Appendix Table A4).

2.2 Ocean chemistry

Geolocation of DHS clusters is used to match birth histories with ocean chemistry data. Data about the ocean's chemistry are obtained from the Hadley Global Environment Model 2 - Earth System, also known as HadGEM2-ES, provided by the European Space Agency (ESA) Pathfinders-OA project (Jones et al., 2011; Sabia et al., 2015). This source uses the Diat-HadOCC ecosystem model (Palmer and Totterdell, 2001) to compute, among other variables, the air-sea flux of CO_2, the ocean's absorption of CO_2, and, ultimately, the ocean's pH. The model matches available information from observational data (Totterdell, 2019).[10] Data are provided as monthly global raster data at the 1° x 1° resolution for a series of chemical features of the ocean in open waters. For each DHS cluster, we apply a proximity criteria by matching birth histories with the closest data point to the cluster's coordinate.

The degree of ocean acidification is measured by pH at the surface, a logarithmic scale indicating acidity–lower values–or basicity–higher values–of an aqueous solution. Data are available for the period 1972–2018. Panel A in Figure 2 shows the time series of pH from January 1972 to January 2018 for open ocean points associated with sampled clusters. The pH of seawater typically ranges between 7.5 and 8.4 (Chester, 2009). For sampled clusters, the average pH reduced from 8.08 to 8.02 in the considered time frame, a clear indication of acidification. Similarly, Panel B shows, for the same sampled points, the monthly mean by year and the monthly median for the entire period. We observe a clear seasonal pattern, with a peak in January (8.10) and a minimum around September (8.09), indicating a median within-year variation of 0.01 units of pH.

The process of climate-change-induced variation in ocean chemistry is multidimensional. The effect of acidification on the ocean is compounded by the rise in the global sea surface temperature, which has risen by 0.7 °C since the end of the 19th century. By 2100, it is predicted to rise an additional 3.1 °C (Keeling et al., 2010). Warmer temperatures reduce the ocean's oxygen content. The latter plays a key role in structuring marine ecosystems and controls the distribution of essentially all marine organisms. For instance, a decreased oxygen content reduces the average size of fish and forces fish

[10] For the use of re-analysis climatology datasets in economics, see, for instance, Harari and La Ferrara (2018); Adhvaryu et al. (2020). For further evidence on the performance of the model, see Halloran et al. (2010); Collins et al. (2011); Booth et al. (2012). Alternative types of measurement for our time-space dimension are currently unavailable as satellites for the direct observation of pH have not yet been thoroughly explored (Land et al., 2019). Nevertheless, any measurement error present in the model would be uncorrelated with unobservable determinants of local development because the model is purely determined on climatology (Doney, 2010). Falsification tests also support the validity of the dataset (Appendix B.3).

to migrate to cooler waters at higher latitudes (Cheung et al., 2013; Gilly et al., 2013).[11] In water, oxygen is found in a dissolved form–measured in units of μmol/kg–and is a vital input for marine life (Keeling et al., 2010). The highest concentrations are found on the surface ($>$ 200 μmol/kg), while below surface concentration is lower due to the respiration of all organisms and bacteria living in the ocean.

We build concentrations of dissolved O_2 at the surface using the HadGEM2-ES model and adopting the same resolution used for pH at surface. Because dissolved O_2 concentrations are highly correlated with pH, we build variation that is unexplained by pH. We first perform a linear regression of dissolved O_2 concentration on pH and then compute the residuals as the unexplained component. While pH and dissolved O_2 concentrations are measuring a common process, Appendix B.4 shows that, once the component measured by ocean's pH is removed from variation in dissolved O_2 concentrations, the latter has no effect on mortality estimates.

Finally, as both mortality and ocean chemistry can be related to precipitations and temperature in the location of birth, we supplement the dataset with time-varying data on average rainfall and temperature at cluster level from the PRIO-GRID database (Tollefsen et al., 2012).

3 Measuring the impact of acidification

To identify the causal effect of ocean acidification on children's outcomes, information on the ocean's pH is matched with children's date and location of birth to build a measure of *in utero* exposure to the ocean's conditions. The ocean's data points are matched to clusters using the proximity criteria and assuming straight distance. Variation in ocean's pH while *in utero* is comparable in its between and within components, suggesting variation originates from both the time and the geographic dimensions (Appendix B.5). Similar to Adhvaryu et al. (2020), we assume a gestation period of 9 months for all children in the sample and use the average pH at surface of the 9 months preceding the date of birth as the main source of variation. We indicate this variable as pH_{mtvc}. Because variation over time in pH is small in its standard scale, we multiply pH_{mtvc} by 100 to relate coefficients to an increase of 0.01 units in pH.

The effect of ocean's pH on children's outcomes is estimated with the following specification, which we label as the benchmark:

$$y_{ikmtvc} = \beta\, pH_{mtvc} + \mathbf{X}_{ikmtvc}\gamma + \Omega_{mtvc} + \epsilon_{ikmtvc} \tag{1}$$

where y_{ikvym} is the outcome of interest for child i born from mother k in month m and year t, whose mother is surveyed in cluster v in country c, $\mathbf{X}_{ikmtvc}$ is a vector of time-varying control variables, Ω_{mtvc} is a set of high-dimensional fixed effects, and ϵ_{ikmtvc} are idiosyncratic errors assumed to be clustered at the ocean raster data point. Appendix B.6 shows robustness of estimates to alternative assumptions about standard errors. Time-varying control variables include the child's gender and birth order, the number of twins born with the child, mother's age at birth (including a square term), mother's

[11] For further information about the effect of global warming on oxygen content refer to Grantham et al. (2004).

age at the time of the interview (including a square term), mother's years of education, and the gender of the household head. To control for other potential confounding variables related to climate, we include the average temperature and rainfall in the year of birth and an interaction between these two measures. To isolate the effect of the ocean's pH from other variables characterizing ocean biochemistry, we also include the estimated residuals of a linear regression of dissolved O_2 concentration on the ocean's pH. Appendix A.4 provides further details for this procedure. Consequently, β captures the effect of the ocean's pH conditional on unexplained dissolved oxygen concentration.

Identification of the parameter of interest, β, relies on high-dimensional fixed effects, $\Omega_{mtvc} = \delta_{cm} + \eta_{mt} + \theta_{vc} + \phi_{tc} + \mu_{mc}$. These aim to capture residual unobserved heterogeneity through different channels. First, the global trend in ocean acidification (Panel A in Figure 2) and unobserved characteristics specific to the child's date of birth are captured by birth year by birth month fixed effects, η_{mt}. Second, unobserved characteristics specific to the location surveyed are captured by cluster fixed effects, θ_{vc}. Third, to control for local variation in yearly trends, we include country by birth year fixed effects, ϕ_{tc}. These are capturing unobserved variation in trends among areas affected by faster or slower acidification. Fourth, we include different sets of fixed effects to control for local seasonality, μ_{mc}. In the preferred specification, we include country by birth month fixed effects. These are capturing whether children born in a specific month have higher or lower pH due to the specific seasonality in their locality of birth. Alternatively, we use global grids at the 5° x 5° and the the 2.5° x 2.5° resolutions and we control for grid cell-by-birth-year fixed effects. The use of a grid verifies the robustness of the results with respect to the potential endogeneity of administrative boundaries.[12] Because ocean's pH varies monthly with a spatial resolution of 1° x 1°, local seasonality controls at the resolution of 2.5° x 2.5° are conservative. Results are robust to alternative specifications for local trends, and controlling for variable-specific trends by interacting year and birth month with socioeconomic indicators (Appendix B.6).

Finally, we compare siblings born on different dates and therefore affected by distinct *in utero* conditions. This strategy restricts the sample to mothers having at least two live births and provides more conservative estimates. These mothers are generally older, have fewer years of education, had a younger age during first birth, and live in slightly poorer households (Appendix B.7). The within-siblings specification allows controlling for mothers' time-invariant characteristics, especially unobserved ones such as attitudes toward risk, ability to cope with shocks, and aspirations for children. The estimates with mother-specific fixed effects are provide additional evidence on the robustness of our benchmark results, especially after controlling for local seasonality, because evidence suggests that children born at different times of the year are conceived by women with varying characteristics (Buckles and Hungerman, 2013). The following specification is estimated:

$$y_{ikmtvc} = \beta\, pH_{mtvc} + \mathbf{X}_{ikmtvc}\gamma + \Omega_{mtvc} + \tau_k + \epsilon_{ikmtvc} \tag{2}$$

where τ_k are mother-specific fixed effects. The remaining variables are the same as in equation (1).

[12]Results are robust to using districts as location identifiers to control for local seasonality. To identify districts we use the region of residence in the DHS datasets. This is the smallest administrative level within the country or a grouping of the first-level administrative units (Croft et al., 2018).

4 Results

4.1 Neonatal and early-life mortality

We begin by focusing on the effect of the ocean's acidity while *in utero* on the Neonatal Mortality Rate (NMR)–the number of deaths in the first month of life per 1,000 live births. Table 2 presents estimates of the effect of ocean's pH on NMR using the benchmark specification from equation (1) in Panel A, and the within-siblings specification from equation (2) in Panel B. Columns (1)–(3) restrict the sample to the coastal area, while columns (4)–(6) restrict the sample to the vulnerable coastal area. For robustness, we use alternative sets of fixed effects to control for local seasonality. Columns (1) and (4) include interaction terms between the cluster's country and the birth month, columns (2) and (5) include interaction terms between the 5° x 5° grid cell and birth month, while columns (3) and (6) include interaction terms between the 2.5° x 2.5° grid cell and birth month.

In coastal areas, ocean acidification increases NMR substantially. Within 100 km from the ocean's shore, a 0.01 decrease in pH experienced while *in utero* increases NMR by 1.6–2.3 deaths per 1,000 live births. Point estimates are smaller in magnitude when local seasonality is captured by interaction terms between the smaller cell or the country and the birth month (columns 1 and 2), and they are larger when local seasonality is captured by interaction terms between the larger cell and the birth month (column 3). The effect is robust to controls for alternative local trends, including highly disaggregated trends in industrial fishing, in economic development, and in population growth (Appendix B.6).

These estimates are function of how we select clusters as part of coastal areas. A different distance upper bound for the inclusion of clusters in the sample would clearly affect the total number of live births considered. By estimating the effect for all bounds smaller than 100 km, we observe that the effect of ocean's pH on NMR reaches its largest magnitude when the upper bound is set at 40 km from the shore (Appendix B.4). In terms of NMR, the most affected communities live within 40 km from the shore, while beyond this distance, the estimate gradually converges to zero. Within 40 km from the shore, a 0.01 decrease in pH increases NMR by 3.1-3.4 deaths per 1,000 live births. Evidence of the effect of acidification on NMR are reinforced by adding mother fixed effects (Panel B), suggesting that family-specific unobserved heterogeneity is not driving estimates. When comparing siblings, a 0.01 decrease in pH increases NMR by 2.2–2.6 deaths per 1,000 live births within 100 km from the shore, and by 3.3–3.7 deaths per 1,000 live births within 40 km from the shore. Estimates are homogeneous across a wide array of individual- and cluster-level characteristics (Appendix B.9). Focusing on child and mother demographics, effects are similar when disaggregating by gender of the child, birth order and year of birth. Higher vulnerability to the ocean's pH is observed among children born from younger mothers, less educated mothers and living in poorer households. However, we cannot highlight any statistically significant difference between these groups.

Rather than focusing purely on distance from the shore, we can also restrict the definition of coastal area by including altitude requirements. For instance, Small and Nicholls (2003) consider a coastal area as the land margin within 100 km of the coastline or less than 100 meters above mean low tide, which ever comes first. Appendix B.4 shows a comparison of coastal areas using alternative selection criteria, and presents estimates of the effect of ocean's pH while *in utero* on NMR for the coastal area

but imposing restrictions based on altitude (Appendix Table B2). When the coastal area is restricted to clusters below 100 meters of altitude, a 0.01 decrease in pH increases NMR by 1.7–2.8 deaths per 1,000 live births, and by 2.5–3.4 deaths per 1,000 live births when comparing siblings. When we impose an even smaller requirement for altitude (50 m), the marginal effect of acidification is considerably larger. A 0.01 decrease in pH increases NMR by 2.1–4.3 deaths per 1,000 live births, and by 2.6–4.7 deaths per 1,000 live births when comparing siblings.

Falsification tests generating artificial exposure to pH while *in utero* by randomly re-allocating the timing or location of birth show that estimates are not spurious (Appendix B.3). In a first test, birth dates are randomly reassigned within each cluster, such that the total exposure within each cluster remains constant, but children are now exposed to different pH levels while *in utero*. In a second test, birth dates are randomly reassigned within each country, independently from the cluster and the survey. In a third test, birth dates are not reassigned, but mothers (and their children) are randomly allocated to different clusters, independently from the country and the survey. The first two tests varies the timing of birth, while maintaining the location constant or in the same country. The third test maintains the timing of birth, but randomizes its location. Together, the three falsification tests allow to vary *in utero* exposure to pH in both space and time randomly, thus isolating individual components in the overall variation in the ocean pH. For all tests we cannot reject a null hypothesis of a zero effect of pH on NMR.

The impact of ocean's pH is driven by the specific temporal and spatial pattern in ocean's pH experienced during gestation. It is specific to *in utero* exposure as opposed to periods prior to conception or following birth (Appendix B.11). In addition, it is specific to acidification as areas that fall in the bottom quartile in the sample distribution of the ocean's pH present a significant increase in mortality, while there is no significant effect for the areas in the top quartile (Appendix B.10). Finally, it is not driven by selective migration among mothers (Appendix B.12). Since variation in the ocean's chemistry is assigned using the location of the interview, migration decisions induced by varying levels of the ocean's pH during the gestation period would lead to an inaccurate assignment of the ocean's pH to the specific child. The ocean's pH during the gestation period has no effect on the mother's probability to migrate after the birth of the child.

While variation in pH is exogenous to unobserved heterogeneity in NMR, estimates might still be confounded by related phenomena, such as coastal water pollution, and conflict for scarce resources.[13] The effects highlighted in Table 2 capture neither of these. First, coastal waters are the most vulnerable marine systems to environmental pollution. Thus, using direct measures of acidification in coastal waters might bias estimates due to the close relationship between human development and contamination. Coastal waters get contaminated from organic pollutants and trace metals deriving from fossil fuels and industrial production, and nutrients from agriculture, such as phosphorus and nitrogen, contained in fertilizers.[14] To control for the possibility that open waters' pH is just proxying for coastal pollution, we use data from the GlobColour project (d'Andon et al., 2009) and introduce chlorophyll concentra-

[13]Appendix B.6 also shows robustness of estimates to controls for intensity of fishing.

[14]The variable influx of freshwater to marine estuaries due to volatile rain patterns associated with climate change, ocean warming and acidification also promote algal blooms in coastal areas.

tion in coastal waters as a control variable. Higher concentrations indicate the presence of nutrients release linked with economic activity and overpopulation that favor algae abundance. It indicates poor water quality, as algae decomposition reduces oxygen availability to fish, shellfish, and crustaceans. Estimates suggest that the effect of ocean's pH on NMR is not driven by the–potentially endogenous–quality of coastal waters (Appendix B.13). Finally, while there is no evidence that changing ocean pH could induce conflict, evidence on food insecurity suggests acidification could have also induced conflict (Martin-Shields and Stojetz, 2018) and indirectly mortality. Also, in line with Wagner et al. (2018), civil conflict impacts NMR. Nevertheless, the estimate of the effect is unaffected by controlling for the presence and intensity of conflict (Appendix B.14).

Beyond NMR, it is important to understand whether the effect of acidification is characterized by a persistent pattern as children grow older or death harvesting–a displacement of mortality that is hastened by the shock. In presence of harvesting, an immediate effect of exposure to varying ocean's pH during gestation would slowly disappear after the first month of life. The initial effect is offset by later decreases in mortality. To test for this mechanism behind the effect of acidification and mortality, we look at the probability of death up to age 5 for each month of life. We focus on the probability of death at the monthly level, rather than mortality rates at standard times, to avoid potential issues related to the heaping of self-reported date of death.[15]

We estimate the probability of death at age x (in months) using equation (1) and restricting the sample to children that, at the time of the interview, are born at least x months before (independently from being alive). We select the sample based on time from birth, rather than age, to avoid selecting children alive and younger than x because we do not know if they will survive up to x. We repeat the same specification for x ranging from 1 month to 60 months (5 years). The dependent variable is updated in every iteration. It is an indicator variable equal to one if the child is dead at time x from birth, and zero if the child is alive. This variable is multiplied by 1,000 such that coefficients are related to changes in deaths per thousand live births. Children who are reported as dead in the dataset, but with an age at death larger than x are coded as alive in the regression correspondent to time x from birth.

Figure 3 shows how this probability is affected by a 0.01 increase in the ocean's pH experienced during the gestation period. For both coastal and vulnerable coastal areas, the effect of ocean's pH while *in utero* peaks in the first month of life (in correspondence with NMR). A smaller net effect is observed for mortality measured beyond the first month of life. For coastal areas, convergence to zero is faster and happens within the first year of life, while for vulnerable coastal areas, the effect is more persistent over time, at least up to the end of year 2 of life. These results provide evidence in favor of a death harvesting mechanism. Acidification experienced during gestation affects mortality selectively among the weakest children by hastening their death. The positive effect of pH *while in utero* on post-neonatal and child mortality further support the idea of selection among children who survive the first month of life (Appendix B.15).

[15] The heaping of deaths at 1 year is common, while mortality rates at ages 2, 3, 4 and 5 are hardly affected by heaping (Croft et al., 2018). In Figure 3, we indicate these points by vertical lines. We do not observe any effect on the estimates due to these potential issues.

4.2 Nutrition and parental investments

Fetal growth restrictions caused by maternal malnutrition are one of the main causes of neonatal deaths (Cudd et al., 2004; Black et al., 2013). While recorded information about maternal nutrition during each pregnancy is not available, evidence suggests that, in periods with lower ocean's acidity, mothers have a higher probability to eat fish, especially in proximity with the ocean's shore, while the consumption of proteins from other animal sources is unaffected.[16]

To test the link between maternal nutrition and neonatal deaths at birth-level, we turn our attention to the importance of fish. Communities relying on fish can be identified purely out of distance from water bodies. In fact, communities using fishing as their main economic activity and relying on fish as their main source for nutrition live on the ocean's shore or along estuaries (Dixon et al., 2001; FAO, 2018). We therefore estimate the impact of the ocean's pH while *in utero* on NMR as a function of distance from the ocean's shore. We estimate the following variant of equation (1):

$$y_{ikmtvc} = \beta\, pH_{mtvc} \cdot f(dist_{vc}) + \mathbf{X}_{ikmtvc}\gamma + \Omega_{mtvc} + \epsilon_{ikmtvc} \tag{3}$$

where $dist_{vc}$ is the distance from the shore of cluster v, and $f(dist_{vc})$ is a functional form in the distance from the shore. We assume that $f(dist_{vc})$ is a cubic function in $dist_{vc}$. Panel A of Figure 4 presents marginal effects at different distances from the shore, assuming all other variables to be constant. Similarly, we estimate the effect of the ocean's acidity on mortality as a function of distance from other water bodies by estimating equation (3) and replacing $dist_{vc}$ with the distance of cluster v from another water body excluding the ocean. Other water bodies include lakes, ponds in islands within lakes, and all rivers (from river-lakes to minor canals).[17] Distance from the shore and distance from other water bodies are not independently distributed, with clusters being closer to the shore also being further away from other water bodies (Appendix A.3). Panel B of Figure 4 plots the marginal effects.

The largest effect on NMR is observed at the shore, while the estimate converges to zero as distance increases. Areas in high proximity to the ocean–within 10 km from the shore–are also areas with higher population densities. This result confirms that the impact of acidification is indeed concentrated in communities that rely more heavily on fish for nutrition. While acidification affects NMR mainly through its effect on communities with stronger ties with the ocean, it operates independently from the presence of other water bodies, as the effect is constant along this dimension. This also confirms the close relationship between the effect on NMR and the ocean's productivity. In addition, estimates are robust to potential sources of error associated with the measurement of distance from the shore (Appendix B.3).

If reduction in fish availability is central in explaining the increase in NMR, we would also expect acidification to have a greater impact in areas where fish stocks are more depleted (see Section

[16]See Appendix B.16. Information about maternal food consumption in the DHS surveys is available at the time of the interview and only for a selected number of surveys.

[17]Freshwater ecosystems are also experiencing water acidification as a consequence of CO_2 emissions (see, e.g., Ou et al., 2015). It is reasonable to assume that communities living in proximity with the ocean rely mainly on the ocean, rather than other freshwater bodies.

1). To verify the link between ocean acidification, the decline in fish supply, and maternal malnutrition, we focus on local variation in fishing pressure to understand heterogeneities in the effect of the ocean's acidity. We rely on two complementary data sources that capture fishing activities at a highly-disaggregated level. The first indicator captures the intensity of *industrial fishing*. Especially for developing countries, marine capture from this activity is mainly feeding the international market and is rarely consumed in the countries where it is caught (Pauly and Zeller, 2016). The Global Fishing Watch dataset provides data on the hours industrial fishing vessels spend at specific locations (Kroodsma et al., 2018). It makes use of 22 billion automatic identification system (AIS) messages to track more than 70,000 industrial fishing vessels. AIS was originally designed to help prevent ship collisions by broadcasting, among other information, a ship's identity and position, which allows identifying commercial fishing activities. Since data are available only for the period 2012–2016, we build a global grid at the 1° x 1° resolution summing fishing hours within each cell over the available period.

The second source captures the intensity of *local fishing*. It focuses on boats that use lights to attract fish, which are expected to operate on a small scale and local basis. Presence of these boats is also capturing the dependency of the local economy to fishing not only for direct nutrition, but also as a source of income. We use the Automatic Boat Identification System for VIIRS Low Light Imaging Data (Elvidge et al., 2015). This algorithm detects boat presence using nightlight measured from satellite imaging and provides the time and geolocation of each detection. We build a global grid at the 1° x 1° resolution with the sum of all detected boats for the period in which data are available (2017–2019). Appendix Figure B13 shows an example of the geographical distribution of both variables.

Using both data sources, we define fishing pressure as the product of the intensity of industrial fishing and local fishing. While we focus on a continuous measure, results are also robust to using subsample analysis (Appendix B.17), or alternative aggregation methods such as averaging z-scores (see, for instance, Kling et al., 2007). For ease of interpretation, we normalize fishing pressure to be between 0 and 1. Areas with high values of fishing pressure are areas where the impact of fishing is expected to have had the maximum impact on the depletion of fish stocks. We then estimate the heterogeneous effect by introducing in equation (1) a linear and a quadratic interaction term between the ocean's pH while *in utero*. Note that we use time-invariant heterogeneity because highly-disaggregated data for fishing pressure are available only for recent years. However, global fishing patterns, especially for industrial fishing, have low sensitivity to economic and environmental variation and are relatively stable over time (Kroodsma et al., 2018).

Panels A1 and B1 in Figure 5 plots the marginal effects of the ocean's pH on NMR at different levels of fishing pressure for both coastal and vulnerable coastal areas. High-pressure areas drive the effect on NMR. For these communities, the marginal effect of the ocean's pH while *in utero* is statistically larger as compared to areas with low fishing pressure. In addition, heterogeneity is very specific to households living in high proximity to the shore (Appendix Figure B16). Formal tests of heterogeneous impacts confirming this result (Appendix Table B15). These corroborate the importance of fish in explaining the neonatal selection induced by the ocean, providing additional evidence of a maternal malnutrition channel.

This mechanism is also supported by the larger effects observed in areas with greater dependency

on fish. Marginal effects are in fact larger in islands (Appendix B.9), where per capita fish consumption and dependence on fish for protein consumption are the largest (FAO, 2018). For instance, Bonham et al. (2009) shows how seafood is central in the diet of pregnant women in the Seychelles islands. Marginal effects are also greater in countries where fish represent a higher percentage of total animal proteins consumed, and where there is a positive trade balance for fish products (Appendix B.1).[18]

As we discussed in Section 1, an alternative channel explaining the effect on neonatal deaths is related to income. To test whether an income shock driven by variation in the ocean's acidity is also driving the main results, we look at health investments on antenatal and delivery care for each pregnancy.[19] For antenatal care, we focus on whether the mother attended any visit, on the number of antenatal care visits, and whether the visits were attended by a health professional. Note that in developing countries antenatal care is also a strong predictor of the correct use of nutrient supplementation plans during pregnancy (Gebremedhin et al., 2014). For delivery care, we focus instead on whether the mother gave birth in a health center, and whether the delivery was attended by a health professional. Table 3 presents the estimates of the effect of ocean's pH while *in utero* on these investments using equation (1). Panel A restricts the sample to the coastal area, while Panel B to the vulnerable coastal area. For cross-survey comparability, the sample is restricted to the last birth, independently from the child being alive at the time of the interview (Boyle et al., 2019). For both antenatal and delivery care and in both coastal and vulnerable coastal areas, we do not observe any significant effect on ocean's pH during the gestation period on the contemporaneous health investments. In addition, although sub-optimum and late initiation of breastfeeding are primary causes of neonatal mortality (Black et al., 2013; Khan et al., 2015), ocean's pH while *in utero* has no effect on breastfeeding practices. This provides evidence that parental investments and adaptation are not driving the effect on NMR.

While poorer households exhibit a larger effect, we cannot identify any statistically significant heterogeneous effect with respect to a household's wealth (Appendix B.9). This suggest that, if investments are unchanged, higher ability to purchase more nutritious food has only a minor contribution in explaining the main effect. The effect is also homogeneous in the birth order and gender of the child. In the presence of adverse economic shocks, mortality tends to vary along with these two characteristics as mothers allocate health investments differently (Baird et al., 2011). Furthermore, looking again at fishing pressure, Panels A2–A3 and B2–B3 in Figure 5 highlight that heterogeneous effects are driven mainly by a higher intensity of industrial fishing, as compared to local fishing. Local fishing has a closer association with fishing-related income for local communities, while industrial fishing is more related with the exploitation of marine resources by foreign developed economies (Appendix B.17).

The absence of an effect in terms of health investments also indicates that mothers do not engage in any compensating behavior in response to variation in the ocean's pH. This evidence strongly suggests that this shock directly affects the availability of scarce marine resources is unobserved by mothers. Thus, acidification is a pure resource shock–an exogenous and not observable reduction in fish supply.

[18] More recently, we observe a pattern in which developing countries export high-quality fish and import low-quality fish, which also leads to a positive balance (Pauly and Zeller, 2016).

[19] We do not look at postnatal care since the main effect of ocean's pH while *in utero* is observed in the first month of life. Therefore, information for postnatal care would be available only for the children that survived, therefore raising issues of sample selection. See Section 4.1 for a discussion on sample selection beyond the first month of life.

This result goes in the opposite direction of other weather-related shocks that are likelier to be observed. In these cases, individuals can respond with a change in health-related behavior to compensate for the adverse effects of the shock (see, for instance, Adhvaryu et al., 2020). The absence of compensating behavior highlights that the lack of individuals' responses amplifies the consequences of several unobservable byproducts of climate change.

Finally, a direct consequence of reduced fish stocks is an increase in local prices for fish. This has both repercussions on maternal malnutrition and on the local economy, with higher prices potentially benefiting communities with higher dependency on fishing activities. However, fish prices at the geographical and temporal disaggregated levels are generally not available, especially at the scale of our analysis.[20] In Appendix B.18 we look at a rare exception: the Philippines. The Philippines, the 5$^{\text{th}}$ largest coastline in the world, and home to 9% of global coral reef, depends highly on fish, and is also extremely vulnerable to climate change (FAO, 2018). This is confirmed by counterfactual estimates presented in Section 5, showing the country as one of the most vulnerable to acidification. The Philippine Statistics Authority (2020) provides monthly retail price for fish at the province level from 1990 to nowadays. Using available prices, we estimate equation (1) by matching geographical and temporal variation in fish prices to *in utero* exposure to average retail fish prices. A 1 percent increase in fish prices while in utero leads to an increase in NMR by 0.06-0.07 per 1000 births in the coastal area, and 0.05-0.06 per 1000 births in the vulnerable coastal area. As higher prices capture the scarcity of fish, their effect on NMR is a clear indication of the link between maternal nutrition and fish consumption. More conservative estimates using mother fixed effects are supporting this conclusion.

4.3 Early-childhood development

Death harvesting generates selection among children surviving their first month of life. To understand the size of these effects on early-childhood development, we estimate the effect of ocean's pH while *in utero* on the anthropometric characteristics, and the morbidity and health status of children alive at the moment of the interview. For anthropometrics, we focus on the weight for height, weight for age, and height for age. These are defined as the percentiles in the distribution of the corresponding variable, standardized using the CDC Standard Deviation-derived Growth Reference Curves derived from the NCHS/FELS/CDC Reference Population (Croft et al., 2018). Heights and weights are not self-reported, but are measured by the DHS data collection team. For morbidity and health, we focus on whether the mother reports the child experienced fever, cough or diarrhea in the weeks previous to the interview, and on whether the child has any anemia. Anemia, defined by haemoglobin levels below 110 g/L, is attributable to low consumption or absorption in the diet, infectious diseases, or genetic factors (Balarajan et al., 2011). Information on anemia is based on blood samples drawn by DHS personnel, and was collected for children aged 6-59 months at the interview (Boyle et al., 2019).

Table 4 shows estimates of the effect of ocean's pH while *in utero* on these characteristics on the selected sample of children. Panel A restricts the sample to the coastal area, while Panel B to the vulnerable coastal area. In the coastal area, we observe no statistically significant effect on anthropo-

[20] National indices rely on trade data rather than retail prices. Fish as a contributor to the global food system has been recognized by the Food and Agriculture Organization only very recently (Tveterås et al., 2012).

metrics, morbidity and health status. In the vulnerable coastal area, children that experienced higher levels of acidity *in utero* tend to have better anthropometrics (mainly in terms of weight) and a lower probability of morbidity. Magnitudes are small, indicating that, if any, differences among children who survived are minimal.

In both coastal and vulnerable coastal area, there is no significant effect on anemia at the time of the interview, suggesting that small differences in anthropometrics and morbidity are not associated with the contemporaneous nutrition, but are rather resulting from an earlier event that is not associated with prenatal investments (see Section 4.2). This provides further evidence in favor of a death harvesting mechanism, especially among the weakest children. This result also shows that the shock experienced *in utero* can have important consequences on neonatal selection. The *missing children*–whose death is hastened by acidification– would have had a lower weight and higher probability of morbidity in absence of any external shock.

5 Aggregate impact of acidification on NMR

We produce counterfactual estimates of NMR under the assumption that children in the sample were exposed to the ocean's conditions during their gestation period at their 1975 level to measure the aggregate effects of ocean acidification. In simpler terms, we assume there is no change in pH or oxygen concentrations. Using the full sample of births within 100 km from shore, first, we predict birth-level NMR under real pH conditions using equation (3), allowing for a more flexible form in the distance from shore. We indicate the prediction by $\widehat{NMR}_{ikmtvc}$. Using estimates from equation (3), NMR is then predicted imposing *in utero* exposure to pH (and residual oxygen concentration) at the 1975 level, allowing for variation in the birth month and keeping everything else constant. We indicate the counterfactual prediction by $\widehat{NMR}^{1975}_{ikmtvc}$. NMR attributed to acidification, Δ_{ikmtvc}, is computed as the average difference between the predicted NMR and its counterfactual prediction at the cluster level. Summary statistics about counterfactual estimates are presented in Appendix C.

In all selected countries, acidification is responsible for an increase in neonatal deaths. NMR associated with acidification ranges in aggregate terms from 3.0 deaths per 1,000 births in the Democratic Republic of Congo to 11.9 deaths per 1,000 births in the Comoros Islands. By comparing country-level average NMR (restricted to selected clusters) and the average NMR attributed to acidification, we highlight considerable heterogeneity in the aggregate effect of ocean acidification. While for the Democratic Republic of Congo the NMR associated with acidification is small relative to an average NMR of 49.4 deaths per 1,000 births, for other countries that are more dependent on the ocean's resources, such as the Philippines and the Comoros Islands, acidification can account for more than half of the average NMR in the period of analysis. There is a large heterogeneity across countries and clusters, especially in those in high proximity to the shore. NMR attributed to acidification decreases in distance from the shore, with the largest level of 10 deaths per 1,000 births at the shore. These results highlight the need to identify areas that have been subjected to high pressure from acidification to improve the targeting of potential mitigation policies.

6 Conclusions

Several papers have analyzed the potential catastrophic scenarios related to ocean acidification, but, to the best of our knowledge, none have quantified its contemporary effects on humans. Small increases in the ocean's pH can significantly affect NMR for communities relying on the ocean for survival. We show that this result is closely related to the availability of nutrients derived from fish during pregnancy, which is vital to understand the effects of the ocean on human life.

We demonstrate that the magnitude of the effect is large and has already impacted the lives of children in developing countries. This evidence raises an umpteenth alarm. Communities in the poorest parts of the world continue to have low mitigation ability, and acidification is expected to worsen if no action is taken. The effect size of a 0.01 unit decrease in pH in terms of NMR is sizable. For instance, the effect of ocean acidification in the gestation period is at least as large as the effect of experiencing violent conflict (Appendix B.14). The Intergovernmental Panel on Climate Change (2013) predicts a decrease in average surface ocean pH of 0.32 units by 2100. We should be wary of large effects in terms of NMR, even in the face of an improved mitigation capacity driven by economic development.

Expected scenarios related to fish supply also stress the importance of this issue. Black et al. (2013) predicts that more than 10% of the global population could face micronutrient and fatty-acid deficiencies due to fish declines over the coming decades, especially in developing countries. Learning about the effect of worsening ocean conditions on human health allows targeting policies to communities that are more vulnerable to acidification. As climate change is a global phenomenon, policymakers need to channel resources efficiently to the communities that can benefit the most from mitigation support. For instance, the use of targeted micronutrient programs for pregnant women allows counteracting the harmful effects of climate change in areas most affected by fish supply reductions.

Lastly, this paper opens a research line to study the impact of the ocean's changing chemistry on human life and decision-making. Ocean acidification impacts commercial and subsistence fishing, with negative consequences for the communities relying on these activities as their primary sources of survival. As resources become even scarcer, understanding how communities adapt their behavior to such a change and how it impacts human development is central to fighting the consequences of climate change.

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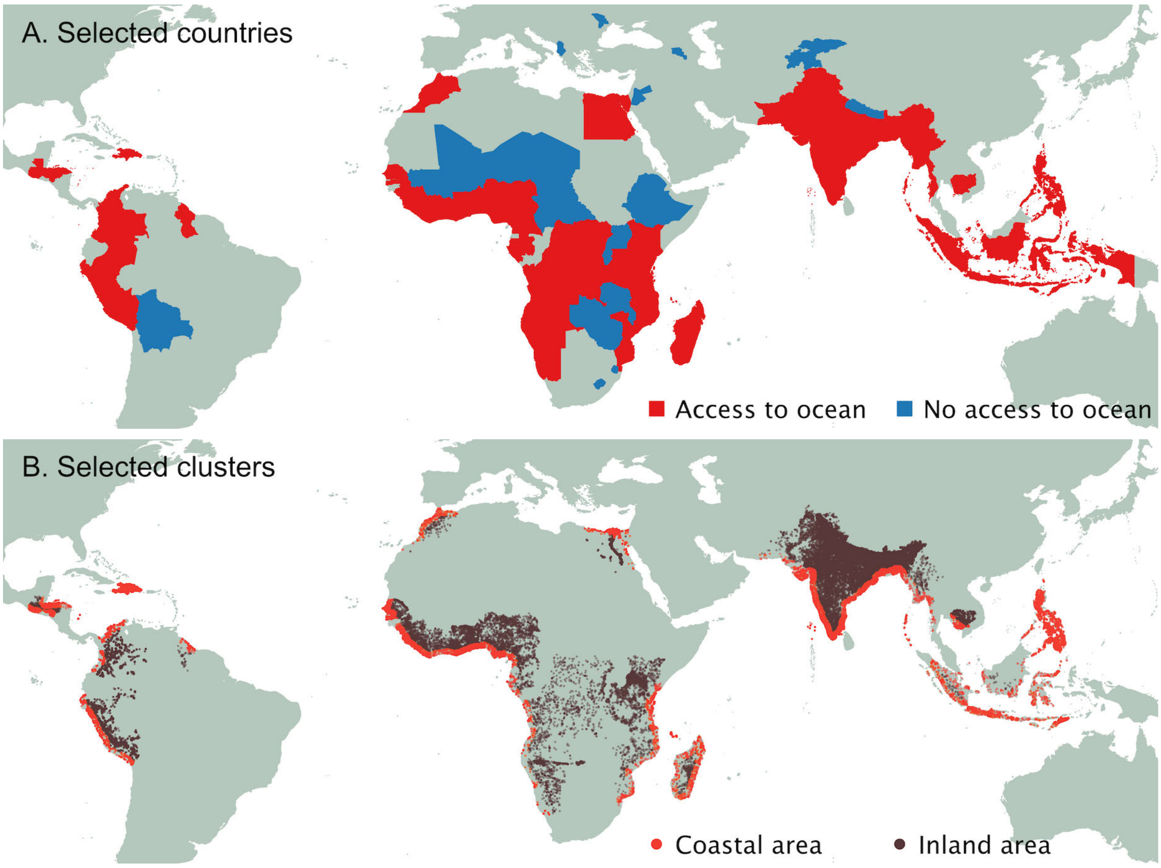
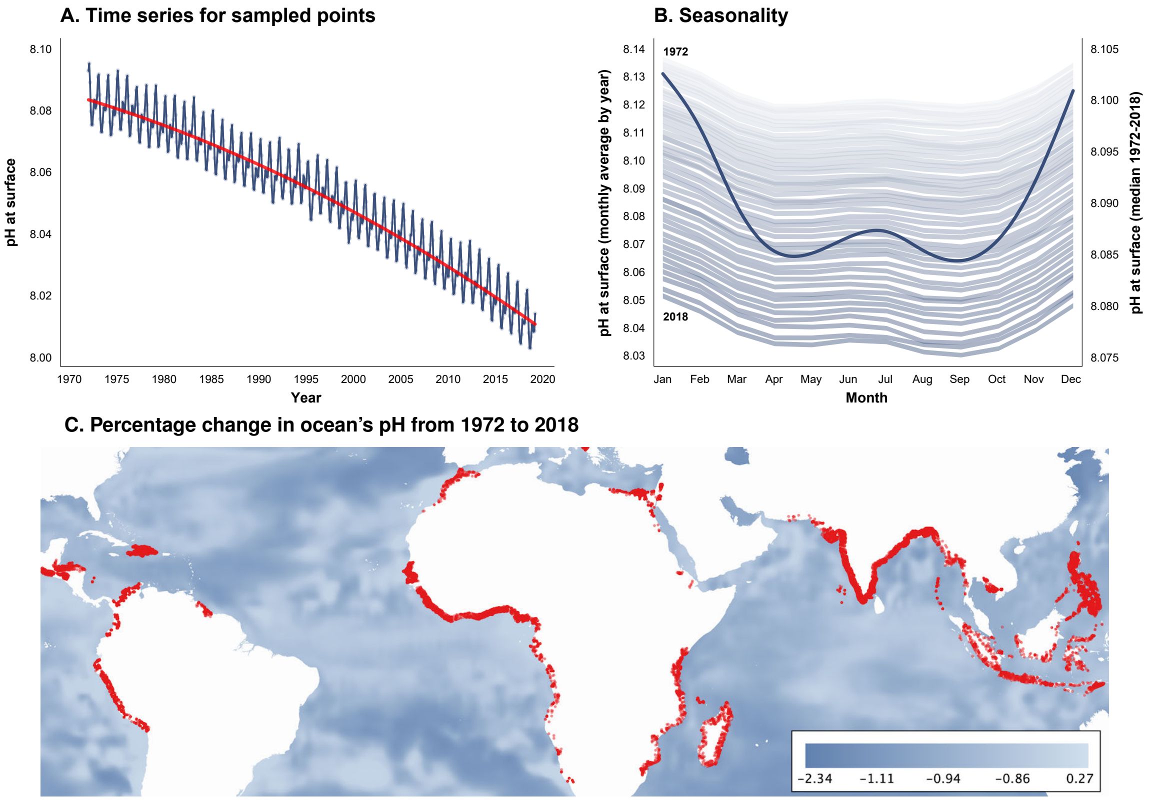
Figure 1: Study area



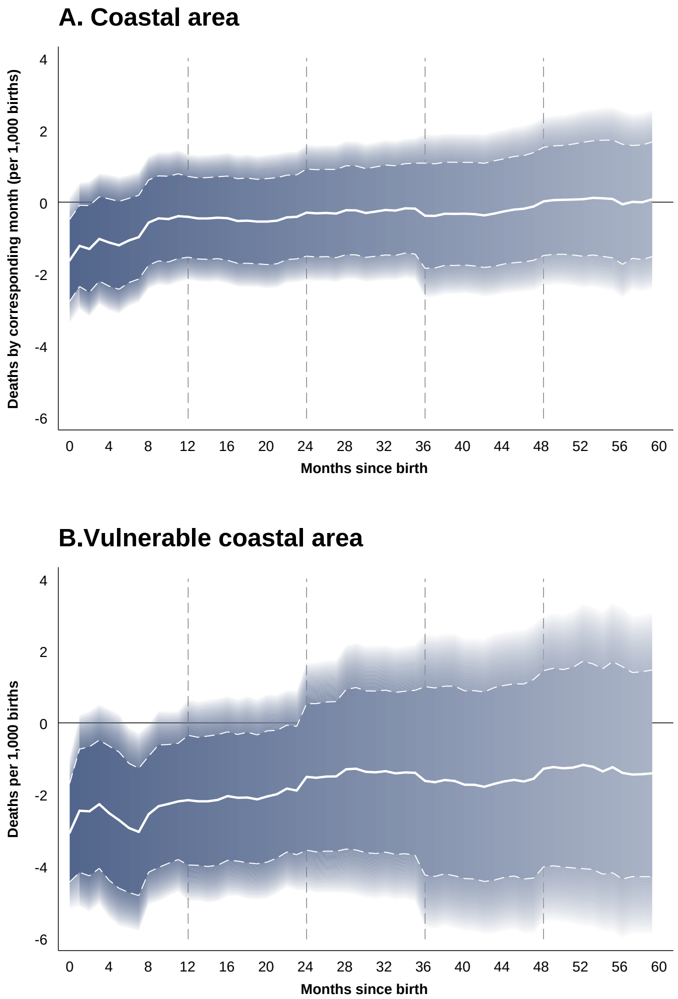
A. Selected DHS countries by their access to the ocean. Only geocoded datasets are included. **B.** For DHS coastal countries, selected clusters by their distance from the shoreline of continental landmasses and ocean islands. **Note.** The coastal area includes all clusters within 100 km from the ocean's shore. Appendix A.3 details the procedure followed to compute distance from shore. The full list of countries and surveys included in the study is reported in Appendix A.2.

Figure 2: Variation in the ocean's acidity for communities in the coastal area



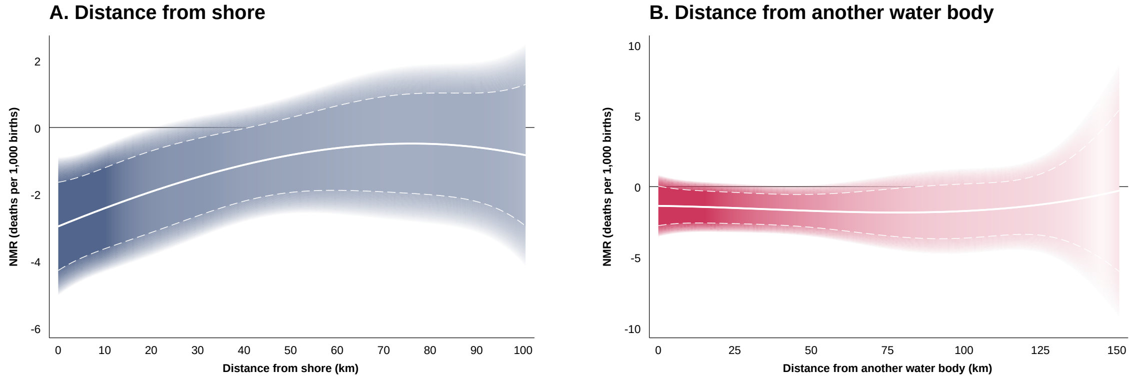
A. Average pH of the ocean in the period 1972–2018. **B.** Mean pH by month for each year (left axis) and median pH by month for the whole period (right axis). **C.** Percentage change in ocean's pH from January 1972 to January 2018 and DHS clusters selected. **Note.** Variation is restricted to cells matched to the sample's DHS clusters (highlighted in Panel C). Each cluster is assigned with a pH value using the nearest cell in the open waters. In Panel A, the solid red line shows the quadratic trend in the series. Information about pH at surface is obtained from the HadGEM2-ES model (Jones et al., 2011), provided by the ESA Pathfinders-OA project (Sabia et al., 2015).

Figure 3: *In utero* exposure and the probability of death up to year 5



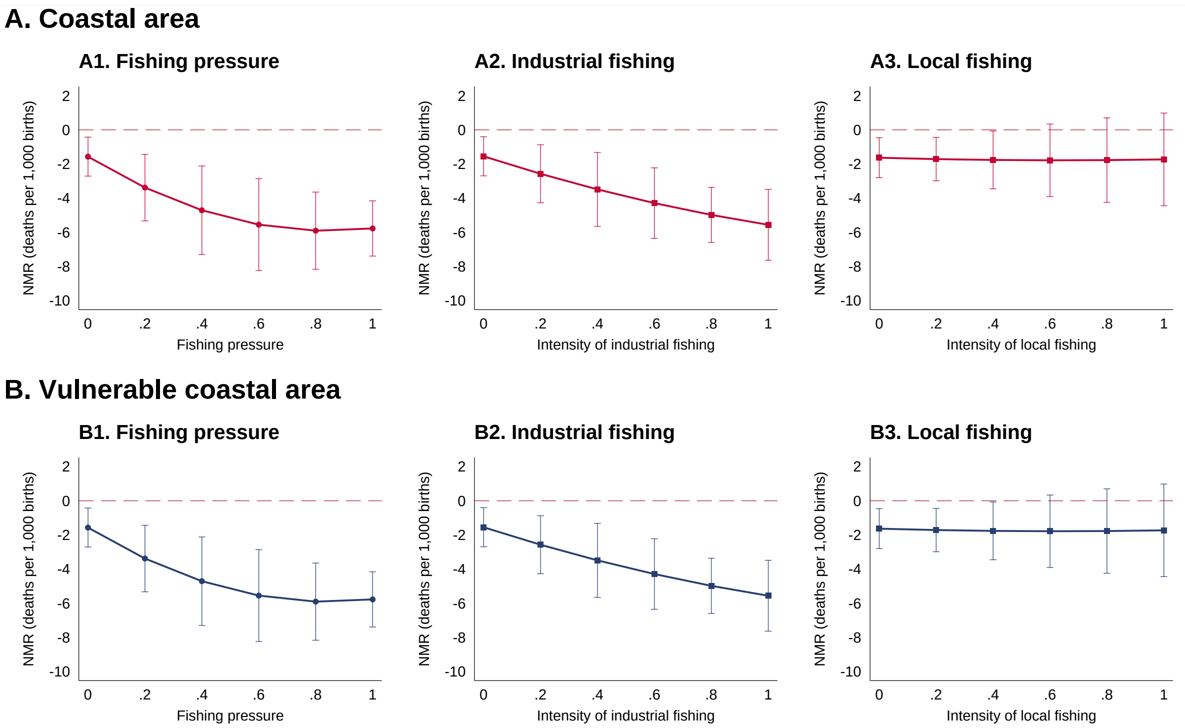
A. Marginal effects of ocean's pH while *in utero* on the probability of death by time since birth in the coastal area. **B.** Marginal effects of ocean's pH while *in utero* on the probability of death by time since birth in the vulnerable coastal area. **Note.** Estimates are based on OLS regressions (equation 3). The specification includes cluster fixed effects, birth month by birth year fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Each point corresponds to an estimate restricting the sample to children that, at the time of the interview, are born at least x months before (independently from being alive). The dependent variable is a dummy variable equal to one if the child is dead at time x from birth, and zero if the child is alive, and it is multiplied by 1,000. The estimate for month 1 corresponds to the effect of ocean's pH while *in utero* on NMR (Table 2). Standard errors are clustered at the ocean raster data point. Dotted lines represent the confidence interval at 90% of confidence. Beyond the 90%, confidence intervals are progressively shaded up to the 99% of confidence. The color intensity of the area is a function of the number of observations, with darker colors indicating larger number of observations (see Appendix A.5). Vertical lines indicate the months corresponding to year 1, 2, 3 and 4 (see discussion about heaping in Footnote 15). See Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study.

Figure 4: *In utero* exposure, NMR and distance from water bodies



A. Marginal effect of ocean's pH while *in utero* on NMR in coastal areas as a function of distance from the shore. **B**. Marginal effect of ocean's pH while *in utero* on NMR in coastal areas as a function of distance from another water body. **Note.** Estimates are based on OLS regressions (equation 3). The specification includes cluster fixed effects, birth month by birth year fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. Ocean's pH while *in utero* is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Appendix A.1 for further information on the variables. The sample is restricted to the coastal area (see Section 2.1 for a definition of coastal and vulnerable coastal areas). Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are clustered at the ocean raster data point. Dotted lines represent the confidence interval at 90%. Beyond that, confidence intervals are progressively shaded up to the 99% confidence interval. The color intensity of the area is a function of the number of observations, with darker colors indicating larger number of observations (see Appendix A.5). Appendix A.3 provides further details about the computation of distance from shore and from another water body. See Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study.

Figure 5: Heterogeneous effect of ocean's acidity while *in utero* on NMR, by fishing intensity



A. Marginal effect of ocean's pH while *in utero* on NMR in the coastal area as function of fishing intensity. **B**. Marginal effect of ocean's pH while *in utero* on NMR in the vulnerable coastal area as function of fishing intensity. **Note.** We consider heterogeneity along three dimensions: fishing pressure (Panels A1 and B1), intensity of industrial fishing (Panels A2 and B2), and local fishing (Panels A3 and B3). For ease of interpretation, these variables are normalized by dividing their value with the 99^{th} percentile of their sample distribution restricted to positive values. Fishing pressure is defined as the product between industrial and local fishing. Marginal effects are estimated using equation (1) by interacting ocean's pH while *in utero* with the corresponding variable and with its squared value, and assuming all other variables remain constant. The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix B.17 and Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study. We exclude DHS surveys for Peru as information for the intensity of local fishing is not available (see Appendix A.1).

Table 1: Descriptive statistics

	Coastal area				Vulnerable coastal area			
	Mean	Std. dev.	Median	Obs.	Mean	Std. dev.	Median	Obs.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Birth-level characteristics								
Child is alive	0.92	0.27	1.00	1589753	0.92	0.27	1.00	1066517
Child is female	0.48	0.50	0.00	1589753	0.49	0.50	0.00	1066517
Birth order	2.54	1.81	2.00	1589753	2.56	1.82	2.00	1066517
Number of twins born with the child	0.03	0.23	0.00	1589753	0.03	0.24	0.00	1066517
Years since birth	12.29	7.88	11.50	1589753	12.13	7.84	11.25	1066517
Weight for height (percentile)	37.71	30.76	30.86	229958	37.82	30.82	30.99	150652
Weight for age (percentile)	27.14	29.41	14.69	231385	28.34	29.95	16.13	151911
Height for age (percentile)	28.12	30.22	15.84	233928	29.68	30.82	17.93	153518
Morbidity	0.35	0.48	0.00	340629	0.36	0.48	0.00	230900
Child has any anemia	0.52	0.50	1.00	115877	0.54	0.50	1.00	72584
Antenatal care: any visit	0.92	0.27	1.00	265186	0.93	0.25	1.00	179760
Antenatal care: number of visits	1.78	0.71	1.95	265186	1.80	0.69	1.95	179760
Antenatal care: with health professional	0.83	0.38	1.00	270537	0.83	0.38	1.00	183451
Delivery care: in health center	0.73	0.44	1.00	269213	0.74	0.44	1.00	182433
Delivery care: with health professional	0.74	0.44	1.00	270837	0.74	0.44	1.00	183558
B. Mother-level characteristics								
Age during first birth	20.89	4.22	20.25	495254	21.02	4.29	20.42	335104
Current age	34.35	8.40	34.25	495254	34.33	8.38	34.17	335104
Years of schooling	6.46	4.72	6.00	487638	6.75	4.73	7.00	329450
Married or cohabiting	0.87	0.33	1.00	495253	0.86	0.34	1.00	335103
Working	0.58	0.49	1.00	424206	0.58	0.49	1.00	293192
C. Household-level characteristics								
Household members	5.17	2.36	5.00	435703	5.20	2.39	5.00	296857
Household head is female	0.19	0.39	0.00	435703	0.21	0.40	0.00	296857
Household head's age	44.11	12.67	43.00	435410	43.93	12.61	42.00	296645
Access to electricity	0.82	0.39	1.00	423994	0.82	0.39	1.00	290468
Wealth index	0.84	1.73	0.97	279285	0.90	1.72	1.06	191724
Distance from shore	32.24	30.17	21.95	435703	12.31	11.36	8.12	296857
Distance from another water body	45.90	98.56	18.39	435703	59.59	119.10	23.15	296857
Altitude	183.10	389.18	38.00	435703	79.71	179.99	24.00	296857
Temperature (° C)	26.28	2.94	27.12	435654	26.60	2.69	27.15	296808
Precipitations (mm)	1574.52	673.03	1553.92	435703	1571.81	647.49	1546.41	296857
Intensity of local fishing	3118.30	6735.04	590.00	435703	2865.75	6495.67	590.00	296857
Intensity of industrial fishing	13.19	42.93	0.00	435703	16.18	48.20	0.00	296857
D. Early-childhood mortality rates								
NMR	27.67	164.03	0.00	1586202	27.00	162.09	0.00	1064077
PMR	23.79	152.41	0.00	1472453	23.51	151.52	0.00	988660
CMR	21.88	146.30	0.00	1143667	21.55	145.20	0.00	767413
IMR	50.94	219.88	0.00	1519137	49.96	217.87	0.00	1018915
U5MR	74.69	262.88	0.00	1219606	73.33	260.68	0.00	816579

Note. Descriptive statistics for the correspondent sample: mean, standard deviation, median and number of observations. In columns (1)–(4), the sample is restricted to clusters in the coastal area. In columns (5)–(8), the sample is restricted to clusters in the vulnerable coastal area. For birth-level characteristics, the sample includes all births from 1972 to 2018. Variables for antenatal and delivery care are restricted to the last birth for cross-survey comparability (Boyle et al., 2019). For early-childhood mortality rates, Neonatal Mortality Rate (NMR), Post-neonatal Mortality Rate (PMR), Child Mortality Rate (CMR), Infant Mortality Rate (IMR), and Under-5 Mortality Rate (U5MR) are defined in Appendix A.1. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Appendix A.3 provides further information about the computation of the distance from the shore. See Section 2.1 for a definition of coastal and vulnerable coastal areas. Years since birth is measured at the time of the interview and is independent from the child being alive. See Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study.

Table 2: The effect of *In utero* ocean's acidity on NMR

Dependent variable:	**NMR (deaths per 1,000 births)**					
Sub-sample:		**Coastal area**			**Vulnerable coastal area**	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Ocean's pH (*in utero*)	-1.613**	-2.332***	-1.885*	-3.041***	-3.441***	-2.790**
	(0.690)	(0.780)	(0.988)	(0.832)	(1.137)	(1.350)
Observations	1566855	1566852	1566837	1049870	1049870	1049851
DHS clusters	31355	31355	31355	21661	21661	21661
Panel B. Mother fixed effects						
Ocean's pH (*in utero*)	-2.202**	-2.576***	-2.291*	-3.671***	-3.342**	-2.651*
	(0.853)	(0.966)	(1.236)	(0.993)	(1.384)	(1.606)
Observations	1474407	1474403	1474383	986593	986593	986567
DHS clusters	31349	31349	31349	21661	21661	21661
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. In Panel A, all specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), and time-varying controls. In Panel B, mother fixed effects are added. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

Table 3: Antenatal and delivery care

	ANTENATAL CARE			**DELIVERY CARE**	
Dependent variables:	**Any visit**	**Number of visits**	**With health professional**	**In health center**	**With health professional**
	(1)	(2)	(3)	(4)	(5)
Panel A. Coastal area					
Ocean's pH (*in utero*)	0.002	-0.001	0.003	-0.004	0.001
	(0.003)	(0.009)	(0.004)	(0.003)	(0.003)
Observations	260056	260056	265418	264108	265717
DHS clusters	29719	29719	29824	29815	29825
Panel B. Vulnerable coastal area					
Ocean's pH (*in utero*)	0.003	-0.007	0.004	-0.003	0.001
	(0.003)	(0.011)	(0.004)	(0.004)	(0.003)
Observations	175989	175989	179688	178679	179793
DHS clusters	20533	20533	20608	20600	20608

Note. Estimates based on equation 1. For cross-survey comparability, the sample is restricted to the last birth, independently from the child being alive (Boyle et al., 2019). All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variables are reported in the column's header. *Any visit* is an indicator variable equal to one if the mother attended any visit during pregnancy for antenatal care, and zero otherwise. *Number of antenatal care visits* is the number of visits attended by the mother during pregnancy for antenatal care (reported in logarithms, adding one unit to allow for zero values). *With health professional* is an indicator variable equal to one if the mother was attended by a health professional (doctor, nurse or other health professional) during pregnancy, and zero otherwise. *In health center* is an indicator variable equal to one if the mother gave birth in a health center, and zero otherwise. *With health professional* is an indicator variable equal to one if delivery was attended by a health professional (doctor, nurse or other health professional), and zero otherwise. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

Table 4: Developmental outcomes among live children

Dependent variables:	ANTHROPOMETRICS Weight for height	Weight for age	Height for age	MORBIDITY AND HEALTH Any symptom	Any anemia
	(1)	(2)	(3)	(4)	(5)
Panel A. Coastal area					
Ocean's pH (*in utero*)	-0.654	-0.342	0.075	-0.002	0.002
	(0.401)	(0.288)	(0.311)	(0.004)	(0.006)
Observations	226097	227499	230037	334823	113088
DHS clusters	24573	24655	24957	29743	15741
Panel B. Vulnerable coastal area					
Ocean's pH (*in utero*)	-0.888**	-0.606**	-0.441	0.009*	-0.002
	(0.446)	(0.289)	(0.330)	(0.005)	(0.010)
Observations	148024	149269	150871	226628	70715
DHS clusters	16373	16439	16643	20588	10319

Note. Estimates based on equation 1. Panel A restricts the sample to coastal areas, while Panel B restricts the sample to the vulnerable coastal area. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variables are reported in the column's header. For anthropometrics, *weight for height*, *weight for age*, and *height for age* are the percentiles in the distribution of the corresponding variable, standardized using the CDC Standard Deviation-derived Growth Reference Curves derived from the NCHS/FELS/CDC Reference Population (Croft et al., 2018). For morbidity and health, *any symptom* is an indicator variable equal to one if the child has experienced fever, cough or diarrhea in the weeks previous to the interview, and zero otherwise. *Any anemia* is an indicator variable equal to one if the child has severe, moderate or mild anemia (haemoglobin levels below 110 g/L), and zero otherwise. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study.

ONLINE APPENDIX

The Ocean and Early-Childhood Mortality and Development

Alex Armand, Ivan Kim Taveras

This Supplementary Material appendix provides greater detail on data sources, variables and methods used in the paper (Appendix section A), summarizes findings from additional analyses (Appendix section B), and discusses conterfactual estimates (Appendix section C).

A Data and methodological procedures

A.1 Variables and data sources

The following table presents a description of the variables used in the paper.

Variable (Source)	Description
Altitude (DHS)	Cluster's elevation in meters from the SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) for the specified coordinate location. Elevations are regularly spaced at 30-arc seconds or approximately 1 km (http://dds.cr.usgs.gov/srtm/version1/SRTM30). The variable is available for the clusters with geocoding in the Demographic and Health Surveys (ICF, 2019).
Agricultural land (PRIO-GRID)	It measures the percentage area of a cell in 1970 that is used for agricultural purposes as defined by the ISAM-HYDE historical landuse dataset (Meiyappan and Jain, 2012). The data are downloaded from the PRIO-GRID version 2.0 database (Tollefsen et al., 2012). It is a vector grid network with a resolution of 0.5° x 0.5° covering all terrestrial areas of the world that is spatially merged to DHS clusters using their geolocation.
Basemaps (Esri)	Basemaps were created using ArcGIS® software by Esri®. Basemaps are used in line with the Esri Master License Agreement, specifically for the inclusion of screen captures in academic publications. We use the *World Topographic Map* (sources: Esri, HERE, Garmin, Intermap, INCREMENT P, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), ®OpenStreetMap contributors, GIS User Community).
Child mortality (DHS)	Child mortality is built from the Demographic and Health Surveys (DHS) Program (ICF, 2019). The project is funded by the United States Agency for International Development (USAID) and implemented by ICF International. Other contributors include UNICEF, UNFPA, WHO, and UNAIDS. DHS surveys have been collected in several countries in Africa, South America and Asia since the mid-1980s. The data are available upon request and approval of the research project. *Neonatal mortality rate (NMR)*: this variable is built using an indicator variable equal to 1 if the child died before their first month of life, and 0 otherwise. The variable is set to missing if the date of the interview is happening less than 1 month after the date of birth. To compute mortality rates, this indicator is multiplied by 1,000. Note that the DHS Program reports two ages of death. The first is self-reported, while the second gives a calculated age from reported information. When dates of birth are not disclosed, these are imputed by the DHS Program (Croft et al., 2018). To compute NMR, we also use special cases of self-reported age of death (198 and 199, which indicate that age at death was reported as a number of days and that the exact number is unknown). In the sample, these are 67 cases, which we consider as neonatal death. Results are robust to dropping these special cases.

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Variable (Source)	Description
	Post-neonatal mortality rate (PMR): this variable is built using an indicator variable equal to 1 if the child died between the ages of 1–11 months, and 0 otherwise. The variable is set to missing if the date of the interview is happening less than 11 months after the date of birth. To compute mortality rates, this indicator is multiplied by 1,000. *Child mortality rate (CMR)*: this variable is built using an indicator variable equal to 1 if the child died between the ages of 12–59 months, and 0 otherwise. The variable is set to missing if the date of the interview is happening less than 59 months after the date of birth. To compute mortality rates, this indicator is multiplied by 1,000. *Infant mortality rate (IMR)*: this variable is built using an indicator variable equal to 1 if the child died between the ages of 0–11 months, and 0 otherwise. The variable is set to missing if the date of the interview is happening less than 11 months after the date of birth. To compute mortality rates, this indicator is multiplied by 1,000. *Under-5 mortality rate (U5MR)*: this variable is built using an indicator variable equal to 1 if the child died between the ages of 0–59 months, and 0 otherwise. The variable is set to missing if the date of the interview is happening less than 59 months after the date of birth. To compute mortality rates, this indicator is multiplied by 1,000.
Chlorophyll concentration (GlobColour)	Chlorophyll concentration in coastal waters is measured in mg/m^3. We use data from the GlobColour project (d'Andon et al., 2009), which provides monthly global rasters for the period 1997–2018 at the 25-meter resolution by merging satellite imaging from five different sources made available by the European Space Agency and NASA (SeaWIFS, MERIS, MODIS AQUA, VIIRS, and OLCI-A). We use the version with AWV weights. GlobColour data are freely available for research and educational purposes. GlobColour data (http://globcolour.info) used in this study have been developed, validated, and distributed by ACRI-ST, France.
Conflict intensity (UCDP)	Number of violent events (and fatalities) in each cell for a specific year. The data are obtained from the Uppsala Conflict Data Program (UCDP) (Sundberg and Melander, 2013).
Distance from shorelines (author's calculations)	Distance (in straight line) between the DHS cluster and the closest shoreline. See *Water bodies* in this table for definitions of shorelines. See Appendix A.3 for details about the procedure. Concerning distance from the ocean's shore, we highlight the following definitions: • *Coastal area*: all clusters located within 100 km from the ocean's shore. • *Vulnerable coastal area*: all clusters located within 40 km from the ocean's shore. • *Less vulnerable coastal area*: all clusters located 40-100 km from the ocean's shore.
Fish dependency (FAO)	Average fish protein supply as proportion of all animal protein supply. The data are obtained from the FAOSTAT database (FAO, 2019). In the analysis of heterogeneity of the effect of ocean's acidity, we opt for a time-invariant version, which averages fish dependency in the period 1960–2013.
Fish prices in the Philippines (Philippine Statistics Authority)	Monthly retail price for fish at the province level from 1990 to nowadays. The series is provided by the Philippine Statistics Authority (2020) provides. See Appendix B.18 for further details.
Gross Cell Product (PRIO-GRID)	Indicates the gross cell product, measured in USD using purchasing-power-parity. Information is based on the G-Econ dataset v4.0 last modified May 2011 (Nordhaus, 2006). This variable is only available for 1990, 1995, 2000, and 2005. Data are downloaded from the PRIO-GRID version 2.0 database (Tollefsen et al., 2012). It is a vector grid network with a resolution of 0.5° x 0.5° covering all terrestrial areas of the world that is spatially merged to DHS clusters using their geolocation.
Household wealth (DHS)	The DHS records information on asset ownership. To create a wealth index that could be compared across surveys, we choose assets that are asked across all surveys: water source, sanitation facilities, type of flooring, electricity, the number of rooms per person living in the house, and possession of radio, television, phone (landline or cellphone), motorcycle and car. In the dataset, 85% had information on all of these assets. The wealth index is created using a principal components analysis normalizing across the entire dataset rather than by survey. Further details are available in Bendavid (2014); Heft-Neal et al. (2018).

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Variable (Source)	Description
Intensity of industrial fishing (Global Fishing Watch)	Total number of hours from industrial fishing activities in the cell. Information is built using the Global Fishing Watch dataset (Kroodsma et al., 2018). The dataset makes use of 22 billion automatic identification system messages and tracking of more than 70,000 industrial fishing vessels from 2012 to 2016 to create time-varying geolocated areas of industrial fishing. Since variation is available only for the period 2012–2016, we first compute total fishing hours in a global grid at 1° x 1° resolution and then average each cell over the available period. This measure can be interpreted as the average intensity of fishing at a highly disaggregated level. Panel B in Figure B13 shows an example of geographical distribution of the variable.
Intensity of local fishing (author's calculations)	We use Automatic Boat Identification System for VIIRS Low Light Imaging Data (Elvidge et al., 2015) to identify detections. The algorithm detects boats using nightlight captured from satellite imaging (Visible Infrared Imaging Radiometer Suite (VIIRS) day/night band). Using individual daily detections (which include geolocation), we build a 1° x 1° global grid with the sum of detections for the period 2017–2019. We select as boats only strong detections (quality flag rating equal to 1). To avoid false positives, data are not available over the South Atlantic Anomaly. The data are therefore missing for the DHS surveys in Peru. Panel A in Figure B13 shows an example of geographical distribution of the variable.
Nightlight (PRIO-GRID)	It measures average nighttime light emission from the DMSP-OLS Nighttime Lights Time Series Version 4 calibrated to account for inter-satellite differences and inter-annual sensor decay using calibration values (Elvidge et al., 2014). Values are standardized to be between 0 and 1, where 1 is the highest observed value in the time-series, and 0 is the lowest. The times-series are available from 1992–2012. The data are downloaded from the PRIO-GRID version 2.0 database (Tollefsen et al., 2012). It is a vector grid network with a resolution of 0.5° x 0.5° covering all terrestrial areas of the world that is spatially merged to DHS clusters using their geolocation.
Ocean chemistry (ESA Pathfinders-OA)	Data about ocean's chemistry are obtained from the Hadley Global Environment Model 2 - Earth System, also known as HadGEM2-ES model (Jones et al., 2011), provided by the European Space Agency (ESA) Pathfinders-OA project (Sabia et al., 2015). The model makes use of an ecosystem model (the Diat-HadOCC model). The data are provided as monthly global raster data at the 1° x 1° resolution for a series of chemical features of the ocean in open waters. We use two variables: pH at surface and dissolved O_2 concentration. pH at surface is multiplied by 100, so that coefficients relate to an increase of 0.01 in the logarithmic scale. Dissolved O_2 concentration is multiplied by 1,000, so that coefficients relate to an increase of 0.001 μmol/kg.
Population (Landscan)	Ambient population (average over 24 hours) distribution at approximately 1 km (30" x 30") spatial resolution. Population distributions are developed using the best available demographic (census) and geographic data, remote sensing imagery analysis techniques within a multivariate dasymetric modeling framework to disaggregate census counts within an administrative boundary. Version used is the LandScan Global 2017 database (Bright et al., 2018).
Population (PRIO-GRID)	It measures population size as the number of persons within the PRIO-GRID grid cell. Information is obtained from the Gridded Population of the World version 3 (CIESIN-CIAT, 2005). Population estimates are available for 1990, 1995, 2000, and 2005. The original pixel value is number of persons. The data are downloaded from the PRIO-GRID version 2.0 database (Tollefsen et al., 2012), a vector grid network with a resolution of 0.5° x 0.5° covering all terrestrial areas of the world, and spatially merged to DHS clusters using their geolocation.
Precipitation (PRIO-GRID)	Yearly total amount of precipitation (in millimeters) in the cell, based on monthly meteorological statistics from the GPCP v.2.2 Combined Precipitation Data Set (Huffman et al., 2012). This variable is available for the years 1979–2014. The data are downloaded from the PRIO-GRID version 2.0 database (Tollefsen et al., 2012), a vector grid network with a resolution of 0.5° x 0.5° covering all terrestrial areas of the world, and spatially merged to DHS clusters using their geolocation.

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Variable (Source)	Description
Temperature (PRIO-GRID)	Yearly mean temperature (in ° C) in the cell, based on monthly meteorological statistics from GHCN/CAMS (Fan and van den Dool, 2008). Data are available for the period 1948–2014. To ensure comparability of the measure across cells, we use standardized temperature deviations, by restricting the standardization to the year level. The data are downloaded from the PRIO-GRID version 2.0 database (Tollefsen et al., 2012), a vector grid network with a resolution of 0.5° x 0.5° covering all terrestrial areas of the world, and spatially merged to DHS clusters using their geolocation.
Trade balance of fish products (FAO)	Sum of exports and re-exports of fish products, minus the sum of imports of fish products. The data are obtained from the FAOSTAT database (FAO, 2019). In the analysis of heterogeneity of the effect of the ocean's acidity, we opt for a time-invariant version, which averages the trade balance in the period 1976-2017.
Water bodies (GSHHG)	Water bodies are identified from the Global Self-consistent Hierarchical High-resolution Geography (GSHHG) database (Wessel and Smith, 1996), provided by the National Oceanic and Atmospheric Administration (NOAA). The data are provided as full-resolution shapefiles derived from shorelines of water bodies. We use the following two bodies. For the *ocean's shoreline*, we consider continental land masses and ocean islands, except Antarctica. These bodies are defined as level 1 in the dataset. For *other water bodies*, we merge into a single shapefile levels 2, 3 and 4 of the dataset. These include lakes, islands in lakes, and ponds in islands within lakes and all levels included in the river database (double-lined rivers or river-lakes, permanent major rivers, additional major rivers, additional rivers, minor rivers, intermittent rivers, major canals, minor canals and irrigation canals).

Note. For time-varying variables, missing values are linearly interpolated.

A.2 Selection of DHS surveys

The Demographic and Health Surveys (DHS) are nationally representative surveys conducted in developing countries. Surveying has a two-stage design. First, clusters are selected from a list of enumeration areas from population censuses. Second, households are randomly selected within each cluster. Finally, women aged 15–49 years are selected from those households for answering an in-depth questionnaire. Table A2 presents the countries in the DHS global dataset that are included in the analysis. The second column indicates the survey rounds available. The last two columns report information about the birth years matched to data about the ocean's chemistry and the total number of births across all surveys. Figure 1 presents a graphical representation of the countries available in the DHS program and the countries selected for the study.

Table A2: Sampled countries

Country	DHS surveys available	Birth years matched	Number of births
Angola	2015	1978-2016	42002
Bangladesh	2000, 2004, 2007, 2011, 2014	1972-2014	183734
Benin	1996, 2001, 2012	1972-2012	84351
Cambodia	2000, 2005, 2010, 2014	1972-2014	150872
Cameroon	1991, 2004, 2011	1972-2011	81516
Colombia	2010	1973-2010	89317
Comoros	2012	1975-2012	10957
DR Congo	2007, 2013	1972-2014	83313
Côte d'Ivoire	1994, 1998, 2012	1972-2012	57785
Dominican Republic	2007, 2013	1972-2013	76051
Egypt	1992, 1995, 2000, 2005, 2008, 2014	1972-2014	303549
Gabon	2012	1974-2012	22908
Ghana	1993, 1998, 2003, 2008, 2014	1972-2014	74319
Guatemala	2015	1978-2015	54993
Guinea	1999, 2005, 2012, 2018	1972-2018	104910
Guyana	2009	1974-2009	10538
Haiti	2000, 2006, 2012, 2016	1972-2017	106348
Honduras	2011	1974-2012	48315
India	2015	1975-2016	1308794
Indonesia	2003	1972-2003	75228
Kenya	2003, 2008, 2014	1972-2014	127484
Liberia	2007, 2013	1972-2013	52464
Madagascar	1997, 2008	1972-2009	68446
Morocco	2003	1972-2004	32256
Mozambique	2011	1974-2011	37946
Myanmar	2016	1980-2016	22989
Namibia	2000, 2006, 2013	1972-2013	51966
Nigeria	1990, 2003, 2008, 2013, 2018	1972-2018	394614
Pakistan	2006	1972-2007	38542
Peru	2000, 2004, 2005, 2006, 2007, 2008, 2009	1972-2009	182648
Philippines	2003, 2008, 2017	1972-2017	104246
Senegal	1993, 1997, 2005, 2010, 2012, 2014, 2015, 2016	1972-2016	216204
Sierra Leone	2008, 2013	1972-2013	68370
Tanzania	1999, 2010, 2015	1972-2016	77212
Timor-Leste	2009, 2016	1974-2016	64620
Togo	1998, 2013	1972-2014	51612

Note. From all DHS surveys available on May 2020, we include only surveys for countries with direct access to the ocean and surveys with available geocoding of clusters. Notice that among all countries surveyed by the DHS program to date and without direct access to the ocean, only Ethiopia has clusters within 100 km from the shore (26 clusters in total). The number of births is computed as the total number of observations in the birth histories (*DHS birth recode*). Figure 1 provides a spatial representation of countries and clusters selected.

The availability of multiple surveys for some countries can lead to issues related to survey selection. To check robustness of the results to this potential issue, Table A3 presents estimates of our

benchmark specification–(1)–assuming different rules for the selection of surveys. Column (1) reports the approach used in all specifications which is including all available surveys and re-weighting observations to correct for oversampling of certain countries. In this case, each observation is weighted by the product of two weights. First, the sampling weight provided by the DHS Program in order to have a nationally representative sample at the country-survey level. Second, a re-weighting factor for countries that have been surveyed multiple times. This is to avoid oversampling of births for these countries. The re-weighting factor is the ratio between the sum of the DHS Program's sampling weights at the country-survey level and the sum of the DHS Program's sampling weights at the country level. As an example, consider birth i in country j with sampling weight $\omega_{i,j}$. Country j is surveyed twice and birth i is sampled in the first survey. For the first survey, the sum of sampling weights is equal to Ω_1, while for the second survey the sum is equal to Ω_2. The resulting weight for birth i is equal to $\omega_{i,j} \times \frac{\Omega_1}{\Omega_1+\Omega_2}$. If a country is surveyed only once, the weight corresponds to the DHS Program's sampling weight.

Columns (2)–(4) show estimates when only one survey per country is selected. "*Latest*" indicates that only the latest survey is selected, "*Largest*" indicates that the survey with the largest number of observations is selected, "*Random*" indicates that one random survey is selected among the available ones. Estimates are highly comparable across different methodologies for selecting the surveys.

Table A3: Robustness to selection of surveys

Dependent variable:	**NMR (deaths per 1,000 births)**			
DHS survey selected:	All	Latest	Largest	Random
	(1)	(2)	(3)	(4)
Ocean's pH (*in utero*)	-1.580**	-1.447**	-1.567**	-1.951***
	(0.705)	(0.733)	(0.694)	(0.727)
Observations	1566855	787889	849344	744650
DHS clusters	31355	17378	18065	16473

Note. Estimates based on equation 1. All specifications include cluster fixed effects, birth year by birth month indicator variables and demographic controls, controls for local trend (country x birth year FE) and for local seasonality (country x birth month FE). The full list of controls is presented in Section 3. In column (1), observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. "*Latest*" indicates that only the latest survey is selected, "*Largest*" indicates that the survey with the largest number of observations is selected, "*Random*" indicates that one random survey is selected among the available ones. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

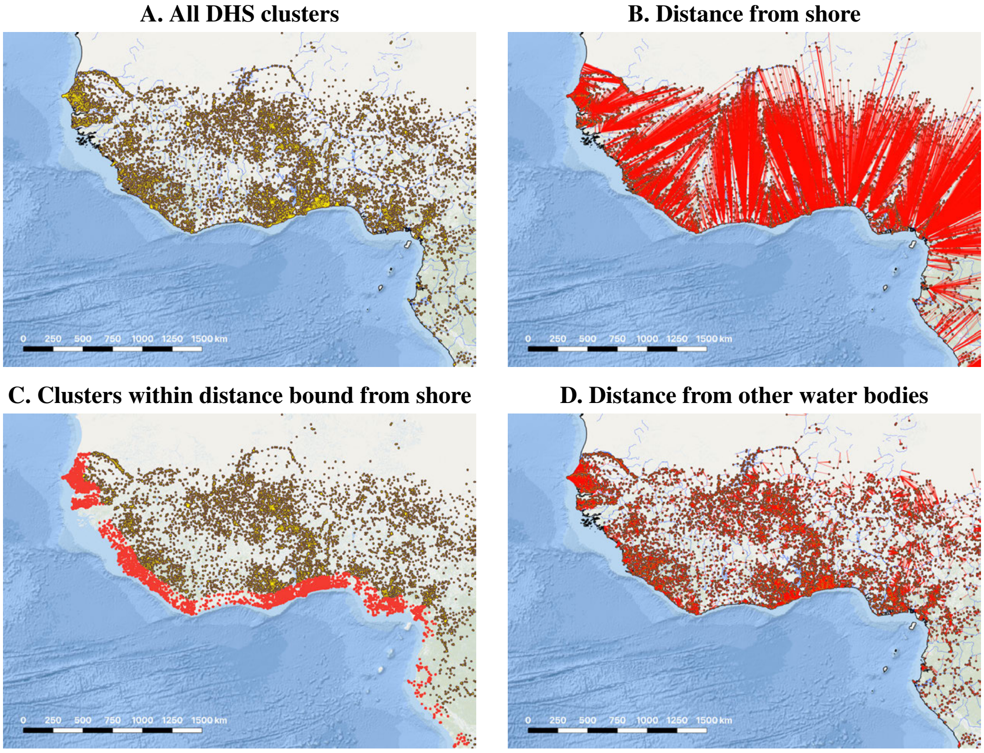
A.3 Computation of distances from ocean and other water bodies

The computation of distances are based on the geocoding on DHS clusters. Coordinates are collected in the field during the survey sampling listing process using GPS receivers. GPS readings for most clusters are accurate to less than 15 meters. To ensure that respondent confidentiality is maintained, the GPS coordinates for all surveys are randomly displaced within a maximum of 2 km for urban clusters, and 10 km for rural clusters. Main findings are robust to measurement error in the geolocation of DHS clusters (Appendix B.3).

For each household, distance is computed as the minimum straight distance from the DHS cluster to the coast and closest alternative water source. This procedure is performed using the *v.distance* function in GRASS. To compute distances to other water bodies, we merged into a single shapefile

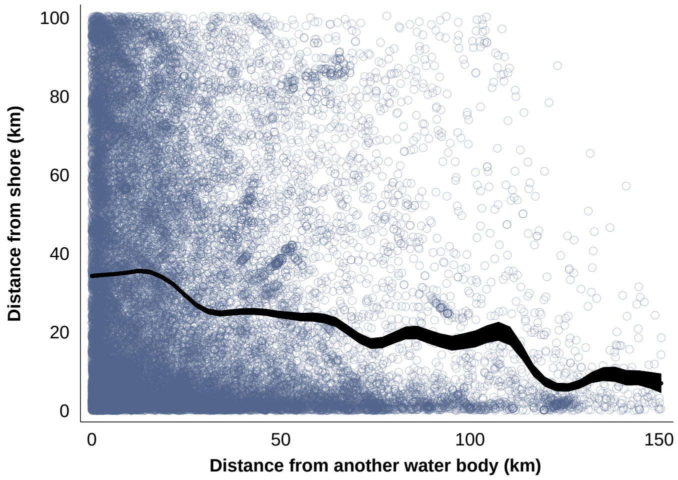
levels 2, 3 and 4 (lakes, islands in lakes, and ponds in islands within lakes) obtained from the shapefiles containing all water bodies considered by the river database. Figure A1 presents an example of the procedure for West Africa. Figure A2 shows the relationship between distance from shore and from other water bodies for the DHS clusters selected in the study. Table A4 presents descriptive statistics for households living within 100 km from the shore and households living beyond 100 km.

Figure A1: Distance to ocean and other water sources: an example for West Africa



A. Geolocation of DHS clusters in the West African sample. **B.** Closest points from each DHS cluster to the ocean. **C.** DHS clusters that are within 100 km from the ocean (in red). **D.** Closest point from each DHS cluster to another water body other than the ocean (in red). **Note.** Lines represent straight distance from a DHS cluster to the closest point on the coast's shoreline or on the shoreline of another water body. Shapefiles for the coastline and other water bodies are obtained from the Global Self-consistent Hierarchical High-resolution Geography database (Wessel and Smith, 1996). Basemap source: Esri (see Appendix A.1 for details and attributions).

Figure A2: Relationship between distance from shore and from other water bodies



Note. Each circle represents a DHS cluster. The darker area presents the 95% confidence interval of the smoothed relationship between distances estimated using a kernel-weighted local polynomial regression of distance from shore on distance from another water body. Distance from another water body is restricted to a maximum value of 150 km. Appendix A.3 provides further details about the computation of distance from shore and from another water body.

Table A4: Descriptive statistics for coastal and inland areas

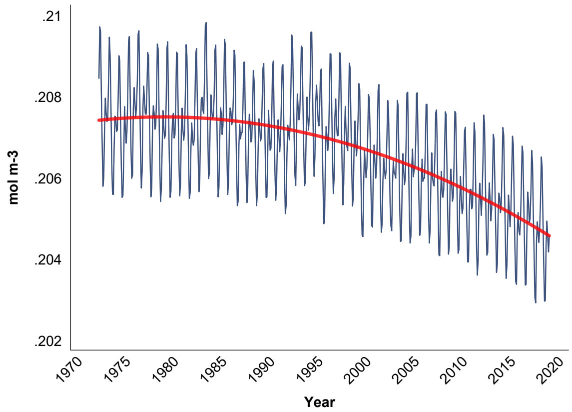
	Coastal area		**Inland area**		**Difference**	
	Mean	Std. dev.	Mean	Std. dev.	P-value	Obs.
	(1)	(2)	(3)	(4)	(5)	(6)
Birth-level characteristics						
Child is alive	0.92	0.27	0.91	0.29	0.00	4561408
Child is female	0.48	0.50	0.48	0.50	0.00	4561408
Birth order	2.54	1.81	2.66	1.84	0.00	4561408
Number of twins born with the child	0.03	0.23	0.03	0.22	0.00	4561408
Years since birth	12.29	7.88	12.09	7.77	0.00	4561408
Weight for height (percentile)	37.71	30.76	29.09	28.12	0.00	713286
Weight for age (percentile)	27.14	29.41	17.48	24.29	0.00	714920
Height for age (percentile)	28.12	30.22	22.04	28.41	0.00	719716
Morbidity	0.35	0.48	0.30	0.46	0.00	969379
Child has any anemia	0.52	0.50	0.60	0.49	0.00	415513
Antenatal care: any visit	0.92	0.27	0.82	0.39	0.00	737581
Antenatal care: number of visits	1.78	0.71	1.36	0.79	0.00	737581
Antenatal care: with health professional	0.83	0.38	0.76	0.43	0.00	749773
Delivery care: in health center	0.73	0.44	0.68	0.47	0.00	747077
Delivery care: with health professional	0.74	0.44	0.70	0.46	0.00	750566
Mother-level characteristics						
Age during first birth	20.89	4.22	20.46	3.82	0.00	1385487
Current age	34.35	8.40	33.80	8.39	0.00	1385487
Years of schooling	6.46	4.72	4.94	4.79	0.00	1367468
Married or cohabiting	0.87	0.33	0.91	0.29	0.00	1385483
Working	0.58	0.49	0.60	0.49	0.00	934706
Household-level characteristics						
Household members	5.17	2.36	5.55	2.51	0.00	1215965
Household head is female	0.19	0.39	0.16	0.37	0.00	1215964
Household head's age	44.11	12.67	44.31	12.96	0.00	1215229
Access to electricity	0.82	0.39	0.74	0.44	0.00	1196311
Wealth index	0.84	1.73	0.06	1.84	0.00	898695
Distance from shore	32.24	30.17	456.54	289.11	0.00	1215965
Distance from another water body	45.90	98.56	24.76	23.85	0.00	1215965
Altitude	183.10	389.18	480.00	588.46	0.00	1215960
Temperature (° C)	26.28	2.94	24.98	3.56	0.00	1215916
Precipitations (mm)	1574.52	673.03	1295.86	671.52	0.00	1215965
Intensity of local fishing	3118.30	6735.04	2792.47	5264.32	0.00	1215965
Intensity of industrial fishing	13.19	42.93	9.91	29.10	0.00	1215965
Mortality rates						
NMR	27.67	164.03	37.29	189.46	0.00	4551309
PMR	23.79	152.41	24.25	153.84	0.05	4206135
CMR	21.88	146.30	27.72	164.18	0.00	3270764
IMR	50.94	219.88	60.81	238.99	0.00	4361546
U5MR	74.69	262.88	89.62	285.63	0.00	3510515

Note. Descriptive statistics by proximity to the ocean for all DHS clusters in selected countries with access to ocean. Coastal area includes all clusters within 100 km from the ocean's shore (see Section 2.1). Inland area includes all clusters that are farther away than 100 km from the ocean's shore. Means are reported in columns (1) and (3), standard deviations are reported in columns (2) and (4). Column (5) presents the difference and significance of t tests on the equality of means assuming unequal variances. Observations are re-weighted to correct for oversampling of countries that have been surveyed multiple times (see Appendix A.2). Years since birth is measured at the time of the interview and is independent from the child being alive. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

A.4 Residual variation in dissolved oxygen concentration

The process of changing ocean biochemistry is not uniquely characterized by pH. As such, it is possible that variation in pH is also capturing variation in other variables determining ocean chemistry. We focus on the role of dissolved O_2 concentration at the ocean's surface. Figure A3 shows the variation over time in dissolved O_2 concentration for DHS clusters in coastal areas. To isolate the effect of the ocean's pH in equation (1), we include the estimated residuals of a linear regression of dissolved O_2 concentration (multiplied by 1,000, so that coefficients relate to an increase of 0.001 μmol/kg), oxy_{mtvc}, on pH. Consequently, $\widehat{oxy}_{mtvc}$ captures variation that is not explained by pH, guaranteeing that β captures the effect of the ocean's pH conditional on dissolved O_2 concentration.

Figure A3: Variation in dissolved O_2 concentration for DHS clusters in coastal area



Average dissolved O_2 concentration at the ocean's surface in the period 1972–2018. **Note.** Variation is restricted to cells matched to the sample's DHS clusters. Each cluster is assigned with a dissolved O_2 concentration value using the nearest cell in open waters. The solid red line shows the quadratic trend in the series. Dissolved O_2 concentration at surface is obtained from the HadGEM2-ES model (Jones et al., 2011), provided by the ESA Pathfinders-OA project (Sabia et al., 2015).

A.5 Coloring of shaded graphs

In selected graphs where the horizontal axis indicates distances or time since birth, the color intensity of the area within the confidence interval is reflecting the share of observations at a specific distance (or time). Because the distribution of births are not random across space and the survival rates are not random in time, the number of observations used for estimation can vary along these dimensions. Color intensity ranges from 0 to 1, with larger values indicating larger number of observations. For Figure 4 and Figure B7, in which the number of observations is a function of the distance from the shore or from another water body, the color intensity is defined as the ratio between the square root of the (smoothed) density of the distribution of the number of observations by distance from shore and the square root of the 90^{th} percentile in the same distribution.

Figure 3 has a different coloring scheme because the number of observations is a function of the time difference between birth and survey interview. As this difference is always much larger than zero, we modify the ratio defining the color intensity. The numerator is given by the difference between the (smoothed) density of the distribution of the number of observations in a specific iteration and a

value correspondent to the 70% of the lower bound of the same distribution for all iterations. The denominator is given by the difference between the 99^{th} percentile of the distribution of the number of observations in all iterations and a value correspondent to the 70% of the lower bound of the same distribution for all iterations. Parameters are chosen to guarantee visibility of shaded areas in the specific figure and might not apply to different settings. The procedure is adapted from Hsiang (2013).

B Supplementary results

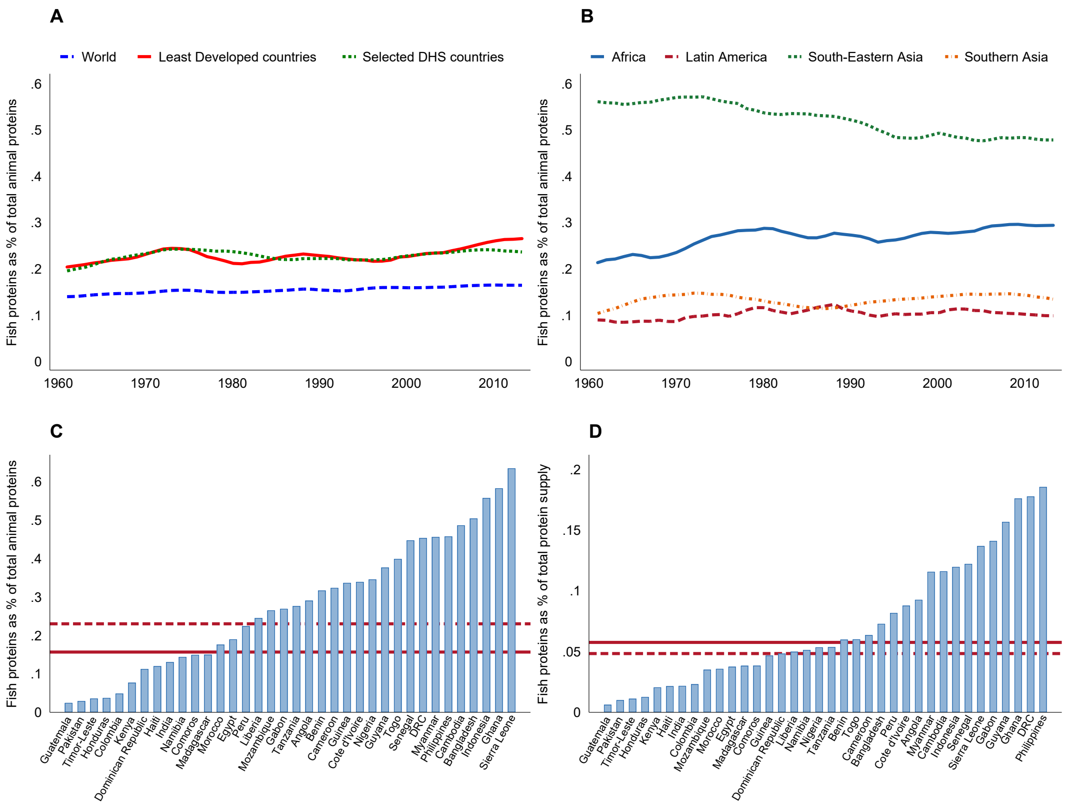
B.1 Fish dependency

To understand heterogeneity by fish dependency, this section makes use of FAOSTAT (FAO, 2019), which provides information about a country's food supply and trade pattern for food products.

Dependency on fish for nutrition

FAO (2019) provides country-level information on the protein content of the food supply for each commodity. Fish dependency is then defined as the share of total proteins of animal origin coming from fish. Figure B1 presents a comparison over time of fish dependency by comparing the world with the selected DHS countries and an aggregate for developing countries in Panel A, and comparing sub-region aggregates among the selected DHS countries in Panel B. Panel C presents average fish dependency expressed as the share of total proteins of animal origin. Panel D presents average fish dependency expressed as share of total proteins derived from fish.

Figure B1: Fish dependency among selected countries

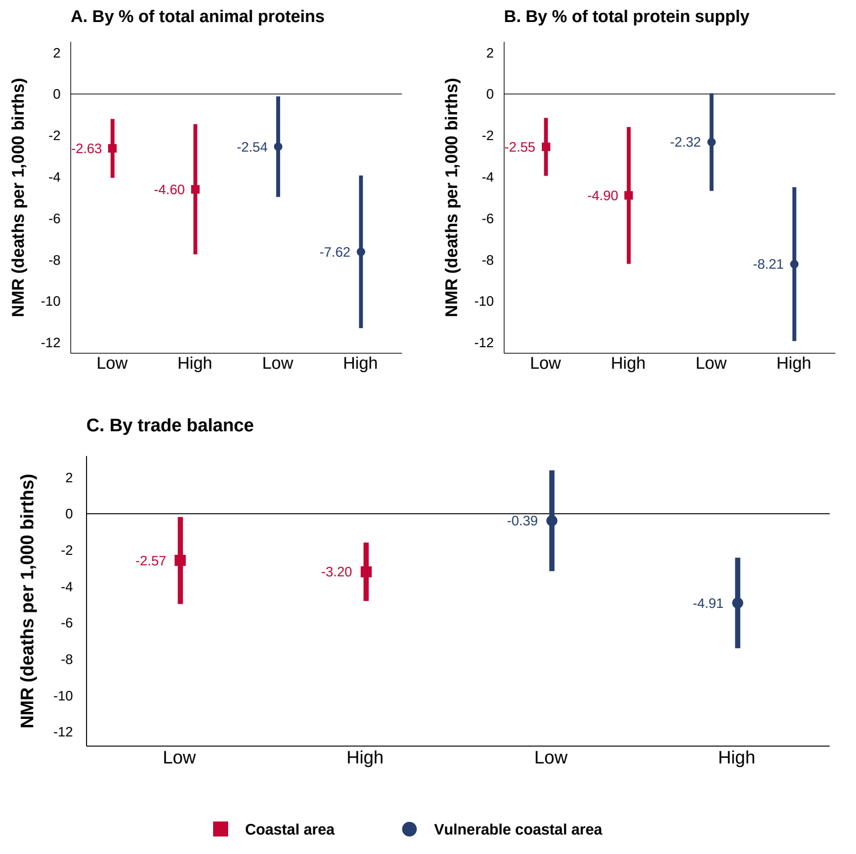


A. Average value of fish proteins as share of total animal proteins by selected area. **B.** Average value of fish proteins as share of total animal proteins in selected DHS survey aggregated by continent. **C.** Average share of total proteins of animal origin coming from fish by country. **D.** Average share of total proteins supply coming from fish by country. **Note.** For A and B, aggregate measures are computed by averaging the value of fish dependency in each country included in the group, weighted by population. For C and D, vertical lines indicate the world's average (solid) and the average among the selected DHS countries (dashed). Source: authors' calculation using FAOSTAT database (FAO, 2019). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

In Figure B2, Panel A and Panel B present estimates of the effect of the ocean's pH while *in utero*

on NMR distinguishing by the level of dependency on fish proteins in the country. In each panel, estimates for each group are computed using equation (1) restricting the sample to the corresponding group. We first average fish dependency by country for the whole period in which data are available, and define dependency as high if the country results in the top tercile of the sample distribution of this variable. Panel A presents heterogeneity with respect to dependency on fish proteins as a percentage of total animal proteins. Panel B presents heterogeneity with respect to dependency on fish proteins as a percentage of total protein supply. While we cannot identify any statistically significant difference across sub-groups, we highlight that larger effects, in absolute value, are concentrated in countries with a higher dependency on fish proteins.

Figure B2: Fish dependency and heterogeneous effect of ocean's acidity on NMR



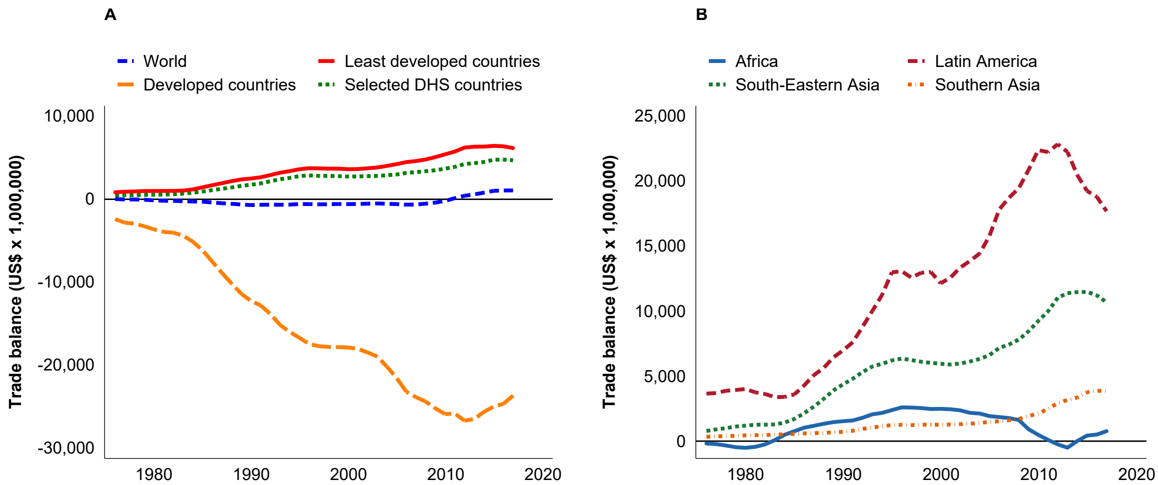
A. Heterogeneous effects of the ocean's pH while *in utero* on NMR by dependency on fish proteins as a % of total animal proteins. **B.** Heterogeneous effects of the ocean's pH while *in utero* on NMR by dependency on fish proteins as a % of total protein supply. **C.** Heterogeneous effects of the ocean's pH while *in utero* on NMR by trade balance for fish products. **Note.** Marginal effects are estimated using equation (1), in which each coefficient is computed in separate regressions where the sample is restricted to the corresponding group. In Panel A and Panel B, dependency is labeled as high if the country is in the top tercile of the sample distribution of the average fish dependency for the period 1960-2013. In Panel C, trade balance is labeled as high if the country is in the top tercile of the sample distribution of the average trade balance for fish products for the period 1976-2017. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level. The black solid lines indicate the value zero. All specifications include cluster fixed effects, year by birth month fixed effects, 5° x 5° grid cell by birth year fixed effects (local trend), 5° x 5° grid cell by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

Fish trade

Given the importance of trade for industrially caught fish, we focus on heterogeneity by trade balance for fish products. Following the indication of FAO (2019), we define the trade balance as the sum of all exports and re-exports of fish products, minus the sum of all imports of fish products. Figure B3 presents a comparison over time of the trade balance for fish products by comparing the world with the selected DHS countries and an aggregate for developing countries in Panel A, and comparing sub-region aggregates among the selected DHS countries in Panel B.

Panel C of Figure B2 presents the estimates of the effect of ocean's pH while *in utero* on NMR distinguishing by the value of the trade balance for fish products. Estimates for each group are computed using equation (1) restricting the sample to the corresponding group. We first average the trade balance by country for the whole period in which data are available, and define the trade balance as high if the country results in the top tercile of the sample distribution of this variable. Similar to fish dependency, while we cannot identify any statistically significant difference across sub-groups, we highlight that larger effects, in absolute value, are concentrated in countries with more positive trade balance for fish products.

Figure B3: Trade balance for fish products among selected countries



A. Trade balance for fish products by selected area. **B.** Trade balance for fish products in selected DHS survey aggregated by continent. **Note.** Aggregate measures are computed by averaging the trade balance in each country included in the group, weighted by population. Source: authors' calculation using FAOSTAT database (FAO, 2019). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.2 Recall bias

To verify the robustness of the main estimates to recall bias, we replicate the results for the effect of the ocean's pH on NMR (Table 2) by restricting the sample to births that happened within a period of 5 years and 10 years from the interview. The focus on more recent births allows reducing the potential effect of non-random recall errors. Table B1 presents the results. Estimates are robust to restricting the sample to more recent births. Since neonatal death is a rare event, a smaller number of observations leads to larger standard errors, as compared to using the full sample.

Table B1: Ocean acidification and NMR with sample restricted to recent births

Dependent variable:	**NMR (deaths per 1,000 births)**					
Sub-sample:	**Coastal area**			**Vulnerable coastal area**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark (≤ 5 years from interview)						
Ocean's pH (*in utero*)	-2.609	-4.420**	-3.617**	-1.753	-3.624	-3.905*
	(1.616)	(1.883)	(1.750)	(1.742)	(2.320)	(2.115)
Observations	369154	369093	369125	248573	248503	248549
DHS clusters	29948	29947	29947	20687	20687	20687
Panel B. Benchmark (≤ 10 years from interview)						
Ocean's pH (*in utero*)	-2.698**	-3.029**	-2.503**	-3.679**	-3.135	-3.849**
	(1.332)	(1.331)	(1.176)	(1.425)	(1.903)	(1.615)
Observations	731190	731160	731168	491701	491678	491693
DHS clusters	30946	30945	30945	21376	21376	21376
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. The sample is restricted to births that happened within a period of 5 years (Panel A) and 10 years (Panel B) from the interview. In Panel A, all specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), and time-varying controls. In Panel B, mother fixed effects are added. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

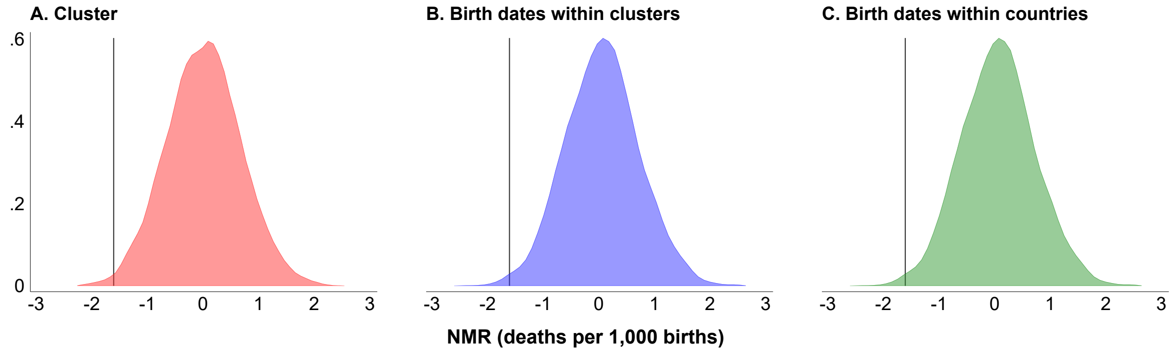
B.3 Falsification tests

This section presents two types of falsification tests. The first refers to random re-allocation of the exposure of pH. The second refers to the randomization of the distance from the shore for the selection of the sample.

First, to verify that the main estimate of the effect of the ocean's pH on NMR is not spurious, we design three falsification tests to check whether alternative space-time variation in pH could explain the main results. In a first test, birth dates are randomly reassigned within each cluster, such that the total exposure within each cluster remains constant, but children are now exposed to different pH levels. In a second test, birth dates are randomly reassigned within each country, independently from the cluster and the survey. In a third test, birth dates are not reassigned, but mothers (and their children) are randomly allocated to different clusters, independently from the country and survey. The first two tests are varying the timing of birth, while maintaining the location of birth constant or in the same country.

The third test maintains the timing of birth, but randomizes its location. Tests are iterated 1,000 times and, for each iteration, the effect of the ocean's pH on NMR is estimated using equation (1). Figure B4 presents the distribution of marginal effects of pH on NMR estimated in each iteration. For the three tests, estimates are centered around zero and the interval within the empirical 1st and 99th percentiles always include the value zero.

Figure B4: Marginal effects of pH on NMR, by falsification test



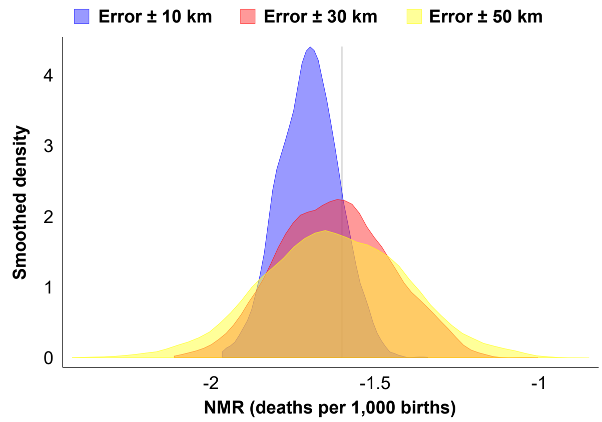
A. Distribution of marginal effects of pH on NMR when mothers (and their children) are randomly allocated to different clusters. **B.** Distribution of marginal effects of pH on NMR when birth dates are randomly reassigned within each cluster. **C.** Distribution of marginal effects of pH on NMR when birth dates are randomly reassigned within each country. **Note.** For each test, 1,000 iterations are performed. The vertical lines represent the main estimate of the effect of ocean's pH on NMR (see column 1 in Table 2). In each iteration, the effect of ocean's pH on NMR is estimated using equation (1). The specification includes cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). The sample is restricted to clusters in the coastal area (see Section 2.1 for the definition). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

Second, selecting a specific distance upper bound for the main estimates can generate issues related to measurement error in the distance from the ocean. First, to protect privacy, the DHS program reallocates clusters within a buffer of a maximum 10-km radius from their original position. DHS displaces urban clusters up to 2 km), and rural clusters, up to 5 km, with a further randomly selected 1% being displaced up to 10 km. Second, we assume a straight line to compute the distance from a DHS cluster to the shoreline. This assumption removes the endogeneity of road distance but could introduce measurement error with respect to the real distance. To test the robustness to the chosen distance upper bound, we simulate a random error in the measurement of the distance of $\pm$ 10 km (the DHS maximum distance for random re-allocation of clusters from their original position to assure anonymity), $\pm$ 30 km, and $\pm$ 50 km. We iterate the simulation 1,000 times, each generating a new distance from the ocean for each cluster and selecting only the clusters within 100 km from the shoreline. We estimate equation (1) for NMR with the preferred specification. Figure B5 shows the distribution of the coefficients in all iterations.

B.4 Definition of coastal area and sample selection

In the literature, there are alternative definitions of a coastal area. More general definitions are based uniquely on distance from the shore, which we compute using straight lines (Appendix A.3). A different distance upper bound for the inclusion of clusters in the sample affects the total number of live

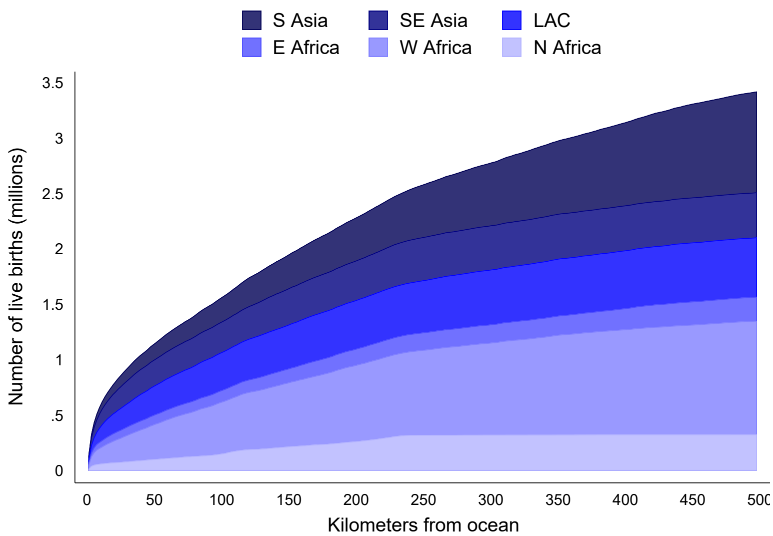
Figure B5: The effect of ocean's acidity on NMR, by magnitude of measurement error



Note. Distribution of the marginal effect of pH on NMR, estimated using (1) and introducing measurement error in the distance from the ocean. The procedure performs 1,000 iterations. The vertical line represents our benchmark point estimate (Table 2). The distribution fits are estimated non-parametrically using kernel density estimation and assuming an Epanechnikov kernel function. Bandwidths are estimated by Silverman's rule of thumb. The sample is restricted to clusters in the coastal area (see Section 2.1 for the definition). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

births considered (Figure B6). Restricting the sample to clusters within 100 km from the shore selects around 1.5 million births, while raising the distance bound to 500 km raises the sample to 3.5 million observations. This highlights a clear trade-off between the need of a larger number of observations to estimate the impact on neonatal mortality, which is a relatively rare event as compared to mortality later on in life, and the focus on households living in proximity to the ocean.

Figure B6: Number of live births, by distance from the shore

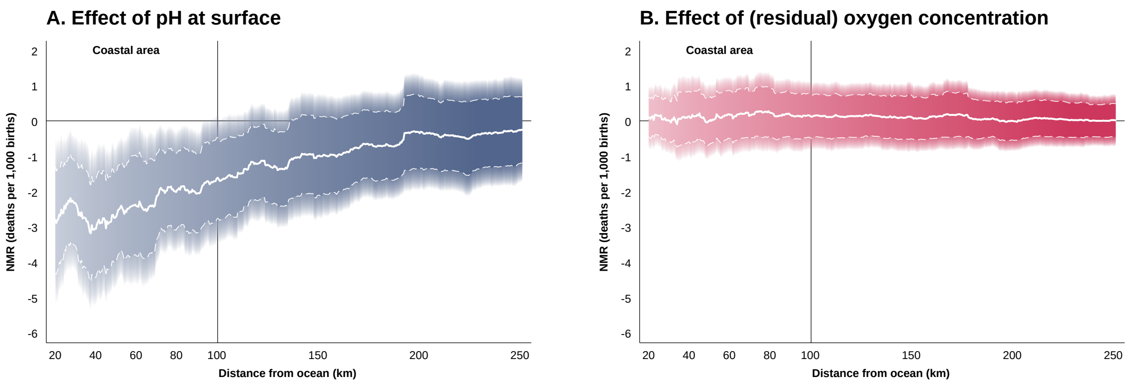


Note. Number of live births (decomposed by region) included in the dataset by distance from the shore. Table A.2 presents the countries and surveys in the DHS global dataset that are included in the sample. Details about the computation of distance from the shore are presented in Appendix A.3. See Appendix A.1 for further information on the variables.

We begin by focusing on a proximity criteria, selecting clusters based on the distance from the ocean's shore. This criteria is generally used to identify coastal pressure, rather than hazard vulnera-

bility. To understand how the effect of the ocean's pH on NMR varies by increasing or decreasing this distance bound from the shore, equation (1) is estimated for a distance $\leq x$, where x varies from 20 to 250 km, allowing x to increase by 1 unit after each iteration. Figure B7 shows how pH and the residual dissolved oxygen estimates change as the distance upper bound varies. It is important to observe that the estimate of the effect of the ocean's pH while *in utero* on NMR reaches the largest magnitude when distance is constrained at 40 km. By increasing the distance bound from the shore, the estimate converges towards zero. We do not highlight any effect of the (residual) dissolved oxygen concentration for any distance bound. Based on these results, we define a *vulnerable coastal area* as the area extending inland from the ocean's shore up to a distance of 40 km, and a *less vulnerable coastal area* as the area extending 40–100 km from the ocean's shore. Panel A of Figure B8 maps clusters according to this criteria. Panel C presents an example of this selection criteria for South-Eastern Africa.

Figure B7: Ocean acidification and NMR: sample selection by distance from shore

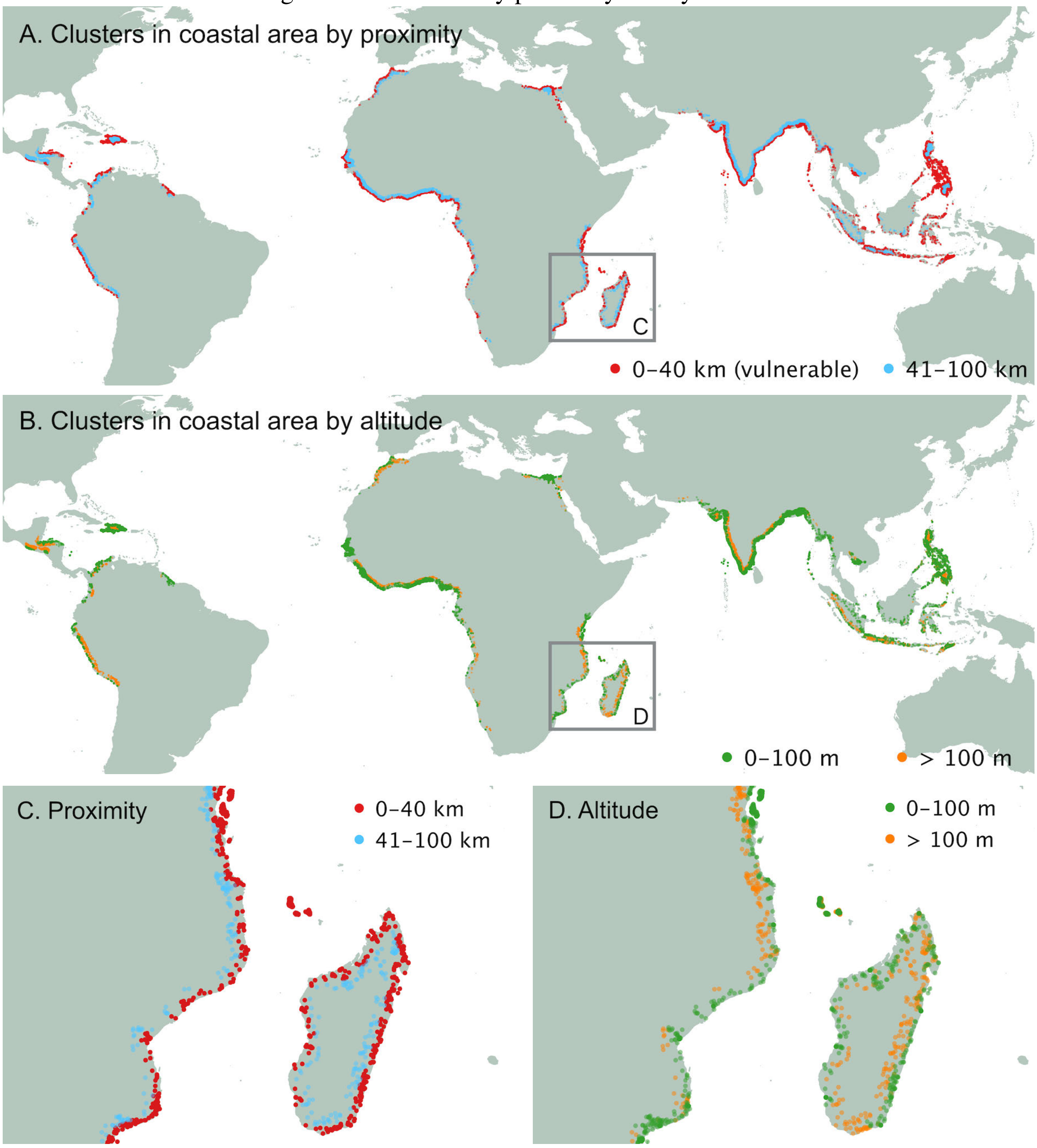


A. Marginal effects of pH on NMR by sample selection according to proximity to the shore. **B.** Marginal effects of residual dissolved O_2 on NMR by sample selection according to proximity to the shore. **Note.** Marginal effects are computed using estimates of equation (1) when the sample is constrained by different bounds on distance from the ocean (reported in the horizontal axis). The specification includes cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Dotted lines represent the confidence interval at 90%. Beyond the 90%, confidence intervals are progressively shaded up the 99%. The color intensity of the area is a function of the number of observations, with darker colors indicating a larger number of observations (see Appendix A.5). See Appendix A.1 for further information on the variables.

Alternative definitions of coastal areas also include altitude requirements. For instance, Christian and Mazzilli (2007) define a coastal area as the land margin within 100 km of the coastline or less than 100 meters above the mean low tide, whichever comes first. We adopt this definition and test the robustness of the effect of the ocean's pH while *in utero* on NMR to this alternative definition. Panel B of Figure B8 shows clusters in coastal areas by distinguishing between clusters at lower altitudes (less or equal to 100 m from sea level) and clusters at higher altitudes (more than 100 m from sea-level). As an example for South-Eastern Africa, in Panel D clusters are further classified by splitting clusters at lower altitudes in clusters below 50 m from sea level and clusters within 50–100 m from sea level. Table B2 presents estimates of the effect of ocean's pH while *in utero* on NMR using equation (1), focusing on clusters within 100 km from the shore, and imposing restrictions on the sample based on altitude. Columns (1)–(3) focus on the definition of Christian and Mazzilli (2007). We use altitude

as provided by the DHS surveys (see Appendix A.1). Alternatively, columns (4)–(6) impose a more demanding restriction on altitude, by restricting the sample to clusters at an altitude lower than 50 meters from the sea level. This is the approach followed by the Millennium Ecosystem Assessment (2013). Results are robust to the use of alternative definitions of a coastal area that include altitude as a requirement.

Figure B8: Selection by proximity and by altitude



A. DHS clusters in coastal areas distinguished by vulnerability. Vulnerable clusters are within 40 km from the shore, less vulnerable clusters are located 40-100 km from the shore. **B.** DHS clusters in coastal areas distinguished by altitude. Clusters at lower (higher) altitudes are located 0–100 m (> 100 m) from sea level. **C.** Example of distribution by proximity to the ocean for DHS clusters in South-Eastern Africa. **D.** Example of distribution by altitude for DHS clusters in South-Eastern Africa. **Note.** Detailed definitions of distance from shore and altitude are presented in Appendix A.1. The full list of countries and surveys included in the study is reported in Appendix A.2. See Section 2.1 for a definition of coastal and vulnerable coastal areas.

Table B2: Ocean acidification and NMR: adding altitude as condition for sample selection

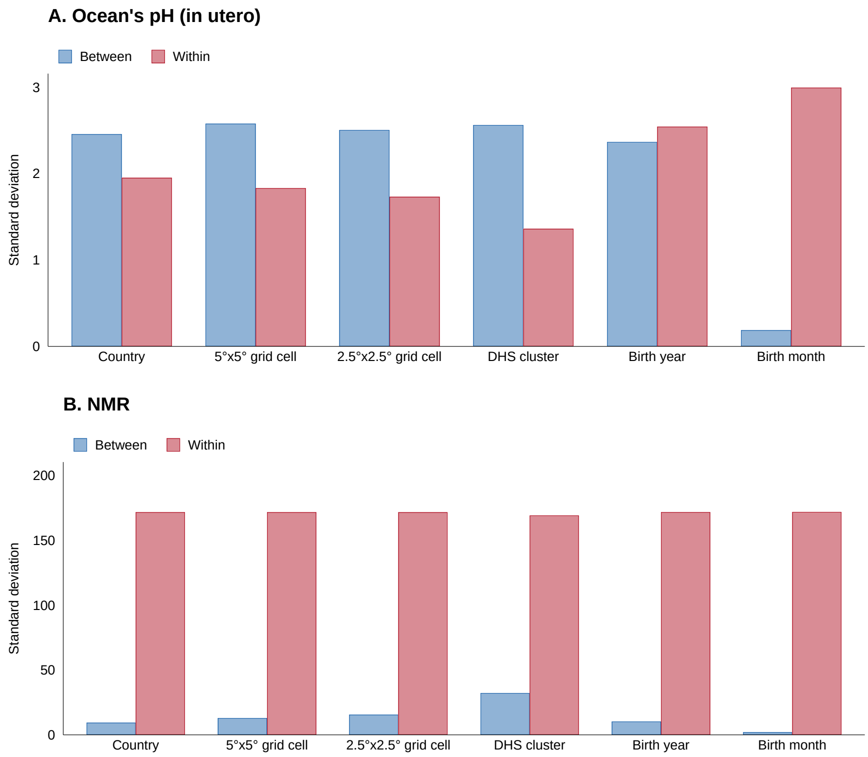
Dependent variable:	**NMR (deaths per 1,000 births)**					
Sub-sample:	**Coastal area (altitude $\leq$ 100 m)**			**Coastal area (altitude $\leq$ 50 m)**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Ocean's pH (*in utero*)	-1.735**	-2.728***	-2.848***	-2.121**	-3.708***	-4.335***
	(0.807)	(0.994)	(0.990)	(0.939)	(1.422)	(1.299)
Observations	1126063	1126057	1126057	909308	909301	909305
DHS clusters	22591	22591	22591	18227	18227	18227
Panel B. Mother fixed effects						
Ocean's pH (*in utero*)	-2.452**	-3.390***	-3.155***	-2.610**	-4.478***	-4.685***
	(1.024)	(1.269)	(1.164)	(1.110)	(1.557)	(1.459)
Observations	1058092	1058084	1058081	854106	854095	854101
DHS clusters	22590	22590	22590	18225	18225	18225
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. In Panel A, all specifications include cluster fixed effects, year by birth month fixed effects (local seasonality), country by birth year fixed effects (local trend), and time-varying controls. In Panel B, mother fixed effects are added. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.5 Temporal versus spatial variation

Our identification strategy presented in Section 3 is based on geographical and time variation in both mortality and the ocean's acidity. Figure B9 presents the between and within decomposition of the overall variation of the ocean's pH while *in utero* (Panel A) and NMR (Panel B) for the sample in the coastal area. The decomposition of the overall standard deviation is presented along different geographical and time indicators. For geographical variation, we present the decomposition by country, 5° x 5° grid cell, 2.5° x 2.5° grid cell, and DHS cluster. For time variation, we present the decomposition by year and month of birth. Most of the variation in the ocean's pH while *in utero* originates from both between and within variation, apart from birth months, for which the main source of variation is coming from the within component. For NMR, since this is a relatively rare event, most of the variation originates from the within components.

Figure B9: Between and within variation for ocean's pH while *in utero* and NMR



A. Decomposition of the standard deviation of the ocean's pH while *in utero*. **B.** Decomposition of the standard deviation of NMR. **Note.** The sample is restricted to clusters in the coastal area (see Section 2.1 for the definition). Geographical and time variables for which the decomposition is computed are reported at the bottom of each figure. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.6 Robustness to alternative specifications

In this section, we test the robustness of main estimates to assumptions related to standard errors and to controls for local trends and seasonality. First, in equation (1) idiosyncratic errors ϵ_{imtvc} are assumed to be clustered at the ocean raster data point. Table B3 shows estimates of equation 1 for NMR using different assumptions for the clustering of standard errors. In column (1), no clustering is assumed, in column (2), clustering is at the 1° x 1° resolution grid cell level, in column (3) is at the matched ocean cell level, in column (4) is at the 5° x 5° resolution grid cell level, in column (5) is at the level of country by survey year indicator, and in column (6) is at the DHS cluster level. Estimates are robust to these various assumptions.

Second, we check robustness to alternative controls for local trends and local seasonality. Table B4 shows results using alternative specifications for local trends in equation (1). In columns (1) and (4), we use alternative administrative units by controlling for district by birth year fixed effects. To identify districts, we make use of the region of residence. Usually the region of residence is the smallest administrative level within the country or a grouping of the first administrative level. Since administrative bounds might be endogenous, in columns (2) and (5), we build a global grid at the 10° x 10° resolution and control for grid cell by birth year fixed effects. Finally, in columns (3) and (6), we

Table B3: Robustness to clustering assumptions

Dependent variable:	**NMR (deaths per 1,000 births)**					
Level of clustering:	None	1°x1° grid cell	Matched ocean cell	5°x5° grid cell	Country x survey year	DHS cluster
	(1)	(2)	(3)	(4)	(5)	(6)
Ocean's pH (*in utero*)	-1.580**	-1.580**	-1.580***	-1.580**	-1.580**	-1.580**
	(0.705)	(0.633)	(0.363)	(0.676)	(0.675)	(0.624)
Observations	1566855	1566855	1566855	1566855	1566855	1566855
DHS clusters	31355	31355	31355	31355	31355	31355

Note. Estimates based on equation 1. Sample is restricted to clusters in the coastal area (Section 2.1). All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis (*** p<0.01, ** p<0.05, * p<0.1). Assumptions about clustering vary by column: (1) no clustering; (2) clustering at the 1°x1° grid cell level; (3) clustering at the matched ocean cell level; (4) clustering at the 5°x5° grid cell level; (5) clustering at the level of country by survey year indicator; (6) clustering at the DHS cluster level. The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

build a global grid at the 5° x 5° resolution and control for grid cell by birth year fixed effects.

Table B4: Ocean chemistry and NMR: alternative local trends

Dependent variable:	**NMR (deaths per 1,000 births)**					
	Coastal area			**Vulnerable coastal area**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Ocean's pH (*in utero*)	-1.913***	-1.821***	-1.934***	-3.210***	-3.201***	-3.155***
	(0.727)	(0.662)	(0.709)	(1.022)	(0.945)	(0.999)
Observations	1566496	1566837	1566745	1049566	1049851	1049781
DHS clusters	31355	31355	31355	21661	21661	21661
Panel B. Mother fixed effects						
Ocean's pH (*in utero*)	-2.782**	-2.459***	-2.812**	-3.869**	-4.221***	-3.956**
	(1.102)	(0.758)	(1.107)	(1.638)	(1.094)	(1.680)
Observations	1474008	1474378	1474260	986242	986561	986456
DHS clusters	31349	31349	31349	21661	21661	21661
Local trend controls:						
District x birth year FE	Yes	No	No	Yes	No	No
10° x 10° cell x birth year FE	No	Yes	No	No	Yes	No
5° x 5° cell x birth year FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries that were surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

As an additional robustness test, equation (1) is estimated introducing variable-specific trends and seasonality controls. Table B5 presents the results. In columns (1) and (2), to isolate the effect of the ocean's pH from trends in fishing pressure, the analysis is supplemented with information about industrial fishing using the Global Fishing Watch dataset (Kroodsma et al., 2018). Since variation is available only for the period 2012-2016, we first compute total fishing hours in a global grid at a 0.25° x 0.25° resolution and then average each cell over the period 2012-2016. This measure can be

interpreted as the average intensity of fishing at a highly disaggregated level. Results are robust to controlling for trends in fishing pressure. In columns (3)–(8), the objective is to control for stability of estimates when introducing trends specific to economic development and population size. We build a 1° x 1° resolution grid based on the PRIO-grid database (Tollefsen et al., 2012), and we make use of three different variables: the gross cell product, which measures the total economic activity of the cell; the population living in the cell; and average nightlight, which also measures economic development. Since these variables are time-varying, to compute trends, the values are averaged across the whole period for which births are available, and are then interacted with birth year and month. When values are not available for each year, these are interpolated linearly over time. Results in columns (3)–(8) shows that estimates are robust to controlling for trends specific to human development.

Table B5: Variable-specific trends and seasonality

Dependent variable:	**NMR (deaths per 1,000 births)**							
Trends:	**Fishing pressure**		**Gross Cell Product**		**Population**		**Nightlight**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ocean's pH (*in utero*)	-1.608**	-1.459**	-1.602**	-1.682**	-1.612**	-1.667**	-1.617**	-1.604**
	(0.728)	(0.645)	(0.701)	(0.732)	(0.689)	(0.681)	(0.713)	(0.723)
Observations	1566855	1566855	1566855	1566855	1557654	1557654	1566855	1566855
DHS clusters	31355	31355	31355	31355	31218	31218	31355	31355
Interaction terms:								
Variable x birth year FE	Yes	No	Yes	No	Yes	No	Yes	No
Variable x birth month FE	No	Yes	No	Yes	No	Yes	No	Yes

Note. Estimates based on equation 1. The sample is restricted to clusters in the coastal area (see Section 2.1 for the definition). All specifications include cluster fixed effects, birth year by birth month fixed effects, country by birth year fixed effects, country by birth month fixed effects and demographic controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH *in utero* is computed as average value in the cell closest to the child's cluster during the 9 months before birth. pH is reported in levels corresponding to 0.01 units of pH. See Appendix A.1 for further information on the variables. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.7 Sample differences in the within-siblings comparison

The within-siblings specification presented in equation (2) introduces mother-specific fixed effects. It removes mothers that at the time of the interview have had only one live birth. Table B6 presents mean characteristics for the sample of mothers with a single birth at the time of the interview in columns (1)–(2), and for the sample of mothers with multiple births in columns (3)–(4).

Table B6: Descriptive statistics for mothers with single versus multiple births

	Mothers with single birth		**Mothers with multiple births**		**Difference**	
	Mean	Std. dev.	Mean	Std. dev.	P-value	Obs.
	(1)	(2)	(3)	(4)	(5)	(6)
Birth-level characteristics						
Child is alive	0.97	0.16	0.92	0.27	0.00	1589753
Child is female	0.46	0.50	0.49	0.50	0.00	1589753
Birth order	1.00	0.00	2.68	1.82	0.00	1589753
Number of twins born with the child	0.00	0.00	0.04	0.24	0.00	1589753
Years since birth	6.03	6.56	12.87	7.74	0.00	1589753
Weight for height (percentile)	38.17	31.62	37.57	30.48	0.04	229958
Weight for age (percentile)	29.94	30.53	26.23	28.98	0.00	231385
Height for age (percentile)	32.02	30.87	26.85	29.90	0.00	233928
Morbidity	0.38	0.48	0.35	0.48	0.00	340629
Child has any anemia	0.51	0.50	0.53	0.50	0.00	115877
Antenatal care: any visit	0.95	0.22	0.91	0.29	0.00	265186
Antenatal care: number of visits	1.91	0.66	1.73	0.72	0.00	265186
Antenatal care: with health professional	0.85	0.35	0.82	0.39	0.00	270537
Delivery care: in health center	0.83	0.37	0.69	0.46	0.00	269213
Delivery care: with health professional	0.83	0.38	0.70	0.46	0.00	270837
Mother-level characteristics						
Age during first birth	22.48	4.69	20.39	3.93	0.00	495254
Current age	28.52	7.99	36.16	7.66	0.00	495254
Years of schooling	8.40	4.47	5.87	4.64	0.00	487638
Married or cohabiting	0.81	0.39	0.89	0.31	0.00	495253
Working	0.53	0.50	0.60	0.49	0.00	424206
Household-level characteristics						
Household members	4.38	2.44	5.38	2.30	0.00	435703
Household head is female	0.22	0.41	0.19	0.39	0.00	435703
Household head's age	43.75	15.71	44.21	11.73	0.00	435410
Access to electricity	0.86	0.35	0.81	0.39	0.00	423994
Wealth index	1.16	1.69	0.75	1.73	0.00	279285
Distance from shore	31.16	29.99	32.53	30.21	0.00	435703
Distance from another water body	40.06	82.33	47.44	102.37	0.00	435703
Altitude	172.04	376.97	186.02	392.29	0.00	435703
Temperature (° C)	26.32	2.94	26.27	2.94	0.00	435654
Precipitations (mm)	1622.28	650.67	1561.88	678.27	0.00	435703
Intensity of local fishing	3264.59	6554.06	3079.58	6781.62	0.00	435703
Intensity of industrial fishing	13.99	44.49	12.98	42.51	0.05	435703
Mortality rates						
NMR	12.93	112.98	29.02	167.86	0.00	1586202
PMR	7.27	84.97	25.14	156.55	0.00	1472453
CMR	6.62	81.09	22.58	148.56	0.00	1143667
IMR	18.18	133.61	53.56	225.15	0.00	1519137
U5MR	23.99	153.04	76.91	266.45	0.00	1219606

Note. Descriptive statistics by number of births per mother. The sample is restricted to the coastal area (see Section 2.1 for a definition of coastal and vulnerable coastal areas). Means are reported in columns (1) and (3), standard deviations are reported in columns (2) and (4). Column (5) presents the difference and significance of t tests on the equality of means assuming unequal variances. Observations are re-weighted to correct for oversampling of countries that have been surveyed multiple times (see Appendix A.2). Years since birth is measured at the time of the interview and is independent from the child being alive. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.8 Breastfeeding and early initiation of breastfeeding

Breastfeeding practices are affected by a wide range of socioeconomic and cultural factor (Rollins et al., 2016). Among factors that could be affected by maternal malnutrition are high-risk pregnancies, assisted delivery and long hospital stays, maternal illness, and preterm, ill newborn babies. To check whether ocean's acidity has an effect on breastfeeding practices, Table B7 shows estimates of the effect of ocean's pH while *in utero* on breastfeeding and early initiation of breastfeeding. We focus on three different outcomes: whether the child was ever breastfed (Panel A), whether the child was breastfed within the first hour from birth (Panel B), and whether the child was breastfed within the first 24 hours from birth (Panel C). In the coastal area, 97% of children is breastfed. Among the children that were breastfed, 51% were breastfed within the first hour from birth, and 85% within the first day from birth. In the vulnerable coastal area, these percentages are highly comparable. Overall, we observe that ocean's acidity has no effect on breastfeeding.

Table B7: Breastfeeding and early initiation of breastfeeding

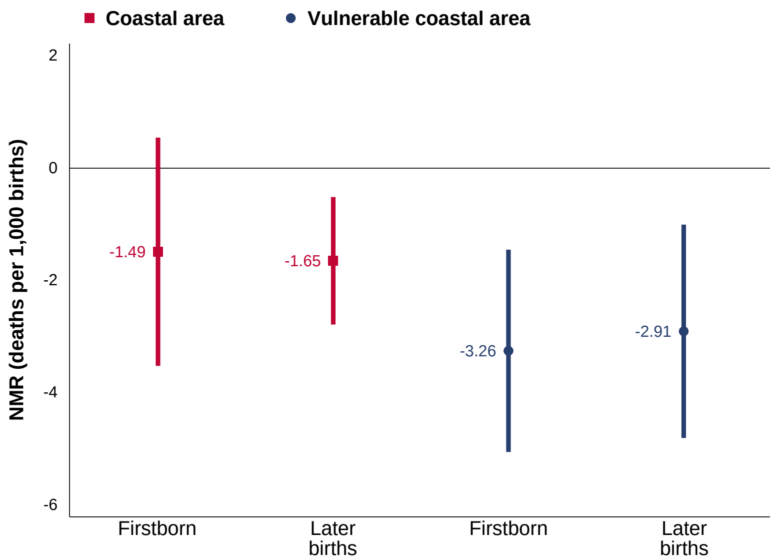
	Dependent variables are indicated in each panel's title					
Sub-sample:	**Coastal area**			**Vulnerable coastal area**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Any breastfeeding						
Ocean's pH (*in utero*)	0.003	0.003	0.003	0.000	0.001	0.003
	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Observations	261478	261442	261329	176751	176718	176604
DHS clusters	29759	29757	29749	20558	20557	20549
Panel B. Breastfeeding in the 1st hour from birth						
Ocean's pH (*in utero*)	0.006	0.007	0.008	0.003	0.003	0.006
	(0.005)	(0.006)	(0.007)	(0.005)	(0.008)	(0.008)
Observations	241813	241777	241650	163524	163493	163369
DHS clusters	28452	28451	28440	19683	19683	19672
Panel C. Breastfeeding in the 1st day from birth						
Ocean's pH (*in utero*)	-0.003	-0.004	-0.003	0.005	0.004	0.008
	(0.003)	(0.005)	(0.005)	(0.004)	(0.006)	(0.008)
Observations	241813	241777	241650	163524	163493	163369
DHS clusters	28452	28451	28440	19683	19683	19672
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. For cross-survey comparability, the sample is restricted to the last birth, independently from the child being alive, and to mothers that gave birth 3 or 5 years before the interview (Boyle et al., 2019). Panel A restricts the sample to coastal areas, while Panel B restricts the sample to the vulnerable coastal area (see Section 2.1 for a definition). All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variables are reported in the each panel's title. *Any breastfeeding* is an indicator variable equal to 1 if the mother reports having breastfed the child, and 0 otherwise (the indicator is set to missing for children that were not breastfed because of death in the first month of life). *Breastfeeding in the 1st hour from birth* is an indicator variable equal to 1 if the mother reports having breastfed the child within the first hour after the birth, and 0 otherwise (the indicator is set to missing if the mother has never breastfed the child). *Breastfeeding in the 1st day from birth* is an indicator variable equal to 1 if the mother reports having breastfed the child within the first day after the birth, and 0 otherwise (the indicator is set to missing if the mother has never breastfed the child). The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.9 Heterogeneous effects by group

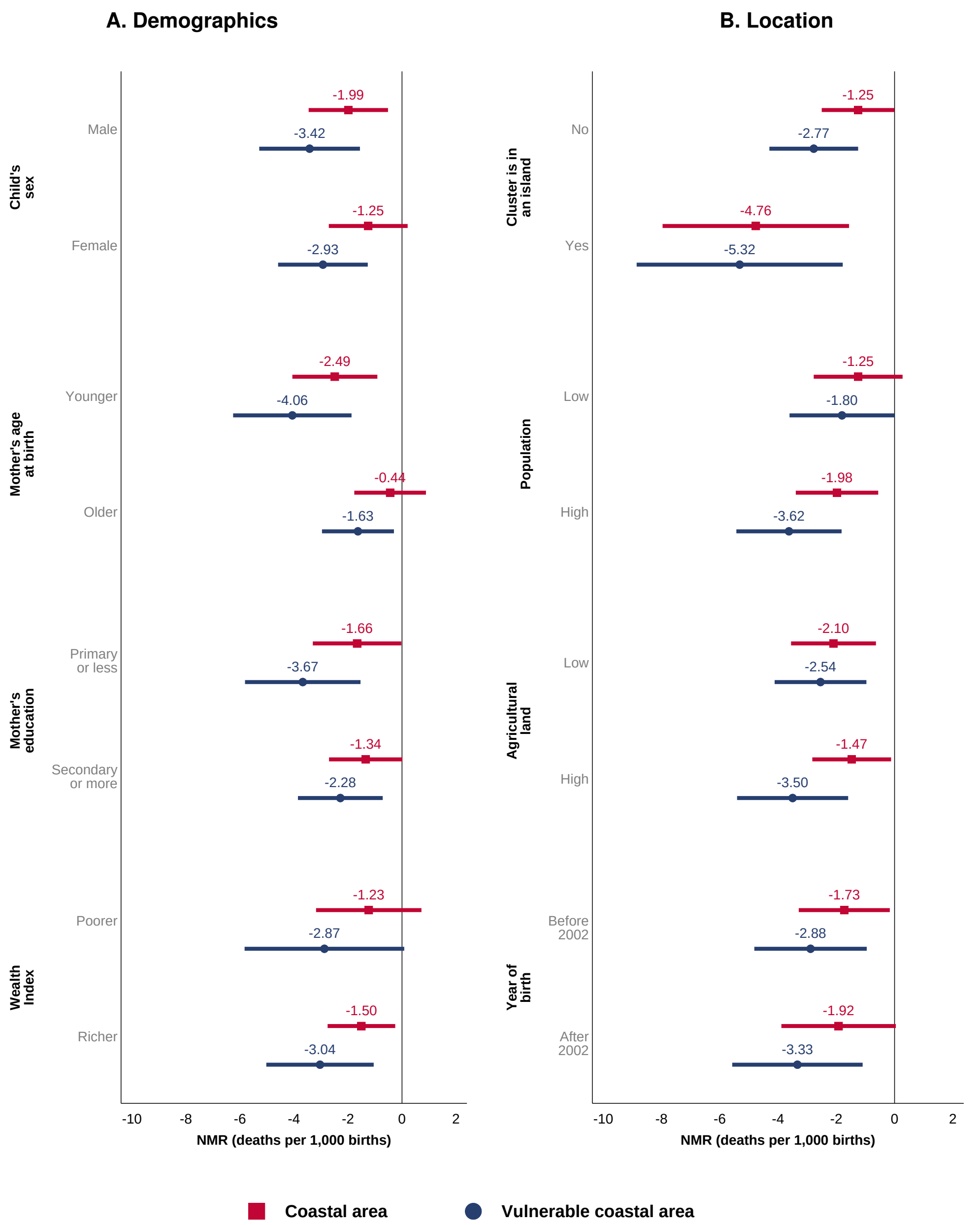
Heterogeneous effects are estimated using equation (1) separately for each sub-sample. The specification includes cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (to control for local trend), country by birth month fixed effects (to control for local seasonality), and time-varying controls. Figure B10 presents instead estimates of heterogeneous effects by birth order. Figure B11 presents estimates of heterogeneous effects for children and mothers' demographics (Panel A) and for location characteristics (Panel B). Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level.

Figure B10: Heterogeneous effect of ocean's acidity on NMR, by birth order



Note. Marginal effect are estimated using equation (1), in which each coefficient is computed in separate regressions where the sample is restricted to the corresponding group. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 95% significance level. The solid line indicate the value zero. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. See Section 2.1 for a definition of coastal and vulnerable coastal areas. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

Figure B11: Heterogeneous effect of ocean's acidity on NMR



A. Heterogeneous effects of ocean's pH while *in utero* on NMR by child and mother's demographics. **B.** Heterogeneous effects of ocean's pH while *in utero* on NMR by location characteristics. **Note.** Marginal effect are estimated using equation (1), in which each coefficient is computed in separate regressions where the sample is restricted to the corresponding group. For mother's age at birth, wealth index, agricultural land, population, fish as a % of animal proteins, and fishing hours, we create a dummy variable indicating whether an observation is above or below the full sample's median of the variable of interest. Agricultural land and population are set at the 1970 level. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level. The solid lines indicate the value zero. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. See Section 2.1 for a definition of coastal and vulnerable coastal area. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.10 Non-linearities in the effect of ocean's pH

Table B8 presents estimates of equation (1), but replacing the ocean's pH while *in utero* with indicator variables for the quartiles of the sample distribution of the ocean's pH. Specifically, we introduce an indicator variable for whether the child experienced, while *in utero*, a level of the ocean's pH in the bottom quartile of the sample distribution, and an indicator variable for whether the child experienced, while *in utero*, a level of pH in the top quartile. In columns (1)–(3), the excluded variables are the middle and top quartiles, while in columns (4)–(6), the excluded variables are the middle quartiles. Estimates are not presented for within-siblings comparison as variation in these broadly-defined indicator variables is limited. The effect of the ocean's acidity on NMR is mainly driven by the experience of levels of pH in the bottom quartile, suggesting the effect is driven by a reduction in pH–an increase in acidity–, rather than an increase.

Table B8: The effect of *in utero* ocean's acidity on NMR: using quartiles

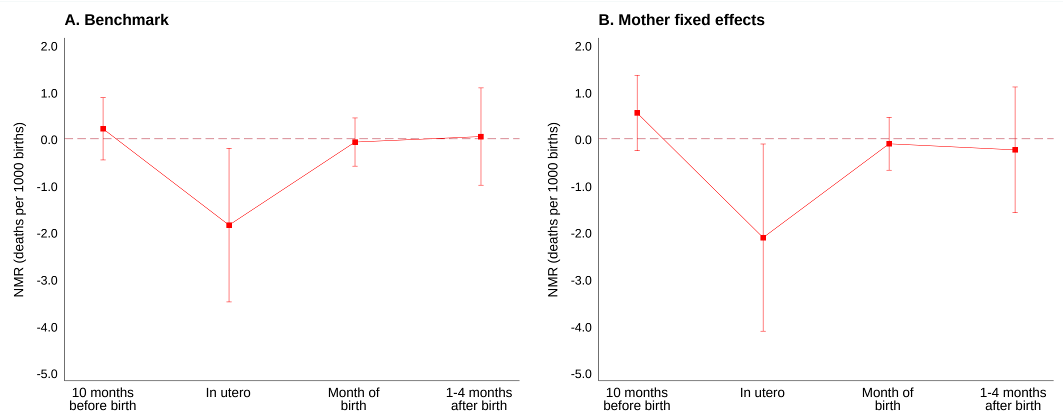
Dependent variable:	**NMR (deaths per 1,000 births)**					
	(1)	(2)	(3)	(4)	(5)	(6)
Ocean's pH (*in utero*) - Bottom quartile	2.636***	2.567***	2.440***	2.640***	2.501***	2.362***
	(0.921)	(0.929)	(0.933)	(0.895)	(0.899)	(0.903)
Ocean's pH (*in utero*) - Top quartile				-0.026	0.453	0.534
				(1.453)	(1.471)	(1.513)
Observations	1566855	1566852	1566837	1566855	1566852	1566837
DHS clusters	31355	31355	31355	31355	31355	31355
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. The sample is restricted to the coastal area (see Section 2.1 for a definition). All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. *Ocean's pH (in utero) - 0-25 pct.* is an indicator variable equal to 1 if the child experienced, while *in utero*, a level of pH in the bottom quartile of the sample distribution of ocean's pH while *in utero*. *Ocean's pH (in utero) - 75-100 pct.* is an indicator variable equal to 1 if the child experienced, while *in utero*, a level of pH in the top quartile of the sample distribution of ocean's pH while *in utero*. The excluded categories are the indicator variables for the middle quartiles. The ocean's pH while *in utero* is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.11 Timing of exposure to the ocean's pH

To understand the timing of exposure to the ocean's pH and its effect on NMR, we estimate equation (1) by adding controls for pH in the period before *in utero* and in post-birth periods. We control for pH one month before conception (assumed to be 10 months before birth), in the month of birth, and the months following the NMR period (average pH for the period 1–4 months after birth). Figure B12 shows the marginal effects for the benchmark specification for the coastal area (left), and for the same specification with mother fixed effects (right). The effect on NMR is specific of the *in utero* period as no significant effects are found for past and future periods.

Figure B12: Timing of exposure to variation in ocean's pH



A. Marginal effects in coastal areas of exposure to ocean's pH at different times in the benchmark specification. **B.** Marginal effects in coastal areas of exposure to ocean's pH at different times with mother fixed effects. **Note.** The sample is restricted to clusters in the coastal area (see Section 2.1 for the definition). Timing of exposure is reported in the horizontal axis. Estimates are based on equation (1) by adding pH at alternative times (relative to birth) in addition to pH (*in utero*). When pH is reported for multiple months, it is averaged for the corresponding period. In Panel A, the specification includes cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. Controls for (residual) dissolved O_2 concentration refers to the same period considered for pH. In Panel B, the specification adds mother fixed effects. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are clustered at the ocean raster data point. Confidence intervals are reported at 90%. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.12 Selective migration

One potential threat to identification is selective migration. Since variation in the ocean's chemistry is assigned using the location of the interview, migration decisions induced by varying levels of the ocean's pH during the gestation period would lead to an inaccurate assignment of the ocean's pH to the specific child. To check whether delivery induces migration differentially as a function of the ocean's pH while *in utero*, we estimate the effect of the ocean's pH while *in utero* on the probability that the mother migrated to the community of the interview within the first five years following delivery. We build this information using self-reported information about the number of years the mother has been living in the community at the time of the interview. This period corresponds to the time period considered for U5MR. Since information about migration to the community in which the interview takes place is provided by the DHS only at yearly granularity, we include in this period the year of

birth and the following 4 years. Table B9 presents the estimates. In addition, we check whether the ocean's pH induces the mother to migrate in between the last birth and the interview. Table B10 presents estimates of equation (1) where the dependent variable is equal to 1 if the mother migrated after the last birth, and 0 otherwise. In both cases, the results highlight that ocean's acidity is not driving selective migration.

Table B9: Post-delivery selective migration

Dependent variable:	**Mother migrated to community 0-4 years after delivery of child**					
Sub-sample:		**Coastal area**			**Vulnerable coastal area**	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Ocean's pH (*in utero*)	-0.000	0.002	0.001	0.001	0.000	-0.001
	(0.002)	(0.004)	(0.004)	(0.002)	(0.003)	(0.003)
Observations	1003268	1003257	1003264	696659	696650	696659
DHS clusters	21860	21860	21860	15365	15365	15365
Panel B. Mother fixed effects						
Ocean's pH (*in utero*)	0.001	0.004	0.003	0.001	0.004	0.003
	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	935380	935371	935375	648618	648609	648618
DHS clusters	21834	21834	21834	15349	15349	15349
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. In Panel A, all specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), and time-varying controls. In Panel B, mother fixed effects are added. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variable is a dummy variable equal to 1 if the mother migrated to the community of the interview in the first 5 years of life of the child, and 0 otherwise. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

Table B10: Migration to the location of the interview after birth

Dependent variable:	**Mother migrated to community after the last birth**					
Sub-sample:		**Coastal area**			**Vulnerable coastal area**	
	(1)	(2)	(3)	(4)	(5)	(6)
Ocean's pH (*in utero*)	-0.003	-0.004	-0.007	-0.002	-0.006	-0.008
	(0.003)	(0.005)	(0.007)	(0.004)	(0.006)	(0.007)
Observations	316615	316598	316550	219702	219691	219639
DHS clusters	21798	21798	21798	15319	15319	15319
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. Sample is restricted to the last birth. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variable is a dummy variable equal to 1 if the mother migrated to the community of the interview after the last birth, and 0 otherwise. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.13 Controlling for quality of coastal waters

As an additional check, we control for coastal quality. The open ocean's pH proxies for pH in coastal waters and the latter is closely related to environmental pollution and thus, human activity. As explained in Section 2, we do not use coastal water quality as the main source of variation due to the potential endogeneity of chlorophyll concentration with idiosyncratic shocks related to child mortality. To isolate the climate-change effect of pH variation, we estimate a version of equation (1) in which we control for coastal water quality, proxied by chlorophyll concentration:

$$y_{imtvc} = \beta \, pH_{mtvc} + \beta_c \, coast_{mtvc} + \mathbf{X}_{imtvc}\gamma + \Omega_{mtvc} + \epsilon_{imtvc} \tag{4}$$

where $coast_{mtvc}$ is the chlorophyll concentration in the closest cell from the cluster, and the other variables are defined as in equation (1). This specification guarantees that β is capturing the effect of ocean's pH conditional on coastal water quality. Table B11 presents the results. Point estimates of the effect of ocean's pH are in line with the estimates in Table 2. However, the loss of observations due to the restriction of births to the period 1998–2018 (when data are available) leads to larger standard errors and lower precision.

Table B11: Ocean chemistry and NMR: control for quality of coastal waters

Dependent variable:	**NMR (deaths per 1,000 births)**					
	Coastal area			**Vulnerable coastal area**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Ocean's pH (*in utero*)	-1.696	-1.764	-2.749*	-3.230***	-3.642**	-3.493*
	(1.049)	(1.178)	(1.434)	(1.137)	(1.651)	(1.949)
Chlorophyll concentration	-0.000	0.060	-0.048	0.149	0.200	0.151
	(0.541)	(0.550)	(0.579)	(0.546)	(0.549)	(0.556)
Observations	771605	771589	771528	516589	516581	516517
DHS clusters	28608	28608	28606	19790	19790	19788
Panel B. Benchmark (alt. local trends)						
Ocean's pH (*in utero*)	-1.813*	-2.087*	-3.362**	-3.167**	-3.723**	-3.406*
	(1.006)	(1.141)	(1.408)	(1.262)	(1.442)	(1.763)
Chlorophyll concentration	0.319	0.412	0.287	0.179	0.284	0.215
	(0.503)	(0.504)	(0.514)	(0.520)	(0.517)	(0.508)
Observations	771589	771573	771512	516578	516569	516505
DHS clusters	28608	28608	28606	19790	19790	19788
Local seasonality controls:						
Country x birth month FE	Yes	No	No	Yes	No	No
5° x 5° cell x birth month FE	No	Yes	No	No	Yes	No
2.5° x 2.5° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on equation 1. All specifications include cluster fixed effects, year by birth month fixed effects, and time-varying controls. To control for local trends, Panel A includes country by birth year fixed effects, while Panel B includes 5° x 5° grid cell by year fixed effects. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) and chlorophyll concentration (*in utero*) are computed as the average value in the cell closest to the child's cluster 9 months before birth. pH is multiplied by a factor of 100. Chlorophyll concentration in coastal waters is measured in mg/m^3 using data from the GlobColour project (d'Andon et al., 2009). Due to data availability, the sample is restricted to children born between 1998 and 2018. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.14 Comparing the effect size with conflict on NMR

To control for the possibility that mortality is induced by conflict rather than by the direct effect of variation in pH, the analysis is supplemented with geolocated information on conflict events from the Uppsala Conflict Data Program (UCDP) database (Sundberg and Melander, 2013). Using a 5° x 5° resolution grid, information about conflict events are matched with DHS clusters. To measure the presence of conflict, we create a dummy variable equal to one if in the 9 months prior to a child's birth there has been at least one conflict event recorded, and zero otherwise. Additionally, we add a variable with the total number of violent events that occurred 9 months before a child's birth in the grid cell associated with the cluster. To measure conflict intensity, we compute the total number of fatalities in the 9 months previous to a child's birth in the grid cell associated with the cluster. Table B12 presents estimates of equation (1) for NMR when these measures are added as control variables. While we cannot assume that conflict is fully exogenous to mortality, estimates of the effect of ocean's acidity are robust.

Table B12: Comparing the effect size of ocean acidification and conflict

Dependent variable:	**NMR (deaths per 1,000 births)**					
Sub-sample:	**Coastal area**			**Vulnerable coastal area**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Ocean's pH (*in utero*)	-1.173*	-1.177*	-1.182*	-2.654***	-2.667***	-2.676***
	(0.651)	(0.652)	(0.655)	(0.835)	(0.838)	(0.840)
At least 1 violent event (in utero)	1.785			3.040***		
	(1.135)			(1.143)		
Violent events (in utero)		3.505			4.873	
		(3.044)			(3.197)	
Fatalities (in utero)			1.684*			1.758**
			(0.863)			(0.762)
Observations	1245249	1245249	1245249	836562	836562	836562
DHS clusters	31239	31239	31239	21586	21586	21586
Panel B. Mother fixed effects						
Ocean's pH (*in utero*)	-1.276	-1.283	-1.290	-3.132***	-3.151***	-3.162***
	(0.911)	(0.912)	(0.915)	(1.057)	(1.059)	(1.061)
At least 1 violent event (in utero)	1.572			2.712**		
	(1.272)			(1.245)		
Violent events (in utero)		3.388			4.492	
		(2.983)			(3.295)	
Fatalities (in utero)			1.958**			1.800***
			(0.761)			(0.675)
Observations	1128319	1128319	1128319	756889	756889	756889
DHS clusters	30915	30915	30915	21358	21358	21358

Note. Estimates based on equation 1. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The ocean's pH (*in utero*) are computed as the average value in the cell closest to the child's cluster during the 9 months before birth. It is reported in levels corresponding to 0.01 units of pH. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.15 Early-life mortality

As pH significantly affects NMR, we also focus on the persistence of the effect of the ocean's pH while *in utero* and the related effect of survival selection beyond the first month of life. We turn to

post-neonatal mortality (PMR), defined as deaths after the first month of life but before the first year per 1,000 live births, and *child mortality* (CMR), defined as deaths between the first year and before turning five years old per 1,000 live births. We also report results on cumulative measures of mortality such as *infant mortality* (IMR), defined as deaths within the first 12 months of life per 1,000 live births, and *under-5 mortality* (U5MR), defined as deaths within the first five years of life per 1,000 live births. Table B13 presents estimates of the marginal effect of pH on early-life mortality using equation (1).

Table B13: Ocean chemistry and early-life mortality

Sub-sample:	**Coastal area**				**Vulnerable coastal area**			
Dependent variables:	**PMR**	**CMR**	**IMR**	**U5MR**	**PMR**	**CMR**	**IMR**	**U5MR**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Benchmark								
Ocean's pH (*in utero*)	1.061**	0.181	-0.370	-0.002	0.918	0.877	-2.085**	-1.446
	(0.511)	(0.372)	(0.710)	(0.966)	(0.644)	(0.771)	(0.964)	(1.728)
Observations	1454363	1129755	1500681	1205080	975384	757207	1005384	805960
DHS clusters	31344	31296	31345	31298	21652	21615	21653	21615
Panel B. Mother fixed effects								
Ocean's pH (*in utero*)	2.093***	0.843*	-0.232	0.842	1.661*	1.713**	-2.267*	-0.782
	(0.786)	(0.486)	(0.866)	(1.131)	(0.862)	(0.769)	(1.285)	(1.948)
Observations	1349636	1038831	1398105	1117756	902863	694703	934271	745895
DHS clusters	31304	31256	31307	31261	21628	21590	21630	21592

Note. Estimates based on equation 1. In Panel A, all specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. In Panel B, mother fixed effects are added. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variables are defined as follows. *PMR*: dummy variable that equals 1 if the child dies after the first month but before month 12. *CMR*: dummy variable that equals 1 if the child dies after month 13 and before month 60 since birth, with sample restricted to children who survived, at least, the first year since birth. *IMR*: dummy variable that equals 1 if the child dies before month 12 since birth. *U5MR*: dummy variable that equals 1 if the child dies before month 60 since birth. Mortality indicators are multiplied by 1,000. Ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth. pH is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.16 Protein consumption

To understand the relationship between the ocean's pH and nutrition, we focus on protein consumption. DHS surveys provide information about the consumption of food among adults only for a selected number of surveys. Information is available for the following DHS rounds: Cambodia (2005), Dominican Republic (2007), Egypt (2008), Ghana (2008), Guatemala (2015), Guyana (2009), Haiti (2006), Liberia (2007), Madagascar (2008), Namibia (2006), Nigeria (2008), Philippines (2008), Sierra Leone (2008), and Timor-Leste (2009 and 2016). We focus on the probability of the female respondent to have eaten any source of animal proteins during the day before the interview. We distinguish between two sources: fish, and meat and dairy. Fish include fresh or dried fish or shellfish, or foods containing those ingredients. Meat and dairy include any meat (beef, pork, lamb, or chicken), eggs, dairy products (cheese, yogurt, or other milk products), or foods containing those ingredients. Fish is consumed by 33% (37%) of respondents in coastal (vulnerable coastal) areas. Meat and dairy are instead consumed by 67% (60%) of respondents in coastal (vulnerable coastal) areas.

Table B14 presents the estimates of the effect of the ocean's pH at the time of the interview on the probability of having consumed each item. Since information is available at the mother's level and for

a reduced number of surveys, we estimate equation (1) using an alternative set of high-dimensional fixed effects. First, we include interview year and month fixed effects to capture common time effects. Second, because there is no variation in the ocean's pH at the time of interview within each DHS cluster and there is limited variation within each district, unobserved characteristics specific to the locations surveyed are captured by a 1° x 1° grid cell fixed effect–the same resolution of the data for ocean's pH. Third, to capture unobserved variation in trends among areas affected by faster or slower acidification we include interactions between the country and the year of the interview. Fourth, to control for local seasonality we include interactions between the country and month of the interview in columns (1), (3), (5) and (7), and interactions between the 5° x 5° grid cell and the month of the interview in columns (2), (4), (6) and (8). In columns (1)–(2) and (5)–(6) the sample is restricted to the coastal area, while in columns (3)–(4) and (7)–(8), the sample is restricted to the vulnerable coastal area. Because for some of these surveys the question is restricted to mothers with children under 3 years old (Boyle et al., 2019), in columns (5)–(8), the sample is further restricted to households with at least a child under 3 years old at the time of the interview. An increase of 0.01 in ocean's pH at the time of the interview leads to a significant increase of 4 percentage points in the probability of a mother to have eaten fish at the time of the interview. The effect is only present in vulnerable coastal areas. We do not observe any significant effects for the consumption of other animal proteins.

Table B14: Protein consumption at the time of the interview

Dependent variable:	**Mother consumed [food] in the day previous to the interview**							
Sub-sample:	**All mothers**				**Mothers with at least one child under 3 y.o.**			
	Coastal area		**Vulnerable coastal area**		**Coastal area**		**Vulnerable coastal area**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Fish								
Ocean's pH (time of interview)	0.014	0.001	0.039**	0.038**	0.013	0.002	0.038**	0.037**
	(0.018)	(0.018)	(0.019)	(0.018)	(0.017)	(0.018)	(0.019)	(0.018)
Observations	42207	42204	26191	26187	35413	35410	24872	24868
Grid cells	236	236	196	196	236	236	196	196
Panel B. Meat and dairy								
Ocean's pH (time of interview)	0.006	0.008	0.014	0.015	0.009	0.009	0.014	0.014
	(0.015)	(0.015)	(0.015)	(0.018)	(0.014)	(0.014)	(0.015)	(0.018)
Observations	42195	42192	26179	26175	35397	35394	24857	24853
Grid cells	236	236	196	196	236	236	196	196
Local seasonality controls:								
Country x month of interview FE	Yes	No	Yes	No	Yes	No	Yes	No
5° x 5° cell x month of interview FE	No	Yes	No	Yes	No	Yes	No	Yes

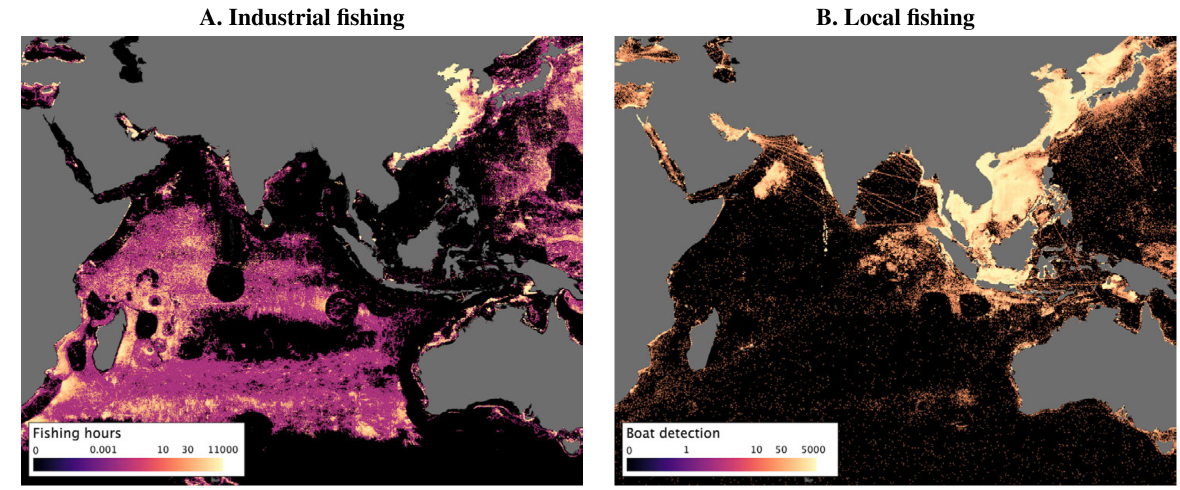
Note. Estimates based on equation 1 using an alternative set of fixed effects. All specifications include location fixed effects (measured using grid cells at the 1° x 1° resolution), year by birth month fixed effects, and other time-varying controls (residual dissolved O_2 concentration is computed at the time of the interview, rainfall, temperature and their interaction are computed for the year of the interview), and country by birth year fixed effects (local trend). The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** p<0.01, ** p<0.05, * p<0.1). In Panel A, the dependent variable is an indicator variable that equals 1 if the female respondent ate fresh or dried fish or shellfish, or foods containing those ingredients, during the day previous to the interview, and 0 otherwise. In Panel B, the dependent variable is an indicator variable that equals 1 if the female respondent ate any meat (beef, pork, lamb, or chicken), eggs, dairy products (cheese, yogurt, or other milk products), or foods containing those ingredients during the day previous to the interview, and 0 otherwise. The ocean's pH (time of interview) is the value in the cell closest to the mother's cluster in the month of the interview, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.17 Fishing pressure: local versus industrial fishing

As discussed in Section 4.2, fishing pressure is built using two data sources capturing different types of fishing activities. The first source captures the intensity of industrial fishing using the Global Fishing Watch dataset (Kroodsma et al., 2018). It contains the hours industrial fishing vessels spent at specific geolocations. The data are merged to each DHS cluster using a global grid at 1° x 1° resolution that sums fishing hours within each cell over the period 2012–2016. The second source captures instead the intensity of local fishing by looking at boats detected using nightlight by the Automatic Boat Identification System for VIIRS Low Light Imaging Data (Elvidge et al., 2015). The data are merged to each DHS cluster using a global grid at the 1° x 1° resolution with the sum of all detections for the period 2017–2019. Appendix A.1 provides additional details of each data source. Figure B13 shows an example of the geographical distribution of both variables for South and Southeast Asia, and for the Eastern coast of Africa.

by looking at fishing hours of industrial fishing vessels at specific geolocations is built using the Global Fishing Watch dataset (Kroodsma et al., 2018). The data are merged to each DHS cluster using a global grid at 1° x 1° resolution that sums fishing hours within each cell over the period 2012–2016. The second source captures instead the intensity of local fishing by looking at boats detected using nightlight (Automatic Boat Identification System for VIIRS Low Light Imaging Data by Elvidge et al., 2015). The data are merged to each DHS cluster using a global grid at the 1° x 1° resolution with the sum of all detections for the period 2017–2019. Appendix A.1 provides additional details of each data source. Figure B13 shows an example of geographical distribution of both variables for South and Southeast Asia, and the Eastern coast of Africa.

Figure B13: Industrial and local fishing: an example

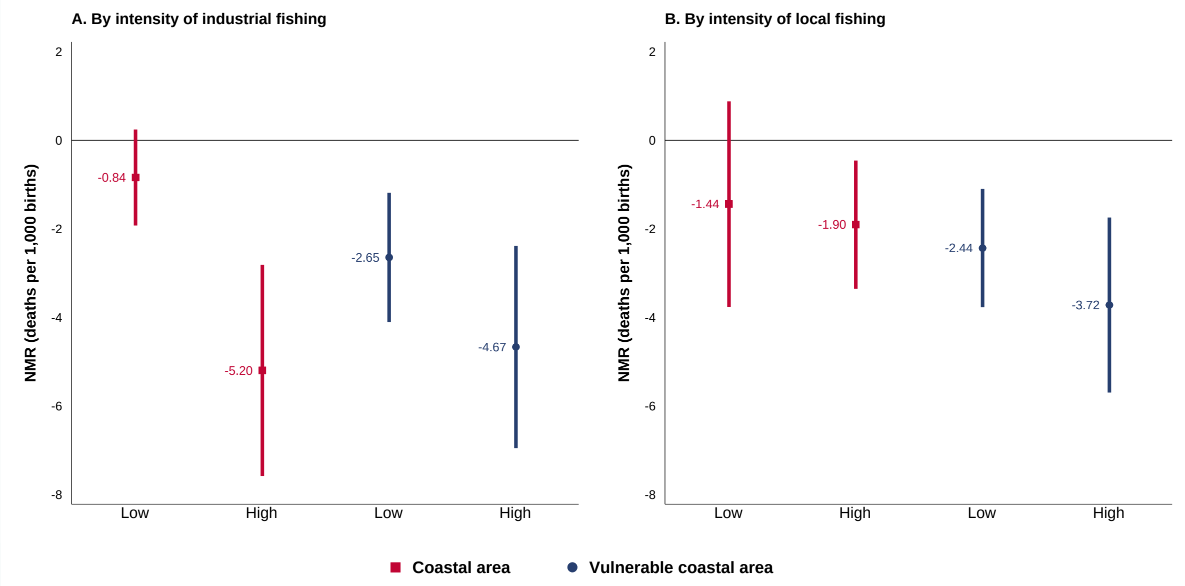


A. Example of the geographical distribution of the intensity of industrial fishing. **B.** Example of geographical distribution of the intensity of local fishing. **Note.** Data reported in the figures is represented at the resolution of 0.25° x 0.25° for Panel A, and the 0.1° x 0.1° in Panel B. Color scales are based on the quantiles of the distribution of each variable. See Appendix A.1 for further details about the variables.

We build indicator variables identifying whether the cluster is experiencing a level of intensity that is below the sample median (*low*) or above the sample median (*high*) to look at the heterogeneity of the effect of the ocean's acidity while *in utero* on NMR by intensity of industrial and local fishing. Equation

(1) is then estimated for each sub-sample. Figure B14 plots the marginal effects for both coastal and vulnerable coastal areas. Panel A refers to heterogeneity by intensity of industrial fishing, while Panel B refers to heterogeneity by intensity of local fishing. The effect presents a clear heterogeneous effect with respect to the intensity of industrial fishing, significantly different between high and low intensity for the coastal area. Areas experiencing higher intensity of industrial fishing are also experiencing larger effects, in absolute value, in terms of NMR. Conversely, in terms of intensity of local fishing we cannot identify any statistically significant heterogeneous effect.

Figure B14: Heterogeneous effect of ocean's acidity on NMR, by intensity of fishing



A. Heterogeneous effects of ocean's pH while *in utero* on NMR by intensity of industrial fishing. **B.** Heterogeneous effects of ocean's pH while *in utero* on NMR by intensity of local fishing. **Note.** Marginal effects are estimated using equation (1), in which each coefficient is computed in separate regressions where the sample is restricted to the corresponding group. Groups are defined using a dummy variable indicating whether an observation is above or below the full sample's median of the variable of interest. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level. The black solid lines indicate the value zero. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. See Section 2.1 for a definition of coastal and vulnerable coastal areas. In Panel B, the sample excludes Peru as data for intensity of local fishing is not available. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

To test whether we observe heterogeneous effects by intensity of industrial fishing and local fishing, and by the combination of the two–defined as *fishing pressure* in Section 4.2–we estimate equation (1) by adding interaction terms between the ocean's pH while *in utero* and each of these variables. We present two alternative specifications: one in which the interaction is introduced linearly, and one in which we also introduce an interaction with a quadratic term. For fishing pressure, while in the main text we consider indicator variables for high versus low pressure, we include interaction terms with the product between intensity of industrial fishing and intensity of local fishing. For each specification, we perform a joint-test of equality to zero of the interaction terms. A rejection of the test indicates heterogeneous effects. Table B15 reports F-statistics and p-values for these tests for each of the selected variables. We observe that heterogeneity is mainly driven by the intensity of industrial fishing, while we do not observe heterogeneous effects for the intensity of local fishing. Marginal effects of the ocean's

pH while *in utero* for the specification with quadratic interaction terms are presented in Figure 5 using the benchmark specification, and in Figure B15 using the specification with mother fixed effects.

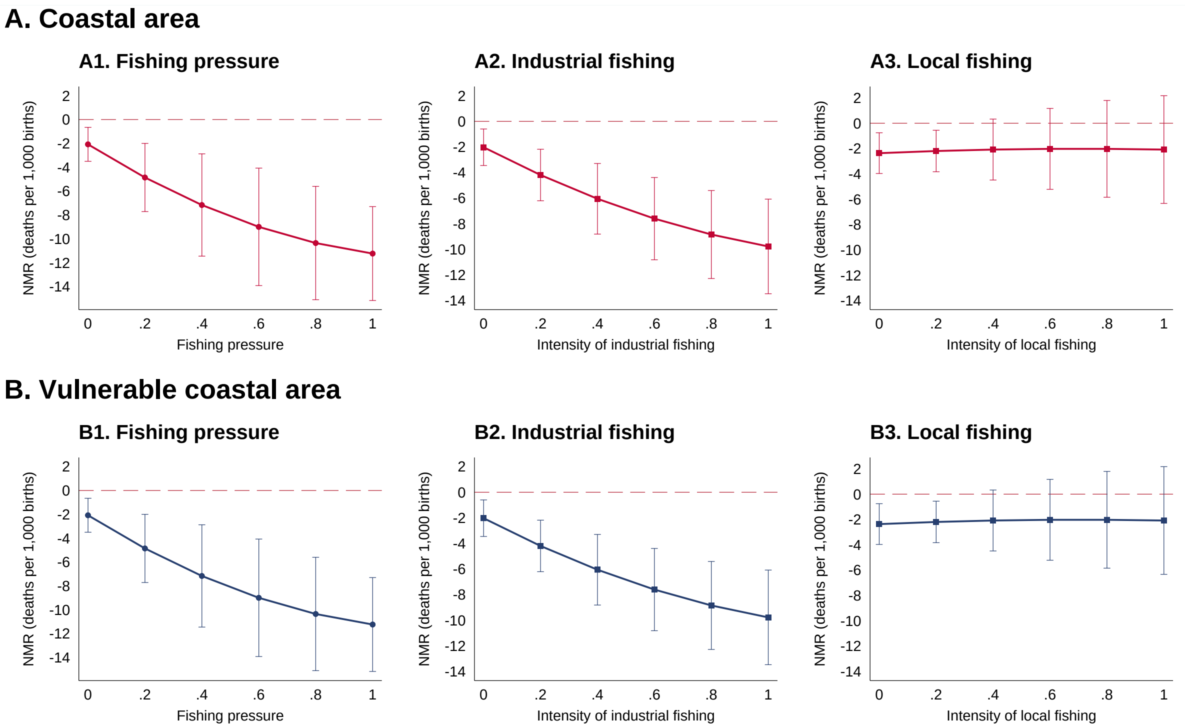
Table B15: Test of heterogeneous effects of ocean's acidity while *in utero* on NMR

Sub-sample:	**Coastal area**				**Vulnerable coastal area**			
Type of interaction:	**Linear**		**Linear+quadratic**		**Linear**		**Linear+quadratic**	
	F	p-value	F	p-value	F	p-value	F	p-value
Heterogeneity by:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Benchmark								
Fishing pressure	44.50	0.00	3.89	0.05	30.09	0.00	2.77	0.10
Intensity of industrial fishing	36.18	0.00	19.22	0.00	14.03	0.00	8.33	0.00
Intensity of local fishing	0.01	0.91	0.03	0.86	0.01	0.93	0.96	0.38
Panel B. Mother fixed effects								
Fishing pressure	19.59	0.00	2.84	0.09	15.97	0.00	3.37	0.07
Intensity of industrial fishing	14.30	0.00	8.02	0.00	7.74	0.01	4.32	0.01
Intensity of local fishing	0.25	0.78	0.25	0.78	0.08	0.78	0.11	0.90

Note. The table reports F-statistics and p-values for joint tests of equality to zero of the estimates on the interaction term(s). Estimates are based on equation (1) by adding interaction terms between ocean's pH while *in utero* and the variables present in the left column. In columns (1)–(2) and (5)–(6), the specification includes the interaction term linearly. In columns (3)–(4) and (7)–(8), the specification includes the interactions with a linear and a quadratic terms. Fishing pressure is defined as the product between intensity of industrial fishing and intensity of local fishing. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are clustered at the ocean raster data point. The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study. We exclude DHS surveys for Peru as information for the intensity of local fishing is not available (see Appendix A.1).

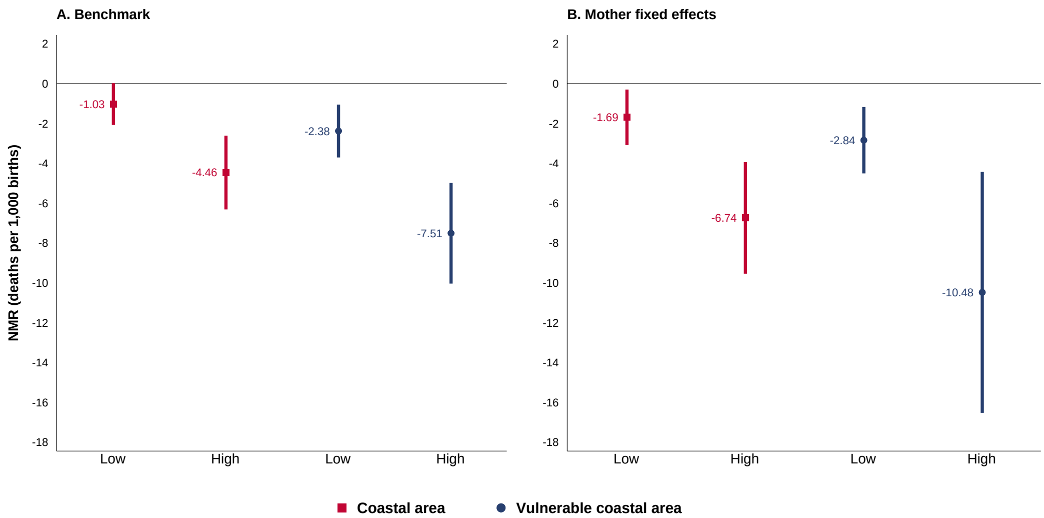
To understand further how the effect on NMR is heterogeneous with respect to fishing pressure, we estimate the effect of the ocean's pH while *in utero* on NMR by sub-samples. In Section 4.2 we focus instead on continuous interactions to measure heterogeneous impacts. We define a sub-sample to experience high fishing pressure if both industrial and local fishing are above their sample median, and low if either industrial or local fishing or both are below their sample median. Equation (1) is then estimated for each sub-sample. Figure B16 plots the marginal effects. Panel A presents the results using the benchmark specification, while Panel B presents the results by adding mother fixed effects. To understand further what drives this heterogeneity, we estimate equation (3) introducing interaction terms between the ocean's pH and distance from the shore. Figure B17 plots marginal effects of the ocean's pH while *in utero* on NMR at different distances from the shore, assuming all other variables to be constant. Panel A presents the marginal effects for areas with low fishing pressure, while Panel B presents the marginal effects for areas with high fishing pressure. Similar to the overall effect of the ocean's pH on NMR, the same heterogeneity in the effect is specific to communities living closer to the coast. For communities living in high proximity with the shore the marginal effect in areas with high fishing pressure is statistically different at a 90% confidence level from the marginal effect for areas with low fishing pressure. For communities living further away from the shore, we cannot identify a statistically significant difference between the two effects.

Figure B15: Within-siblings heterogeneous effect of ocean's acidity while *in utero* on NMR



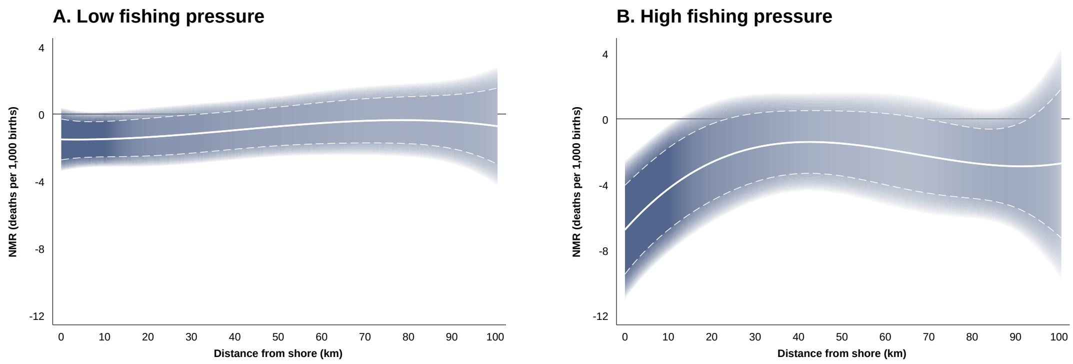
A. Marginal effect of ocean's pH while *in utero* on NMR in the coastal area as function of fishing intensity. **B**. Marginal effect of ocean's pH while *in utero* on NMR in the vulnerable coastal area as function of fishing intensity. **Note.** We consider heterogeneity along three dimensions: fishing pressure (Panels A1 and B1), intensity of industrial fishing (Panels A2 and B2), and local fishing (Panels A3 and B3). Fishing pressure is defined as the product between industrial and local fishing. For ease of interpretation, these variables are normalized by dividing their value with the 99th percentile of their sample distribution restricted to positive values. Marginal effects are estimated using equation (1) by interacting ocean's pH while *in utero* with the corresponding variable and with its squared value, and assuming all other variables remain constant. The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH (*in utero*) is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level. All specifications include mother fixed effects, cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix B.17 and Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study. We exclude DHS surveys for Peru as information for the intensity of local fishing is not available (see Appendix A.1).

Figure B16: Heterogeneous effect of ocean's acidity while *in utero* on NMR, by fishing pressure



A. Marginal effect of ocean's pH while *in utero* on NMR by fishing pressure using benchmark specification. **B**. Marginal effect of ocean's pH while *in utero* on NMR by fishing pressure using the specification with mother fixed effects. **Note.** Marginal effects are estimated using equation (1), in which each coefficient is computed in separate regressions where the sample is restricted to the corresponding group. *Low* fishing pressure is assigned to clusters in which both the intensity of industrial fishing and of local fishing are below the sample median, or at least one of the two is below the sample median. *High* fishing pressure is assigned to clusters in which both the intensity of industrial fishing and of local fishing are above the sample median. We exclude DHS surveys for Peru as information for the intensity of local fishing is not available (see Appendix A.1). Appendix B.17 provides further details about the heterogeneous effects by intensity of industrial fishing and local fishing. Standard errors are clustered at the ocean raster data point and confidence intervals are built using a 90% confidence level. The black line indicates the value zero. All specifications include cluster fixed effects, year by birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. See Section 2.1 for a definition of coastal and vulnerable coastal areas. The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). See Appendix A.1 for further information on the variables and for the full list of countries and surveys included in the study.

Figure B17: Heterogeneous effect by intensity of fishing and distance from water bodies

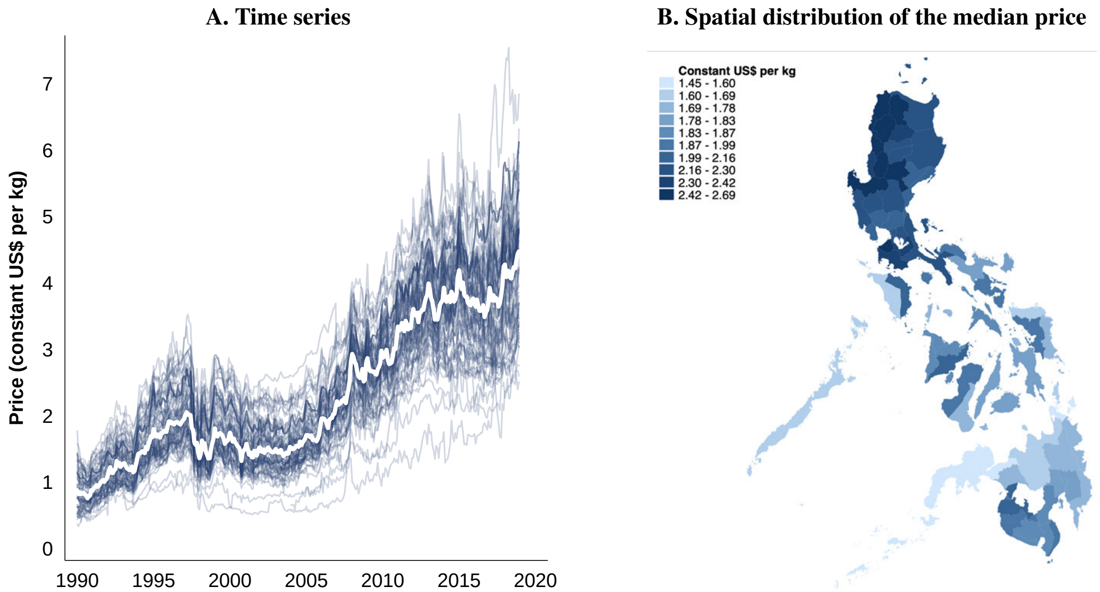


A. Marginal effect of the ocean's pH while *in utero* on NMR in areas with low fishing pressure as a function of distance from the shore. **B**. Marginal effect of ocean's pH while *in utero* on NMR in areas with high fishing pressure as a function of distance from the shore. **Note.** Estimates are based on OLS regressions (equation 3). The specifications include cluster fixed effects, year and birth month fixed effects, country by birth year fixed effects (local trend), country by birth month fixed effects (local seasonality), and time-varying controls. The full list of controls is presented in Section 3. The dependent variable is a dummy variable that equals 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. The ocean's pH while *in utero* is computed as the average value in the cell closest to the child's cluster during the 9 months before birth, and is multiplied by a factor of 100. The sample is restricted to the coastal area (see Section 2.1 for a definition), excluding Peru as data for intensity of local fishing is not available (see Appendix A.1). In Panel A (B), the sample is further restricted to areas with low (high) fishing pressure. Fishing pressure is high if both industrial and local fishing are above their sample medians, and low if either industrial fishing or local fishing or both are below their sample medians. Standard errors are clustered at the ocean raster data point. Dotted lines represent the confidence interval at 90%. Beyond the 90%, confidence intervals are progressively shaded up to the 99%. The color intensity of the area is function of the number of observations, with darker colors indicating larger number of observations (see Appendix A.5). Appendix A.3 provides further details about the computation of distance from shore and from another water body. See Appendix A.1 for further information on the variables and the full list of countries and surveys included in the study.

B.18 Fish prices and NMR in the Philippines

The Philippine Statistics Authority (2020) provides monthly retail prices for fish at the province level from 1990 to nowadays for the following fishes and crustaceans: indian mackerel, milkfish, threadfin bream, blue crab, caesio, anchovies, frigate tuna, tilapia, tiger prawn, slipmouth, and roundscad. Missing fish-level price data are imputed using linear interpolation for each province and each fish type. Panel A in Figure B18 shows the time series of fish prices from 1990 to 2018. In order to link DHS clusters with fish prices, we match each series to the geographical identifier of the province. Panel B in Figure B18 shows instead the spatial distribution of the median prices for the period 1990–2018.

Figure B18: Time series and spatial distribution of retail price for fish



A. Time series of retail prices of fish. **B.** Spatial distribution of the median fish price for the period 1990–2018. **Note.** In Panel A, each line corresponds to the price series for one province. Each price is the (unweighted) average of all available prices. The thicker line corresponds to the median price at national level. Prices are obtained from the Philippine Statistics Authority (2020), and are available for the following fishes and crustaceans: indian mackerel, milkfish, threadfin bream, blue crab, caesio, anchovies, frigate tuna, tilapia, tiger prawn, slipmouth, and roundscad. Original price series are reported in Philippine Peso per kg. Prices are converted in constant US$ (base 2010) using exchange rates and Consumer Price Index from the International Financial Statistics dataset (IMF, 2020).

Fish prices are matched to each birth history using the location and date of birth for each child. Locations are assigned using the provinces. We then estimate the effect of the fish price while *in utero* on NMR. The sample is restricted to births following the year 1990 since fish prices are not available for the previous years. Similar to the analysis for ocean's acidity, we assume a gestation period of 9 months for all children in the sample and use the average of fish prices in the 9 months preceding the date of birth as the main source of variation. Table B16 presents the results. Columns (1)–(3) refer to the coastal area, while columns (4)–(6) refer to the vulnerable coastal area. Panel A presents estimates using equation (1), while Panel B presents estimates using equation (2) and controlling for mother fixed effects. The specification using mother fixed effects is particularly important since variation in prices is not exogenous. Since we focus on a specific country, we control for local trends using interaction terms between the 5° x 5° grid cell and the birth year. For local seasonality, we present three different set of controls. Columns (1) and (4) introduce interaction terms between the 5° x 5° grid cell indicator and

the birth month. Columns (2)–(3) and (5)–(6) controls instead for local seasonality at a higher level of granularity. Columns (2) and (5) introduce interaction terms between 2.5° x 2.5° grid cell indicator and the birth month. Columns (3) and (6) introduce interaction terms between 1° x 1° grid cell indicator and the birth month. Across the different specifications, we observe a positive effect of fish prices on mortality. Estimates are robust to alternative controls for local seasonality and to mother fixed effects.

Table B16: Fish prices and NMR

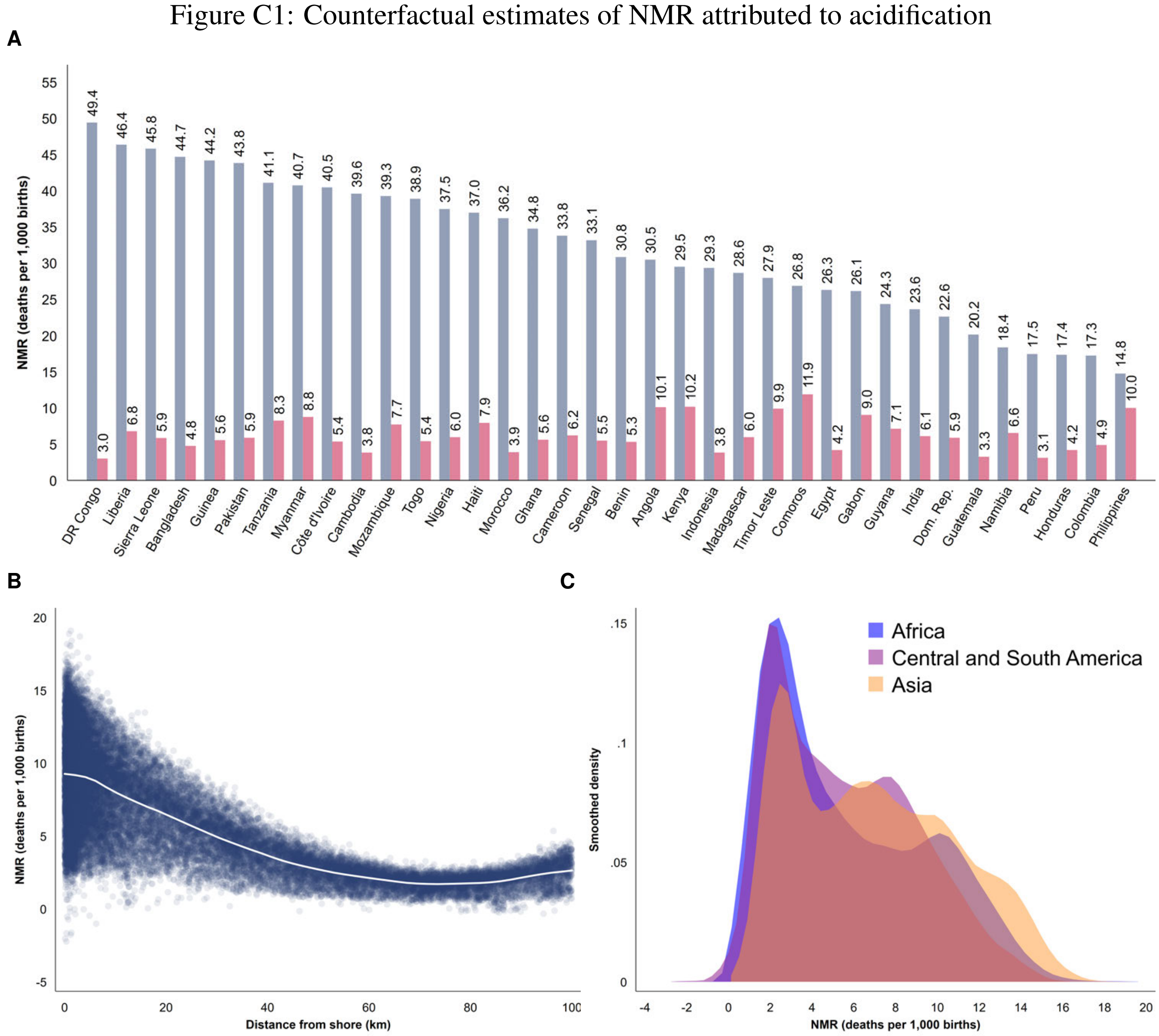
Dependent variable:	**NMR (deaths per 1,000 births)**					
Sub-sample:	**Coastal area**			**Vulnerable coastal area**		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Benchmark						
Fish price (*in utero*)	7.490***	7.657***	7.698***	5.765**	5.814**	5.877**
	(2.481)	(2.394)	(2.344)	(2.389)	(2.338)	(2.330)
Observations	78564	78562	78546	68785	68783	68767
DHS clusters	2721	2721	2721	2418	2418	2418
Panel B. Mother fixed effects						
Fish price (*in utero*)	8.570**	8.971***	8.857***	6.748*	7.255**	7.108**
	(3.330)	(3.174)	(3.280)	(3.516)	(3.316)	(3.342)
Observations	73840	73837	73819	64608	64605	64587
DHS clusters	2718	2718	2718	2416	2416	2416
Local seasonality controls:						
5° x 5° cell x birth month FE	Yes	No	No	Yes	No	No
2.5° x 2.5° cell x birth month FE	No	Yes	No	No	Yes	No
1° x 1° cell x birth month FE	No	No	Yes	No	No	Yes

Note. Estimates based on OLS regressions using DHS surveys for the Philippines restricting the sample to birth from 1990 to 2018 (due to availability of fish prices; see Appendix B.18 for further information). All specifications include cluster fixed effects, year and birth month fixed effects, 5° x 5° grid cell by birth year fixed effects (local trend), and time-varying controls (excluding direct measures of ocean's chemistry). The full list of controls is presented in Section 3. Observations are re-weighted to correct for oversampling of countries surveyed multiple times (see Appendix A.2). Standard errors are reported in parenthesis and clustered at the ocean raster data point (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). The dependent variable is a dummy variable equal to 1 if the child died within the first month of life and 0 if the child survived, multiplied by 1,000. Fish price (*in utero*) is computed as the average fish price in the location of birth during the 9 months before birth, and is reported in logarithms. See Section 2.1 for a definition of coastal and vulnerable coastal areas. See Appendix A.1 for further information on the variables.

C Counterfactual estimates

Figure C1 presents summary statistics of counterfactual estimates following the procedure detailed in Section 5. Panel A shows the country-level average NMR in the coastal area and the average NMR attributed to acidification. Panel B shows the kernel-weighted local polynomial regression of cluster-level NMR attributed to acidification on distance from shore. Finally, Panel C shows the continent-specific kernel density of cluster-level NMR attributed to acidification.

Figure C1: Counterfactual estimates of NMR attributed to acidification



A. Country-level average NMR in the coastal area (blue) and average NMR attributed to acidification (red). **B**. Kernel-weighted local polynomial regression of cluster-level NMR attributed to acidification on distance from shore. **C**. Kernel density of cluster-level NMR attributed to acidification, by continent. **Note.** See Section C for details about the procedure. For Panel B, the relationship between NMR attributed to acidification and distance from shore is estimated using a local polynomial regression. For Panel C, the distributions are estimated using a kernel density estimator. Both estimators assume an Epanechnikov function and a width of the smoothing window around each point determined using a rule-of-thumb.

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